# Switzerland's

# Greenhouse Gas Inventory

# 1990–2020

## National Inventory Report

Including reporting elements under the Kyoto Protocol

Submission of April 2022
under the United Nations Framework Convention on Climate Change
and under the Kyoto Protocol

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Bern, April 2022

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# Glossary

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|---|---|
| °C | degree Celsius |
| AAU | Assigned Amount Unit (under the Kyoto Protocol) |
| AD | Activity data |
| AFOLU | Agriculture, Forestry and Other Land Use |
| AREA1 | Swiss Land Use Statistics 1979/85 (ASCH1 data re-evaluated according to the AREA set of land-use and land-cover categories) |
| AREA2 | Swiss Land Use Statistics 1992/97 (ASCH2 data re-evaluated according to the AREA set of land-use and land-cover categories) |
| AREA3 | Swiss Land Use Statistics, third survey 2004/09 |
| AREA4 | Swiss Land Use Statistics, fourth survey 2013/18 |
| AREA5 | Swiss Land Use Statistics, fifth survey |
| ART | Agroscope Reckenholz-Tänikon Research Station (formerly FAL) since 2014 Agroscope |
| ASCH1 | Swiss Land Use Statistics, first survey 1979/85 |
| ASCH2 | Swiss Land Use Statistics, second survey 1992/97 |
| Avenergy | Avenergy Suisse (Swiss Petroleum Association) formerly Erdöl-Vereinigung (EV) |
| BAFU | Bundesamt für Umwelt (German for FOEN) |
| BCEF, BEF | Biomass conversion and expansion factor, biomass expansion factor |
| CAEP | Committee on Aviation Environmental Protection |
| Carbura | Swiss organisation for the compulsory stockpiling of oil products |
| Cemsuisse | Association of the Swiss Cement Industry |
| CER | Certified Emission Reduction (under the Kyoto Protocol) |
| CC | Combination category |
| CDM | Clean Development Mechanism (under the Kyoto Protocol) |
| CFC | Chlorofluorocarbon (organic compound: refrigerant, propellant) |
| $CH_4$ | Methane, 2006 IPCC GWP: 25 (UNFCCC 2014a, Annex III) |
| CHP | Combined heat and power |
| chp. | Chapter |
| CNG | Compressed natural gas |
| CLRTAP | UNECE Convention on Long-Range Transboundary Air Pollution |
| CO | Carbon monoxide |
| $CO_2$, $CO_2$ eq | Carbon dioxide, carbon dioxide equivalent |
| COVID-19 | Coronavirus disease 2019 is a contagious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) |
| CORINAIR | CORe INventory of AIR emissions (under the European Topic Centre on Air Emissions and under the European Environment Agency) |
| CRF | Common Reporting Format |

| | |
|---|---|
| CSC | Carbon stock change |
| CSCF | Carbon stock change factor |
| DBH | Diameter (of trees) at breast height |
| DDPS | Federal Department of Defence, Civil Protection and Sport |
| DETEC | Dept. of the Environment, Transport, Energy and Communications |
| dt | decitonne (100 kg) |
| EF | Emission factor |
| EMEP | European Monitoring and Evaluation Programme (under the Convention on Long-range Transboundary Air Pollution) |
| EMIS | Swiss Emission Information System (German: Emissions Informations System Schweiz) |
| EMPA | Swiss Federal Laboratories for Materials Science and Technology |
| EnAW | Energy Agency of the Swiss Private Sector |
| ERT | Expert review team (under the UNFCCC and the Kyoto Protocol) |
| ERU | Emission Reduction Unit (under the Kyoto Protocol) |
| ETS | Emission Trading System |
| EU | European Union |
| EV | Erdöl-Vereinigung (Swiss Petroleum Association), since 1. July 2019 Avenergy Suisse |
| FAL | Swiss Federal Research Station for Agroecology and Agriculture (since 2006: ART; since 2014 Agroscope) |
| FAO | Food and Agriculture Organization of the United Nations |
| FC | Fuel consumption |
| FCA | Federal Customs Administration, since 03.01.2022: Federal Office for Customs and Border Security (FOCBS) |
| FDFA | Federal Department of Foreign Affairs |
| FEDRO | Swiss Federal Roads Office |
| FiBL | Research Institute of Organic Agriculture |
| FMRL | Forest management reference level |
| FOAG | Federal Office for Agriculture |
| FOCA | Federal Office of Civil Aviation |
| FOCBS | Federal Office for Customs and Border Security, formerly FCA |
| FOD | First order decay (model) |
| FOEN | Federal Office for the Environment (former name SAEFL until 2005) |
| FSO | Federal Statistical Office (formerly SFSO) |
| GHG | Greenhouse gas |
| GL | Guidelines |
| g | gram |
| GVS | Swiss Foundry Association |
| GWP | Global Warming Potential |

| | |
|---|---|
| ha | hectare |
| HFC | Hydrofluorocarbons (e.g. HFC-32 difluoromethane) |
| HAFL | School for Agricultural, Forest and Food Sciences |
| HWP | Harvested wood products |
| ICAO | International Civil Aviation Organization |
| IDP | Inventory Development Plan |
| IEA | International Energy Agency |
| IFR | Instrument Flight Rules |
| IPCC | Intergovernmental Panel on Climate Change |
| IPPU | Industrial processes and product use |
| IVZ | Information system for traffic admission (Informationssystem Verkehrszulassung IVZ) run by FEDRO, formerly MOFIS |
| JI | Joint Implementation (under the Kyoto Protocol) |
| KCA | Key category analysis |
| kha | kilo hectare |
| kt | kilo tonne (1'000 tonnes) |
| L1, L2 | Key category according to level assessment with approach 1, approach 2 |
| LPG | Liquefied Petroleum Gas (Propane/Butane) |
| LTO | Landing/Take-Off cycle (Aviation) |
| LULUCF | Land Use, Land-Use Change and Forestry |
| MOFIS | Swiss federal vehicle registration database run by FEDRO (since 2022: IVZ) |
| MSW | Municipal solid waste |
| MSWIP | Municipal solid waste incineration plant |
| NABO | Swiss Soil Monitoring Network |
| NCV | Net calorific value |
| NCAC | (livestock) not covered by agricultural census |
| $NF_3$ | Nitrogen trifluoride 2006 IPCC GWP: 17'200 (UNFCCC 2014a, Annex III) |
| NFI1, NFI2, NFI3 | First (1983–1985), Second (1993–1995), Third (2004–2006), |
| NFI4, NFI5 | Fourth (2009–2017) and Fifth (ongoing) National Forest Inventory |
| NIR | National Inventory Report |
| NIS | National Inventory System |
| NFR | Nomenclature for Reporting (under the UNECE) |
| NMVOC | Non-methane volatile organic compounds |
| $N_2O$ | Nitrous oxide; 2006 IPCC GWP: 298 (UNFCCC 2014a, Annex III) |
| $NO_x$ | Nitrogen oxides |
| ODS | Ozone-depleting substances (CFCs, halons etc.) |
| PFC | Perfluorinated carbon compounds (e.g. Tetrafluoromethane) |

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| SAEFL | Swiss Agency for the Environment, Forests and Landscape<br>(since 2006: Federal Office for the Environment FOEN) |
| SEF | Standard Electronic Format (under the Kyoto Protocol) |
| SBV | Schweizerischer Bauernverband; Swiss Farmers Union |
| SCR | Selective catalytic reduction |
| SD | Standard deviation |
| SDC | Swiss Agency for Development and Cooperation (of the FDFA) |
| $SF_6$ | Sulphur hexafluoride, 2006 IPCC GWP: 22'800<br>(UNFCCC 2014a, Annex III) |
| SGWA | Swiss Gas and Water Industry Association |
| SECO | State Secretariat for Economic Affairs |
| SDC | Swiss Agency for Development and Cooperation (German: DEZA) |
| SFOE | Swiss Federal Office of Energy |
| SFSO | Swiss Federal Statistical Office, now: Federal Statistical Office (FSO) |
| SGWA | Swiss Gas and Water Industry Association (see SVGW/SSIGE) |
| $SO_2$ | Sulphur dioxide |
| SOC | Soil organic carbon |
| SOLV | Swiss Organisation for the Solvent Recovery of Industrial Enterprises in the Packaging Sector |
| SSIP | Sewage sludge incineration plant |
| SVGW/SSIGE | Schweizerischer Verein des Gas- und Wasserfaches / Société Suisse de l'Industrie du Gaz et des Eaux (Swiss Gas and Water Industry Association) |
| SWIP | Special waste incineration plant |
| SWISSMEM | Swiss Mechanical and Electrical Engineering Industries (Schweizer Maschinen-, Elektro- und Metallindustrie) |
| T1, T2 | Key category according to trend assessment with approach 1, approach 2 |
| tCER | Temporary Certified Emission Reduction (under the Kyoto Protocol) |
| PSD | Prosperity and Sustainability Division (of the FDFA) |
| QA/QC | Quality assurance/Quality control |
| QMS | Quality management system |
| RMU | Removal Unit (under the Kyoto Protocol) |
| UBA | Umweltbundesamt (Federal Environment Agency in Germany) |
| UNECE | United Nations Economic Commission for Europe |
| UNFCCC | United Nations Framework Convention on Climate Change |
| VFR | Visual Flight Rules |
| VOC | Volatile organic compounds |
| VSG | Verband der Schweizerischen Gasindustrie / Association Suisse de l'Industrie Gazière (ASIG) (Swiss Gas Industry Association) |
| VSZ | Verband Schweizerische Ziegelindustrie (Swiss association of brick and tile industry) |

| | |
|---|---|
| VSLF | Swiss association for coating and paint applications |
| VSTB | Swiss Association of Grass Drying Plants |
| VTG | Swiss Armed Forces – Defense |
| WSL | Swiss Federal Institute for Forest, Snow and Landscape Research |
| WWT | Wastewater treatment |
| ZPK | Verband der Schweizerischen Zellstoff-, Papier- und Kartonindustrie |

# Executive summary

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## ES 1 Background information on greenhouse gas inventories, climate change and supplementary information required under Art. 7.1. KP

### ES 1.1 Background information on climate change

In 2016, a comprehensive assessment of climate change and its impacts in Switzerland, both in the past and in the future, has been published by the Swiss Academies of Sciences (SCNAT 2016). Long-term measurements indicate a marked shift towards a warmer climate for Switzerland. Between 1864 and 2016, the average temperature in Switzerland has increased by +2.0°C compared to +0.9°C globally (FOEN 2018d).

In the course of the 21st century, Swiss climate is projected to depart significantly from present and past conditions. Mean temperature will very likely increase in all regions and seasons (CH2018 2018). Summer mean precipitation will likely decrease by the end of the century all over Switzerland by up to 40% depending on the emission scenario, while winter precipitation will likely increase, particularly in Southern Switzerland. The expected trends in precipitation will have a marked impact on the hydrological cycle. Furthermore, higher intensity of storms as well as reduced snowfall and snow cover duration are expected, increasing the risk and frequency of floods, landslides and debris flows.

The retreat and massive loss of volume of glaciers in the Alps is the most apparent indicator of the recent increase in atmospheric temperature. In recent years a dramatic acceleration of glacial melting was observed. From the ca. 2’900 square kilometres of glacier area in the mid-1970s, only about 2’100 square kilometres remained in 2003 and an estimated 1’900 square kilometres in 2013 (FOEN 2018d).

Concerning biodiversity, climate change is expected to affect species composition, distribution, their cycles, synchronicity, the overall genetic diversity, and the provision of ecosystem services. This in turn will increase the vulnerability of forests and potentially impair their protective, productive, and social functions. Species distribution will shift upward to higher elevations, thermophile species will spread, new species from warmer areas will arrive, and phenological shifts will occur.

For agriculture, climate change is expected to entail a shift of suitable areas for agricultural production, and to involve both positive (e.g. a longer vegetation period) and negative (e.g. increasing incidence of pest infestations owing to milder winters) aspects. Changes in the nature of extreme weather events, in particular more frequent, intense and longer-lasting summer heat waves, could also challenge agriculture, e.g. by reducing the yields.

Various sectors of the Swiss economy are likely to be adversely affected by progressing climate change: in particular, winter tourism will suffer from increased scarcity of snow, hydroelectric power stations are confronted with altered runoff and sediment transport regimes, and insurance companies may face increased losses due to winter storms and floods. Natural hazards and extreme weather events potentially pose a growing risk to infrastructures and settlements. Heat waves in combination with elevated tropospheric ozone levels present a serious threat to human health. Finally, it remains to be seen to what extent vector borne diseases spread due to changing climatic conditions. Switzerland analysed these challenges in detail and developed an effective adaptation strategy in order to hedge against negative effects resulting from climate change in Switzerland (FOEN 2012b, FOEN 2020m).

### ES.1.2 Background information on greenhouse gas inventories

On 10 December 1993, Switzerland ratified the United Nations Framework Convention on Climate Change (UNFCCC). Since 1996, the submission of its national greenhouse gas inventory has been based on IPCC Guidelines. From 1998 onwards, the inventories have been submitted in the Common Reporting Format (CRF). In 2004, Switzerland started submitting annually its National Inventory Report (NIR) under the UNFCCC.

On 9 July 2003, Switzerland ratified the Kyoto Protocol (KP) under the UNFCCC. The Swiss National Inventory System (NIS) according to Article 5.1 of the Kyoto Protocol was implemented and is fully operational since.

The Federal Office for the Environment (FOEN) is in charge of compiling the emission data and bears overall responsibility for Switzerland’s national greenhouse gas inventory and the national registry. In addition to the FOEN, the Swiss Federal Office of Energy (SFOE), Agroscope, the Swiss centre of excellence for agricultural research, and the Federal Office of Civil Aviation (FOCA) participate directly in the compilation of the inventory. Several other administrative offices and research institutions are involved in the preparation of the inventory.

In preparing the national greenhouse gas inventory, Switzerland takes recommendations and encouragements of the review process into account. The changes in response to the review process are documented in chp. 10.1.1.

### ES.1.3 Background information on supplementary information required under article 7.1. of the Kyoto Protocol (KP)

Switzerland accounts for the mandatory activity Forest management under Article 3, paragraph 4 of the Kyoto Protocol (FOEN 2016c). In accordance with Annex I to Decision 2/CMP.7 (Annex I, Para 13), credits from Forest management are capped in the second commitment period. This cap is set at 3.5% of the 1990 emissions (excluding LULUCF).

Switzerland will account for emissions and removals from activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol (FOEN 2016c, FOEN 2016d) over the entire second commitment period. In addition to the mandatory submission of the inventory years 2013–2020, selected data for the time series since 1990 are shown in chp. 11.

## ES.2 Summary of national emissions and removals related trends, and emissions and removals from KP-LULUCF activities

### ES.2.1 Greenhouse gas (GHG) inventory

In 2020, Switzerland emitted 43’291 kt $CO_2$ eq (kilo tonnes of $CO_2$ equivalent), corresponding to 5.0 t $CO_2$ eq per capita ($CO_2$: 3.8 t per capita), to the atmosphere, excluding emissions from international aviation and marine bunkers (2’082 kt $CO_2$ eq), excluding indirect greenhouse gas emissions (121 kt $CO_2$ eq) and excluding emissions and removals from Land use, land-use change, and forestry (LULUCF, -1’705 kt $CO_2$ eq). For emissions that are relevant under the Kyoto Protocol see chapter ES.3.3.

#### Key category analysis (KCA)

Key category analyses were conducted according to approaches 1 and 2 (see details in chp. 1.5.1.2 and IPCC (2006)). For both approaches, level assessments were conducted for the years 2020 and 1990 and a trend assessment for 1990–2020, including LULUCF categories and indirect $CO_2$ emissions. A total of 46 key categories out of 186 considered categories have been identified, detailed as follow:

- Approach 1: For 2020, 31 categories among a total of 186 are identified as level key categories. About half of these categories are part of sector 1 Energy, accounting for the largest share of total national emissions.
- Approach 2: For 2020, 27 categories among a total of 186 are identified as level key categories. Under approach 2, the most important categories originate from sectors 3 Agriculture and 4 LULUCF.

Key category analyses are also performed excluding LULUCF categories. They are not represented in the NIR but are available on request.

#### Switzerland’s GHG emissions by gases

Table E-1 shows Switzerland’s annual GHG emissions by individual gases from 1990 (base year) to 2020. Total emissions excluding LULUCF reach a minimum in 2020 with 19.2% below 1990.

Table E-1 Greenhouse gas emissions in $CO_2$ equivalent (kt) by gas (excluding indirect $CO_2$). HFC emissions increased by more than 5 million percent when compared to 1990 levels (1990 = 0.025 kt $CO_2$ equivalent).

| **Greenhouse Gas Emissions** | **1990** | **1995** | **2000** | **2005** | **2010** |
|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | |
| $CO_2$ emissions including net $CO_2$ from LULUCF | 42'032 | 39'410 | 48'749 | 42'843 | 42'053 |
| $CO_2$ emissions excluding net $CO_2$ from LULUCF | 44'160 | 43'419 | 43'622 | 45'779 | 45'046 |
| $CH_4$ emissions including $CH_4$ from LULUCF | 5'820 | 5'535 | 5'155 | 5'091 | 5'031 |
| $CH_4$ emissions excluding $CH_4$ from LULUCF | 5'792 | 5'517 | 5'141 | 5'077 | 5'019 |
| $N_2O$ emissions including $N_2O$ from LULUCF | 3'416 | 3'381 | 3'323 | 3'179 | 3'134 |
| $N_2O$ emissions excluding $N_2O$ from LULUCF | 3'361 | 3'331 | 3'276 | 3'132 | 3'085 |
| HFCs | 0.025 | 244 | 636 | 1'048 | 1'308 |
| PFCs | 117 | 17 | 61 | 50 | 38 |
| $SF_6$ | 137 | 93 | 152 | 213 | 161 |
| $NF_3$ | NO | NO | NO | NO | 13 |
| **Total (including LULUCF)** | **51'522** | **48'680** | **58'076** | **52'424** | **51'737** |
| **Total (excluding LULUCF)** | **53'566** | **52'622** | **52'889** | **55'299** | **54'670** |

| **Greenhouse Gas Emissions** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2020 vs.1990** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | | | | | | | % |
| $CO_2$ emissions including net $CO_2$ from LULUCF | 39'677 | 39'704 | 41'105 | 38'868 | 36'502 | 36'987 | 36'220 | 35'906 | 34'555 | 32'473 | -22.7% |
| $CO_2$ emissions excluding net $CO_2$ from LULUCF | 40'985 | 42'253 | 43'188 | 39'234 | 38'732 | 39'185 | 38'179 | 36'874 | 36'733 | 34'241 | -22.5% |
| $CH_4$ emissions including $CH_4$ from LULUCF | 4'981 | 4'958 | 4'887 | 4'878 | 4'851 | 4'819 | 4'760 | 4'724 | 4'645 | 4'599 | -21.0% |
| $CH_4$ emissions excluding $CH_4$ from LULUCF | 4'967 | 4'946 | 4'874 | 4'865 | 4'838 | 4'804 | 4'747 | 4'712 | 4'633 | 4'588 | -20.8% |
| $N_2O$ emissions including $N_2O$ from LULUCF | 3'056 | 3'029 | 3'037 | 3'019 | 3'024 | 2'957 | 3'110 | 2'977 | 3'044 | 2'953 | -13.6% |
| $N_2O$ emissions excluding $N_2O$ from LULUCF | 3'006 | 2'980 | 2'987 | 2'969 | 2'974 | 2'905 | 3'059 | 2'926 | 2'994 | 2'903 | -13.6% |
| HFCs | 1'380 | 1'453 | 1'432 | 1'469 | 1'508 | 1'481 | 1'504 | 1'525 | 1'429 | 1'387 | see caption |
| PFCs | 36 | 39 | 28 | 23 | 26 | 20 | 32 | 36 | 32 | 34 | -70.4% |
| $SF_6$ | 169 | 230 | 276 | 285 | 278 | 236 | 233 | 183 | 152 | 138 | 0.4% |
| $NF_3$ | 9.3 | 0.54 | 0.14 | 0.60 | 0.73 | 0.77 | 0.80 | 0.50 | 0.54 | 0.41 | - |
| **Total (including LULUCF)** | **49'309** | **49'414** | **50'765** | **48'542** | **46'188** | **46'500** | **45'859** | **45'352** | **43'858** | **41'586** | **-19.3%** |
| **Total (excluding LULUCF)** | **50'552** | **51'901** | **52'786** | **48'845** | **48'355** | **48'631** | **47'754** | **46'257** | **45'974** | **43'291** | **-19.2%** |

With regard to the distribution of emissions by individual greenhouse gases, $CO_2$ is the largest single contributor accounting for almost 80% of total GHG emissions (excluding LULUCF) in 2020. The shares of $CH_4$ and $N_2O$ are about 10% and 7%, respectively. The share of $CO_2$ shows a slightly decreasing trend in the period 1990–2020, whereas aggregated F-gases, which contributed only 0.5% in 1990, increased to a share of over 3% in 2020 (Table E-2).

Table E-2 Contribution of individual gases to total emissions (excluding LULUCF, excluding indirect $CO_2$) in $CO_2$ equivalent (kt) and (%).

| **Greenhouse Gas Emissions** | **1990** | | **1995** | | **2000** | | **2005** | | **2010** | |
|---|---|---|---|---|---|---|---|---|---|---|
| (excluding LULUCF) | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % |
| $CO_2$ | 44'160 | 82.4% | 43'419 | 82.5% | 43'622 | 82.5% | 45'779 | 82.8% | 42'253 | 81.4% |
| $CH_4$ | 5'792 | 10.8% | 5'517 | 10.5% | 5'141 | 9.7% | 5'077 | 9.2% | 4'946 | 9.5% |
| $N_2O$ | 3'361 | 6.3% | 3'331 | 6.3% | 3'276 | 6.2% | 3'132 | 5.7% | 2'980 | 5.7% |
| HFCs | 0.025 | 0.0% | 244 | 0.5% | 636 | 1.2% | 1'048 | 1.9% | 1'453 | 2.8% |
| PFCs | 117 | 0.2% | 17 | 0.0% | 61 | 0.1% | 50 | 0.1% | 39 | 0.1% |
| $SF_6$ | 137 | 0.3% | 93 | 0.2% | 152 | 0.3% | 213 | 0.4% | 230 | 0.4% |
| $NF_3$ | NO | - | NO | - | NO | - | NO | - | 0.54 | 0.0% |
| **Total (excluding LULUCF)** | **53'566** | **100%** | **52'622** | **100%** | **52'889** | **100%** | **55'299** | **100%** | **51'901** | **100%** |

| **Greenhouse Gas Emissions** | **2016** | | **2017** | | **2018** | | **2019** | | **2020** | |
|---|---|---|---|---|---|---|---|---|---|---|
| (excluding LULUCF) | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % |
| $CO_2$ | 39'185 | 80.6% | 38'179 | 79.9% | 36'874 | 79.7% | 36'733 | 79.9% | 34'241 | 79.1% |
| $CH_4$ | 4'804 | 9.9% | 4'747 | 9.9% | 4'712 | 10.2% | 4'633 | 10.1% | 4'588 | 10.6% |
| $N_2O$ | 2'905 | 6.0% | 3'059 | 6.4% | 2'926 | 6.3% | 2'994 | 6.5% | 2'903 | 6.7% |
| HFCs | 1'481 | 3.0% | 1'504 | 3.2% | 1'525 | 3.3% | 1'429 | 3.1% | 1'387 | 3.2% |
| PFCs | 20 | 0.0% | 32 | 0.1% | 36 | 0.1% | 32 | 0.1% | 34 | 0.1% |
| $SF_6$ | 236 | 0.5% | 233 | 0.5% | 183 | 0.4% | 152 | 0.3% | 138 | 0.3% |
| $NF_3$ | 0.77 | 0.0% | 0.80 | 0.0% | 0.50 | 0.0% | 0.54 | 0.0% | 0.41 | 0.0% |
| **Total (excluding LULUCF)** | **48'631** | **100%** | **47'754** | **100%** | **46'257** | **100%** | **45'974** | **100%** | **43'291** | **100%** |

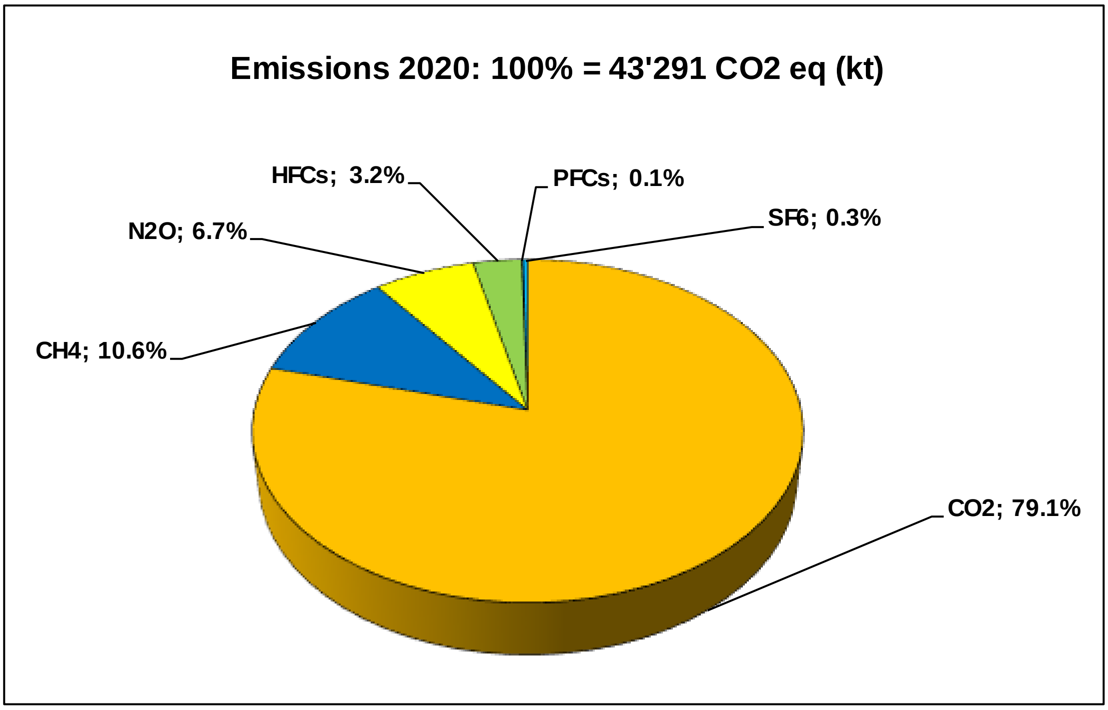


Figure E-1 Contribution of individual gases to total greenhouse gas emissions (excluding LULUCF, excluding indirect $CO_2$) in 2020.

## Uncertainty analysis

Uncertainties were assessed according to approach 1 (uncertainty propagation) and approach 2 (Monte Carlo simulations), including and excluding LULUCF categories for the years 1990 and 2020 (level) and for the period 1990–2020 (trend) (see details in chp. 1.6 and IPCC (2006)). Mean uncertainty results from both approaches are in concordance. The uncertainty results are displayed in Table E-3. Due to high uncertainties in sector 4 LULUCF, uncertainties are generally higher for the analyses including LULUCF categories compared to the analyses excluding LULUCF categories.

Table E-3 Relative uncertainties, expressed in percentage of the mean, for Switzerland's national total greenhouse gas emissions and removals excluding and including the LULUCF sector. Uncertainties are obtained by approach 1 (uncertainty propagation) and 2 (Monte Carlo simulations) for emission levels in 1990, 2020 and for the trend (1990–2020) and are detailed by negative, positive and mean uncertainty. The uncertainty analysis is based on emissions and removals including indirect $CO_2$ emissions.

| Inventory | Level uncertainty 1990 | | | Level uncertainty 2020 | | | Trend uncertainty 1990-2020 | | |
|---|---|---|---|---|---|---|---|---|---|
| | (-)% | (+)% | mean % | (-)% | (+)% | mean % | (-)% | (+)% | mean % |
| Approach 2 Uncertainty analysis | | | | | | | | | |
| excl. LULUCF | 4.6 | 5.7 | 5.2 | 4.3 | 4.8 | 4.6 | 5.7 | 5.4 | 5.6 |
| incl. LULUCF | 6.0 | 6.8 | 6.4 | 6.1 | 6.4 | 6.2 | 6.7 | 6.8 | 6.7 |
| Approach 1 Uncertainty analysis | | | | | | | | | |
| excl. LULUCF | 3.2 | 7.4 | 5.3 | 3.3 | 5.9 | 4.6 | 3.5 | 3.6 | 3.6 |
| incl. LULUCF | 4.6 | 8.3 | 6.4 | 5.3 | 7.3 | 6.3 | 5.3 | 5.3 | 5.3 |

### Recalculations

For the latest recalculated year (2019), the total national emissions (excluding LULUCF, excluding indirect $CO_2$) decreased from 46’108 kt $CO_2$ eq in the previous submission (FOEN 2021) to 45’974 kt $CO_2$ eq (latest submission). See detailed explanations of the recalculations in the sectoral chapters and the summary in chp. 10.

### ES.2.2 KP-LULUCF activities

Switzerland reports the mandatory LULUCF activities Afforestation and Deforestation (Reforestation is not occurring in Switzerland) under Article 3, paragraph 3, of the Kyoto Protocol, and Forest management as a mandatory activity under Article 3, paragraph 4, of the Kyoto Protocol. The contribution of these activities is shown in Table E-4. All activities include net emissions and removals of all GHG (i.e. $CO_2$, $CH_4$, $N_2O$) from Harvested wood products (HWP), biomass burning, drainage and N mineralisation, where appropriate (see chp. 11.3).

Table E-4 Net $CO_2$ eq emissions (positive sign) and removals (negative sign) for activities accounted for under Article 3, paragraph 3 (Afforestation, Deforestation) and Forest management under Article 3, paragraph 4, of the Kyoto Protocol in kt $CO_2$ eq.

| | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | kt $CO_2$ equivalent | | | | |
| A. Article 3.3 activities | 83.64 | 106.76 | 129.77 | 142.35 | 160.69 |
| B. Article 3.4 Forest management | -2'327.34 | -4'587.76 | 4'222.81 | -3'435.69 | -3'564.51 |

| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| | kt $CO_2$ equivalent | | | | | | | | | |
| A. Article 3.3 activities | 163.73 | 165.70 | 167.99 | 169.77 | 167.75 | 168.08 | 175.67 | 179.14 | 177.89 | 180.25 |
| B. Article 3.4 Forest management | -2'083.10 | -3'209.25 | -2'964.66 | -1'592.72 | -3'147.28 | -3'017.74 | -2'916.12 | -1'678.94 | -2'658.92 | -2'330.00 |

## ES.3. Overview of source and sink category estimates and trends, including KP-LULUCF activities

### ES.3.1 GHG inventory (Convention on Climate Change)

Table E-5 shows the GHG emissions and removals by the main source and sink categories. Sector 1 Energy clearly dominates national emissions, accounting for more than three quarters of the total GHG emissions (excluding LULUCF, excluding indirect $CO_2$), as shown in Table E-6. Sectors 2 Industrial processes and product use (IPPU) and 3 Agriculture contribute a considerable share of GHG emissions as well, while sectors 5 Waste and 6 Other are of minor importance. LULUCF categories from sector 4 represent a net GHG sink over the inventory period except for the year 2000.

Overall, Switzerland's GHG emissions decreased in 2020 compared to 1990. This effect is mainly driven by decreases in the Energy and Agriculture sectors, which outweigh the increase in the Industrial processes and product use sector.

Table E-5 Greenhouse gas emissions (excluding indirect $CO_2$) in $CO_2$ equivalent (kt) by individual source (positive numbers) and sink (negative numbers) categories.

| Source and Sink Categories | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | |
| 1 Energy | 41'842 | 41'899 | 42'219 | 43'981 | 43'212 |
| 1A1 Energy industries | 2'519 | 2'642 | 3'172 | 3'816 | 3'846 |
| 1A2 Manufacturing industries and construction | 6'570 | 6'295 | 6'007 | 6'041 | 5'865 |
| 1A3 Transport | 14'690 | 14'314 | 15'981 | 15'855 | 16'336 |
| 1A4 Other sectors | 17'481 | 18'056 | 16'550 | 17'819 | 16'751 |
| 1A5 Other | 220 | 163 | 151 | 139 | 137 |
| 1B Fugitive emissions from fuels | 362 | 429 | 358 | 311 | 278 |
| 2 Industrial processes and product use | 4'012 | 3'421 | 3'784 | 4'432 | 4'530 |
| 3 Agriculture | 6'582 | 6'371 | 5'984 | 5'934 | 6'053 |
| 5 Waste | 1'118 | 919 | 892 | 938 | 862 |
| 6 Other | 12 | 12 | 13 | 14 | 12 |
| Total (excluding LULUCF) | 53'566 | 52'622 | 52'892 | 55'299 | 54'670 |
| 4. Land use, land-use change and forestry | -2'044 | -3'941 | 5'187 | -2'875 | -2'932 |
| Total (including LULUCF) | 51'522 | 48'680 | 58'079 | 52'424 | 51'737 |

| Source and Sink Categories | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | *2020 vs. 1990* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | | | | | | | % |
| 1 Energy | 39'155 | 40'546 | 41'472 | 37'423 | 37'090 | 37'489 | 36'503 | 35'210 | 35'087 | 32'651 | *-22.0%* |
| 1A1 Energy industries | 3'598 | 3'640 | 3'735 | 3'605 | 3'291 | 3'376 | 3'294 | 3'357 | 3'366 | 3'276 | *30.0%* |
| 1A2 Manufacturing industries and construction | 5'436 | 5'433 | 5'499 | 5'097 | 4'979 | 4'986 | 4'950 | 4'792 | 4'705 | 4'499 | *-31.5%* |
| 1A3 Transport | 16'159 | 16'273 | 16'188 | 16'081 | 15'344 | 15'182 | 14'920 | 14'926 | 14'883 | 13'577 | *-7.6%* |
| 1A4 Other sectors | 13'555 | 14'808 | 15'682 | 12'275 | 13'124 | 13'587 | 12'992 | 11'793 | 11'799 | 10'968 | *-37.3%* |
| 1A5 Other | 125 | 132 | 133 | 139 | 135 | 139 | 128 | 127 | 115 | 119 | *-45.6%* |
| 1B Fugitive emissions from fuels | 282 | 259 | 235 | 225 | 218 | 219 | 219 | 216 | 219 | 212 | *-41.5%* |
| 2 Industrial processes and product use | 4'533 | 4'517 | 4'524 | 4'533 | 4'479 | 4'423 | 4'586 | 4'454 | 4'406 | 4'198 | *4.6%* |
| 3 Agriculture | 6'011 | 6'013 | 5'954 | 6'069 | 5'994 | 5'957 | 5'936 | 5'882 | 5'783 | 5'757 | *-12.5%* |
| 5 Waste | 840 | 810 | 821 | 809 | 780 | 749 | 716 | 697 | 687 | 674 | *-39.8%* |
| 6 Other | 13 | 14 | 14 | 12 | 12 | 12 | 13 | 14 | 11 | 12 | *-4.9%* |
| Total (excluding LULUCF) | 50'552 | 51'901 | 52'786 | 48'845 | 48'355 | 48'631 | 47'754 | 46'257 | 45'974 | 43'291 | *-19.2%* |
| 4. Land use, land-use change and forestry | -1'244 | -2'488 | -2'021 | -303 | -2'167 | -2'132 | -1'895 | -905 | -2'116 | -1'705 | *-16.6%* |
| Total (including LULUCF) | 49'309 | 49'414 | 50'765 | 48'542 | 46'188 | 46'500 | 45'859 | 45'352 | 43'858 | 41'586 | *-19.3%* |

As shown in Figure E-2 GHG emissions in the period 1990–2020 are subject to fluctuations with a decreasing trend starting after 2005. The fluctuations derive from the year-to-year variability of the energy sector emissions caused by changing winter temperatures and hence, changing heating fuel use. Since around 2006, a growing decoupling of fuel combustion emissions and winter temperature is observed, reflecting the impact of emission reduction measures in the building sector.

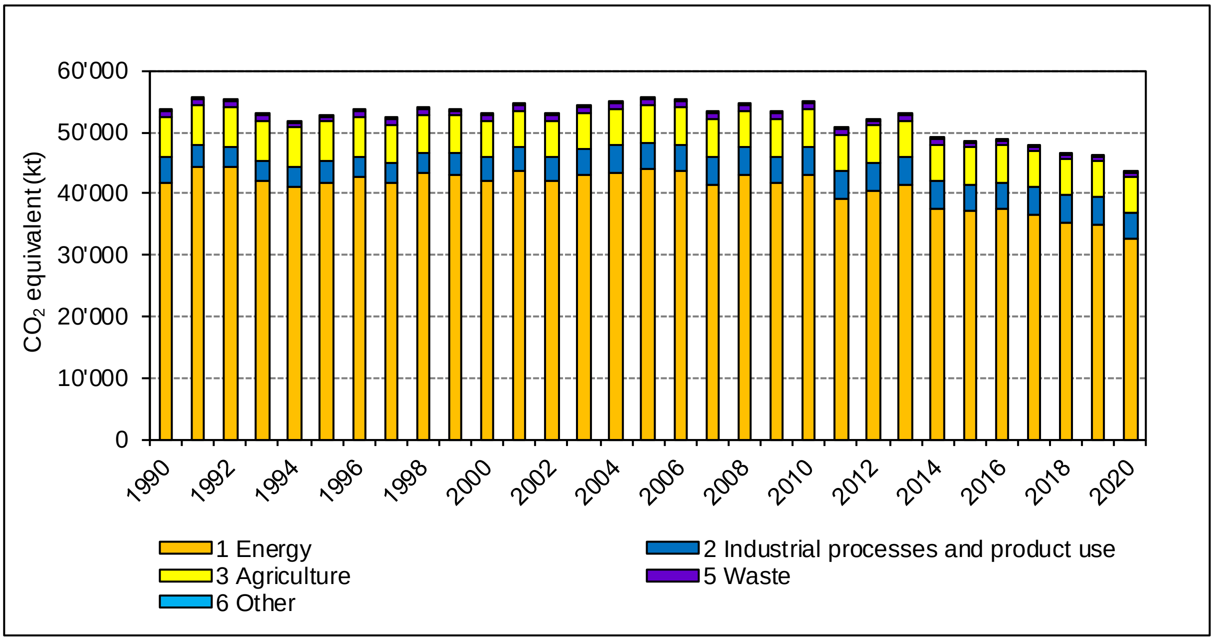


Figure E-2 Greenhouse gas emissions in $CO_2$ equivalent (kt) by sectors (excluding LULUCF, excluding indirect $CO_2$).

Table E-6 provides more detailed information on individual sectors' contributions to total emissions for selected years (excluding LULUCF). In general, the relative contributions of the different sectors have been rather stable between 1990 and 2020. When comparing the contributions in 2020 to 1990, the following development can be observed:

- Slightly lower relative contribution of sectors 1 Energy and 5 Waste.
- Larger relative contribution of sector 2 Industrial processes and product use.
- Similar relative contribution of sector 3 Agriculture.

Table E-6 Greenhouse gas emissions (excluding LULUCF, excluding indirect $CO_2$) in $CO_2$ equivalent (kt) and the relative contribution of individual source categories.

| Source and Sink Categories | 1990 | | 1995 | | 2000 | | 2005 | | 2010 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % |
| 1 Energy | 41'842 | 78.1% | 41'899 | 79.6% | 42'219 | 79.8% | 43'981 | 79.5% | 43'212 | 79.0% |
| *1A1 Energy industries* | 2'519 | *4.7%* | 2'642 | *5.0%* | 3'172 | *6.0%* | 3'816 | *6.9%* | 3'846 | 7.0% |
| *1A2 Manufacturing industries and construction* | 6'570 | *12.3%* | 6'295 | *12.0%* | 6'007 | *11.4%* | 6'041 | *10.9%* | 5'865 | *10.7%* |
| *1A3 Transport* | 14'690 | *27.4%* | 14'314 | *27.2%* | 15'981 | *30.2%* | 15'855 | *28.7%* | 16'336 | *29.9%* |
| *1A4 Other sectors* | 17'481 | *32.6%* | 18'056 | *34.3%* | 16'550 | *31.3%* | 17'819 | *32.2%* | 16'751 | *30.6%* |
| *1A5 Other* | 220 | *0.4%* | 163 | *0.3%* | 151 | *0.3%* | 139 | *0.3%* | 137 | *0.3%* |
| *1B Fugitive emissions from fuels* | 362 | *0.7%* | 429 | *0.8%* | 358 | *0.7%* | 311 | *0.6%* | 278 | *0.5%* |
| 2 Industrial processes and product use | 4'012 | 7.5% | 3'421 | 6.5% | 3'784 | 7.2% | 4'432 | 8.0% | 4'530 | 8.3% |
| 3 Agriculture | 6'582 | 12.3% | 6'371 | 12.1% | 5'984 | 11.3% | 5'934 | 10.7% | 6'053 | 11.1% |
| 5 Waste | 1'118 | 2.1% | 919 | 1.7% | 892 | 1.7% | 938 | 1.7% | 862 | 1.6% |
| 6 Other | 12 | 0.0% | 12 | 0.0% | 13 | 0.0% | 14 | 0.0% | 12 | 0.0% |
| Total (excluding LULUCF) | 53'566 | 100.0% | 52'622 | 100.0% | 52'892 | 100.0% | 55'299 | 100.0% | 54'670 | 100.0% |

| Source and Sink Categories | 2016 | | 2017 | | 2018 | | 2019 | | 2020 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % |
| 1 Energy | 37'489 | 77.1% | 36'503 | 76.4% | 35'210 | 76.1% | 35'087 | 76.3% | 32'651 | 75.4% |
| *1A1 Energy industries* | 3'376 | *6.9%* | 3'294 | *6.9%* | 3'357 | *7.3%* | 3'366 | *7.3%* | 3'276 | *7.6%* |
| *1A2 Manufacturing industries and construction* | 4'986 | *10.3%* | 4'950 | *10.4%* | 4'792 | *10.4%* | 4'705 | *10.2%* | 4'499 | *10.4%* |
| *1A3 Transport* | 15'182 | *31.2%* | 14'920 | *31.2%* | 14'926 | *32.3%* | 14'883 | *32.4%* | 13'577 | *31.4%* |
| *1A4 Other sectors* | 13'587 | *27.9%* | 12'992 | *27.2%* | 11'793 | *25.5%* | 11'799 | *25.7%* | 10'968 | *25.3%* |
| *1A5 Other* | 139 | *0.3%* | 128 | *0.3%* | 127 | *0.3%* | 115 | *0.3%* | 119 | *0.3%* |
| *1B Fugitive emissions from fuels* | 219 | *0.4%* | 219 | *0.5%* | 216 | *0.5%* | 219 | *0.5%* | 212 | *0.5%* |
| 2 Industrial processes and product use | 4'423 | 9.1% | 4'586 | 9.6% | 4'454 | 9.6% | 4'406 | 9.6% | 4'198 | 9.7% |
| 3 Agriculture | 5'957 | 12.2% | 5'936 | 12.4% | 5'882 | 12.7% | 5'783 | 12.6% | 5'757 | 13.3% |
| 5 Waste | 749 | 1.5% | 716 | 1.5% | 697 | 1.5% | 687 | 1.5% | 674 | 1.6% |
| 6 Other | 12 | 0.0% | 13 | 0.0% | 14 | 0.0% | 11 | 0.0% | 12 | 0.0% |
| Total (excluding LULUCF) | 48'631 | 100.0% | 47'754 | 100.0% | 46'257 | 100.0% | 45'974 | 100.0% | 43'291 | 100.0% |

## ES.3.2 KP-LULUCF activities

An overview of net $CO_2$ eq emissions and removals of activities under Article 3, paragraph 3 and Forest management under paragraph 4 of the Kyoto Protocol is shown in Table E-7 and Figure E-3.

Detailed quantitative information for selected years in the period 1990–2020 is reported in chp. 11.4, chp. 11.5, and displayed in Table 11-1. Fluctuations in annual GHG emissions and removals from Afforestation and Deforestation (Figure 11-2) can mainly be attributed to the changes in their respective areas (see Table 11-2 for activity data). The relative changes in the area of managed forest are comparatively small and fluctuations of the annual net carbon stock changes in Forest management can primarily be explained by changes in the carbon losses from the (1) living biomass pool, (2) dead wood pool and (3) litter pool (Table 11-1). The exceptionally high net emissions of Forest management in 2000 and the small net removals in the following year 2001 originate from winter storm "Lothar" at the end of 1999, which caused large-scale damages in forest stands and increased losses of living biomass due to salvage logging. Harvesting rates in Swiss forests gradually increased between 1991 and 2007. Peak values in 2006 and 2007 resulted in small removals from Forest management. In 2008 harvesting rates dropped (Table 6-14) due to the international and domestic economic framework conditions and remained relatively constant thereafter with interannual fluctuation of ca. 2 to 8%. These fluctuations are reflected in the year-to-year variability of the removals from Forest management. The small net removals in 2011, 2014 and 2018 are due to relative high harvesting rates in conjunction with above-average losses in the litter pool (related to climatic circumstances). Fluctuations in the Harvested wood products (HWP) pool are mainly caused by changes in the production of sawnwood and panels (see Table 6-33 and Figure 6-14). The contribution of paper and paperboard to changes in HWP fluctuates over the years, but is rather small compared to the contribution of sawnwood and panels.

Table E-7 Net $CO_2$ eq emissions (positive sign) and removals (negative sign) of activities accounted for under Article 3, paragraph 3 (Afforestation, Deforestation) and paragraph 4 (Forest management, Harvested wood products HWP) of the Kyoto Protocol in kt $CO_2$ eq.

| | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | kt $CO_2$ equivalent | | | | |
| A. Article 3.3 activities | 83.64 | 106.76 | 129.77 | 142.35 | 160.69 |
| Afforestation | -2.99 | -14.72 | -19.28 | -23.00 | -23.74 |
| Deforestation | 86.62 | 121.48 | 149.05 | 165.35 | 184.43 |
| B. Article 3.4 Forest Management | -2'327.34 | -4'587.76 | 4'222.81 | -3'435.69 | -3'564.51 |
| Forest management excl. HWP | -1'158.58 | -4'100.80 | 4'945.36 | -2'708.56 | -3'109.17 |
| HWP | -1'168.76 | -486.96 | -722.55 | -727.12 | -455.33 |

| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| | kt $CO_2$ equivalent | | | | | | | | | |
| A. Article 3.3 activities | 163.73 | 165.70 | 167.99 | 169.77 | 167.75 | 168.08 | 175.67 | 179.14 | 177.89 | 180.25 |
| Afforestation | -21.56 | -20.71 | -19.38 | -16.83 | -18.11 | -17.56 | -17.24 | -15.11 | -16.94 | -15.89 |
| Deforestation | 185.29 | 186.41 | 187.37 | 186.60 | 185.86 | 185.64 | 192.92 | 194.25 | 194.83 | 196.14 |
| B. Article 3.4 Forest Management | -2'083.10 | -3'209.25 | -2'964.66 | -1'592.72 | -3'147.28 | -3'017.74 | -2'916.12 | -1'678.94 | -2'658.92 | -2'330.00 |
| Forest management excl. HWP | -1'729.56 | -3'076.68 | -3'022.95 | -1'480.54 | -3'051.95 | -2'965.81 | -2'901.57 | -1'583.13 | -2'716.06 | -2'278.86 |
| HWP | -353.54 | -132.57 | 58.29 | -112.18 | -95.33 | -51.93 | -14.54 | -95.81 | 57.14 | -51.14 |

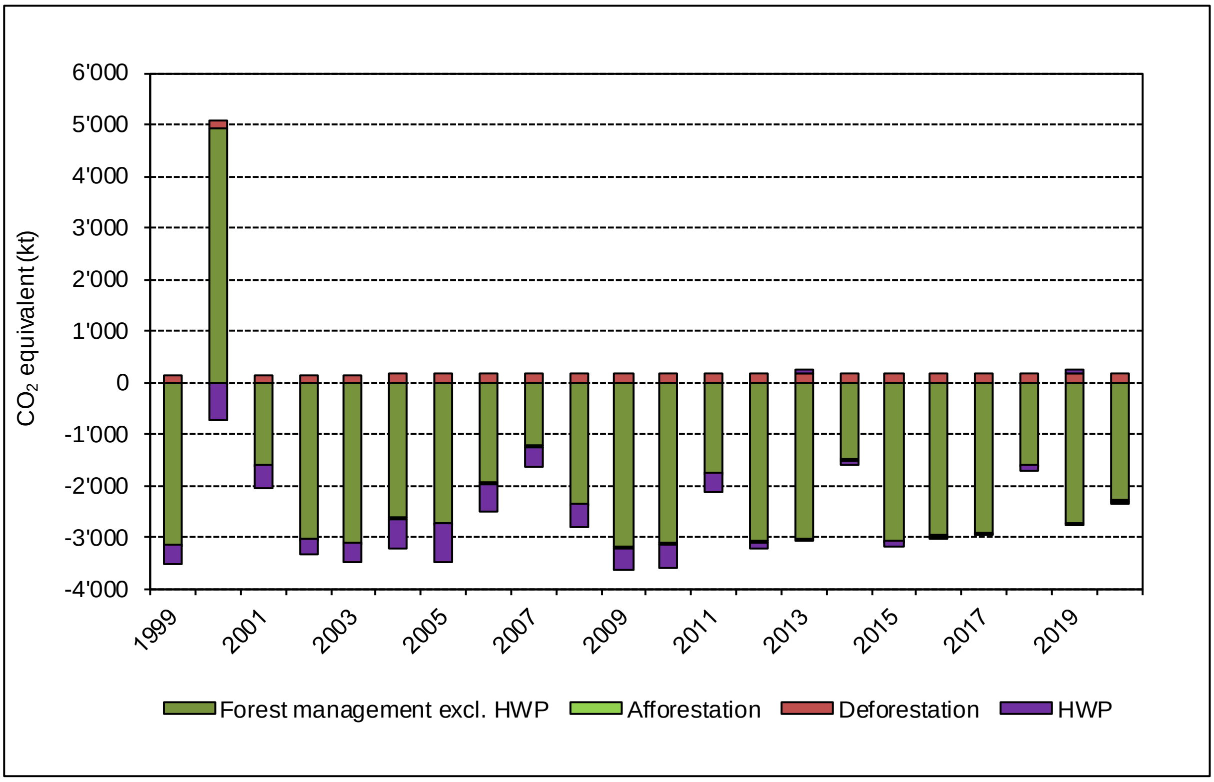


Figure E-3 Greenhouse gas emissions (positive sign) and removals (negative sign) from Afforestation (too small to be distinguishable) and Deforestation under Article 3, paragraph 3, Forest management excluding HWP, and HWP under Article 3, paragraph 4.

### ES.3.3 GHG inventory (Kyoto Protocol)

Relevant emissions and removals under the Kyoto Protocol by sectors and gases are shown in Table E-8 and Table E-9. Total emissions reported under the Kyoto Protocol differ from those reported under the UNFCCC because sectors 4 LULUCF, 6 Other, and international bunkers are not accounted for under the Kyoto Protocol. However, activities under Article 3, paragraph 3 (Afforestation and Reforestation, Deforestation) and Article 3, paragraph 4 (Forest management, Cropland management, Grazing land management, Revegetation and Wetland drainage and rewetting) as well as indirect $CO_2$ emissions are included in the tables. Under the activities of Article 3, paragraph 4, of the Kyoto Protocol, Switzerland only accounts for Forest management. Base year emissions (as shown in Table E-8 and Table E-9), which are relevant for calculating the cap on activities under Art. 3.4 (see decision 2/CMP.7, paragraph 13) are reported in Switzerland's Second Initial Report (FOEN 2016c) and the update to the report following the UNFCCC in-country review (FOEN 2016d).

Table E-8 Summary of greenhouse gas emissions in $CO_2$ equivalent (kt) as well as emissions and removals under KP-LULUCF by sectors. Excluded are emissions and removals from sectors 4 LULUCF, 6 Other, and from International bunkers.

| | | **Sector** | **Base year** | **1991** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $CO_2$ equivalent (kt) | | | | | | | | | |
| Annex A sources | | 1 Energy + indirect $CO_2$ from this sector | 41'881 | 44'312 | 44'359 | 42'183 | 41'067 | 41'964 | 42'836 | 41'922 | 43'488 | 43'277 |
| | | 2 Industrial processes and product use + indirect $CO_2$ from this sector | 3'887 | 3'971 | 3'751 | 3'491 | 3'659 | 3'659 | 3'554 | 3'514 | 3'545 | 3'641 |
| | | 3 Agriculture | 6'804 | 6'551 | 6'466 | 6'378 | 6'364 | 6'371 | 6'293 | 6'082 | 6'046 | 5'999 |
| | | 5 Waste + indirect $CO_2$ from this sector | 1'135 | 1'027 | 1'026 | 974 | 913 | 920 | 917 | 908 | 898 | 889 |
| | | **Total (Annex A sources)** | **53'707** | **55'861** | **55'601** | **53'026** | **52'003** | **52'914** | **53'600** | **52'427** | **53'977** | **53'805** |

| | | **Sector** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $CO_2$ equivalent (kt) | | | | | | | | | |
| Annex A sources | | 1 Energy + indirect $CO_2$ from this sector | 42'269 | 43'672 | 43'662 | 43'264 | 43'586 | 44'019 | 43'640 | 41'594 | 42'982 | 41'879 |
| | | 2 Industrial processes and product use + indirect $CO_2$ from this sector | 3'955 | 4'018 | 4'143 | 4'121 | 4'408 | 4'552 | 4'585 | 4'672 | 4'621 | 4'382 |
| | | 3 Agriculture | 5'984 | 6'019 | 5'969 | 5'883 | 5'861 | 5'934 | 5'972 | 6'031 | 6'125 | 6'028 |
| | | 5 Waste + indirect $CO_2$ from this sector | 893 | 914 | 933 | 921 | 950 | 939 | 937 | 919 | 900 | 878 |
| | | **Total (Annex A sources)** | **53'101** | **54'623** | **54'706** | **54'189** | **54'805** | **55'444** | **55'134** | **53'216** | **54'629** | **53'168** |
| KP-LULUCF | Art.3.3 | Afforestation & Reforestation | | | | | | | | | -25 | -26 |
| | | Deforestation | | | | | | | | | 177 | 181 |
| | Art.3.4 | Forest management | | | | | | | | | -2763 | -3'613 |
| | | Cropland management | | | | | | | | | NA | NA |
| | | Grazing land management | | | | | | | | | NA | NA |
| | | Revegetation | | | | | | | | | NA | NA |
| | | Wetland drainage and rewetting | | | | | | | | | NA | NA |

| | | **Sector** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | ***2020 vs. base year*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $CO_2$ equivalent (kt) | | | | | | | | | | | *%* |
| Annex A sources | | 1 Energy + indirect $CO_2$ from this sector | 43'244 | 39'186 | 40'576 | 41'499 | 37'450 | 37'116 | 37'515 | 36'528 | 35'234 | 35'112 | 32'675 | *-16%* |
| | | 2 Industrial processes and product use + indirect $CO_2$ from this sector | 4'643 | 4'644 | 4'624 | 4'626 | 4'633 | 4'576 | 4'522 | 4'685 | 4'547 | 4'502 | 4'292 | *16%* |
| | | 3 Agriculture | 6'053 | 6'011 | 6'013 | 5'954 | 6'069 | 5'994 | 5'957 | 5'936 | 5'882 | 5'783 | 5'757 | *-15%* |
| | | 5 Waste + indirect $CO_2$ from this sector | 864 | 842 | 812 | 823 | 810 | 781 | 750 | 717 | 699 | 688 | 675 | *-39%* |
| | | **Total (Annex A sources)** | **54'804** | **50'682** | **52'025** | **52'903** | **48'962** | **48'467** | **48'745** | **47'866** | **46'362** | **46'085** | **43'399** | ***-14%*** |
| KP-LULUCF | Art.3.3 | Afforestation & Reforestation | -24 | -22 | -21 | -20 | -17 | -18 | -18 | -17 | -15 | -17 | -16 | |
| | | Deforestation | 184 | 185 | 186 | 187 | 187 | 186 | 186 | 193 | 194 | 195 | 196 | |
| | Art.3.4 | Forest management | -3'565 | -2'083 | -3'209 | -2'965 | -1'593 | -3'147 | -3'018 | -2'916 | -1'679 | -2'659 | -2'330 | |
| | | Cropland management | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | |
| | | Grazing land management | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | |
| | | Revegetation | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | |
| | | Wetland drainage and rewetting | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | |

Table E-9 Contribution of individual gases to total emissions (excluding 4 LULUCF, 6 Other, and International bunkers) in $CO_2$ equivalent (kt), as well as emissions and removals under KP-LULUCF. HFC emissions increased by more than 5 million percent when compared to 1990 levels.

| | | GHG | Base year | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $CO_2$ equivalent (kt) | | | | | | | | | |
| Annex A sources | | $CO_2$ + indirect $CO_2$ | 44'516 | 46'522 | 46'378 | 43'944 | 42'992 | 43'713 | 44'384 | 43'305 | 44'863 | 44'669 |
| | | $CH_4$ | 6'086 | 5'731 | 5'666 | 5'564 | 5'505 | 5'516 | 5'469 | 5'327 | 5'267 | 5'185 |
| | | $N_2O$ | 2'852 | 3'368 | 3'320 | 3'330 | 3'298 | 3'330 | 3'340 | 3'289 | 3'213 | 3'242 |
| | | HFCs | 0.025 | 1.5 | 16 | 33 | 80 | 244 | 296 | 360 | 456 | 533 |
| | | PFCs | 117 | 99 | 81 | 35 | 21 | 17 | 20 | 21 | 24 | 32 |
| | | $SF_6$ | 137 | 139 | 141 | 121 | 107 | 93 | 90 | 125 | 153 | 140 |
| | | $NF_3$ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| | | **Total (Annex A sources)** | **53'707** | **55'861** | **55'601** | **53'026** | **52'003** | **52'914** | **53'600** | **52'427** | **53'975** | **53'802** |

| | | GHG | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $CO_2$ equivalent (kt) | | | | | | | | | |
| Annex A sources | | $CO_2$ + indirect $CO_2$ | 43'833 | 45'273 | 43'647 | 44'816 | 45'391 | 45'925 | 45'518 | 43'509 | 44'847 | 43'671 |
| | | $CH_4$ | 5'140 | 5'173 | 5'128 | 5'050 | 5'036 | 5'077 | 5'090 | 5'071 | 5'146 | 5'044 |
| | | $N_2O$ | 3'276 | 3'253 | 3'322 | 3'181 | 3'105 | 3'132 | 3'107 | 3'149 | 3'071 | 2'949 |
| | | HFCs | 636 | 736 | 826 | 910 | 1'009 | 1'048 | 1'160 | 1'253 | 1'275 | 1'272 |
| | | PFCs | 61 | 37 | 36 | 67 | 69 | 50 | 62 | 52 | 45 | 35 |
| | | $SF_6$ | 152 | 151 | 161 | 166 | 195 | 213 | 197 | 182 | 245 | 188 |
| | | $NF_3$ | NO | NO | NO | NO | NO | NO | NO | NO | 0.12 | 7.6 |
| | | **Total (Annex A sources)** | **53'099** | **54'623** | **53'120** | **54'189** | **54'805** | **55'444** | **55'134** | **53'216** | **54'629** | **53'168** |
| KP-LULUCF | Art.3.3 | $CO_2$ | | | | | | | | | 149 | 153 |
| | | $CH_4$ | | | | | | | | | NO | NO |
| | | $N_2O$ | | | | | | | | | 2.9 | 3.1 |
| | Art.3.4 | $CO_2$ | | | | | | | | | -2766.7 | -3'617 |
| | | $CH_4$ | | | | | | | | | 2.7 | 2.7 |
| | | $N_2O$ | | | | | | | | | 1.2 | 1.2 |

| | | GHG | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | *2020 vs. base year* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $CO_2$ equivalent (kt) | | | | | | | | | | | % |
| Annex A sources | | $CO_2$ + indirect $CO_2$ | 45'181 | 41'116 | 42'378 | 43'306 | 39'351 | 38'844 | 39'300 | 38'292 | 36'980 | 36'845 | 34'350 | *-17%* |
| | | $CH_4$ | 5'018 | 4'967 | 4'946 | 4'874 | 4'865 | 4'838 | 4'804 | 4'746 | 4'711 | 4'632 | 4'587 | *-24%* |
| | | $N_2O$ | 3'085 | 3'005 | 2'980 | 2'987 | 2'968 | 2'973 | 2'904 | 3'058 | 2'926 | 2'994 | 2'902 | *5%* |
| | | HFCs | 1'308 | 1'380 | 1'453 | 1'432 | 1'469 | 1'508 | 1'481 | 1'504 | 1'525 | 1'429 | 1'387 | *see caption* |
| | | PFCs | 38 | 36 | 39 | 28 | 23 | 26 | 20 | 32 | 36 | 32 | 34 | *-73%* |
| | | $SF_6$ | 161 | 169 | 230 | 276 | 285 | 278 | 236 | 233 | 183 | 152 | 138 | *11%* |
| | | $NF_3$ | 13 | 9.3 | 0.54 | 0.14 | 0.60 | 0.73 | 0.77 | 0.80 | 0.50 | 0.54 | 0.41 | *NA* |
| | | **Total (Annex A sources)** | **54'804** | **50'682** | **52'025** | **52'903** | **48'962** | **48'467** | **48'745** | **47'866** | **46'362** | **46'085** | **43'399** | ***-14%*** |
| KP-LULUCF | Art.3.3 | $CO_2$ | 158 | 160 | 162 | 165 | 166 | 164 | 165 | 172 | 175 | 174 | 176 | |
| | | $CH_4$ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | |
| | | $N_2O$ | 3.2 | 3.3 | 3.3 | 3.4 | 3.5 | 3.5 | 3.6 | 3.6 | 3.7 | 3.7 | 3.7 | |
| | Art.3.4 | $CO_2$ | -3'568 | -2'089 | -3'212 | -2'968 | -1'596 | -3'151 | -3'025 | -2'921 | -1'683 | -2'662 | -2'333 | |
| | | $CH_4$ | 2.3 | 4.0 | 2.2 | 2.2 | 2.4 | 2.4 | 5.0 | 3.1 | 2.5 | 2.0 | 1.9 | |
| | | $N_2O$ | 0.98 | 2.1 | 0.97 | 0.95 | 1.1 | 1.1 | 2.8 | 1.6 | 1.2 | 0.85 | 0.80 | |

## ES.4. Other information

Emissions from precursor gases show a very pronounced decline (see Table 2-6 and Figure 2-10). A strict air pollution control policy led to strong decreases in emissions of precursor gases over the period 1990–2020. An overview concerning precursors is given in chp. 2.4 and details are provided in Switzerland's Informative Inventory Report (FOEN 2022b).

# PART 1

# 1. Introduction

| Responsibilities for Introduction | |
|---|---|
| Author | Regine Röthlisberger (FOEN) |
| Key Category Analyses (KCA) | Myriam Guillevic (FOEN) |
| Uncertainty analyses | Myriam Guillevic (FOEN) |
| Annual updates (NIR text, tables, figures) | Dominik Eggli (Meteotest), Pascal Graf (Meteotest, KCA) |
| Quality control NIR (annual updates) | Michael Bock (FOEN), Anna Ehrler (INFRAS), Beat Rihm (Meteotest; Uncertainties), Felix Weber (INFRAS; KCA, Uncertainties) |
| Internal review | Michael Bock (FOEN) |

## 1.1. Background information on Swiss greenhouse gas inventories, climate change and supplementary information of the Kyoto Protocol (KP)

### 1.1.1. Information on climate change

The Swiss Academies of Sciences have published a comprehensive assessment of climate change and its impacts in Switzerland, both in the past and in the future (SCNAT 2016). Long-term measurements indicate a marked shift towards a warmer climate for Switzerland. Between 1864 and 2016, the average temperature in Switzerland has increased by +2.0°C compared to +0.9°C globally (FOEN 2018d).

In the course of the 21st century, Swiss climate is projected to depart significantly from present and past conditions. Mean temperature will very likely increase in all regions and seasons (CH2018 2018). Summer mean precipitation will likely decrease by the end of the century all over Switzerland by up to 40%, while winter precipitation will likely increase, particularly in Southern Switzerland.

The retreat and massive loss of volume of glaciers in the Alps is the best visible indicator of the recent increase in atmospheric temperature. The changes of the glaciers in the Swiss Alps are measured every year and compiled by the network GLAMOS (www.glamos.ch). In recent years, evidence of vigorous impacts on glaciers has been accumulated, including collapse of structures on the glacier surface, disintegration into pieces, separation of glacier tongues from the main ice body at steep slopes, leaving dead ice in formerly covered areas. At various locations all over the Swiss Alps, glacier lakes have formed or grown as a result of continuing glacier retreat. From the ca. 2’900 square kilometres of glacier area in the mid-1970s, only about 2’100 square kilometres remained in 2003 and an estimated 1’900 square kilometres in 2013. Several studies indicate that Alpine glaciers are far out of balance with the current climate. Due to delayed response effects, glaciers would continue to shrink even without any further increase in temperature. If temperatures are going to increase further as projected by climate models e.g. Swiss Climate Change Scenarios (CH2018 2018), the loss of glacier mass will be even more dramatic. Modelling studies indicate a strong future area loss of 50–90% (for a temperature increase between two and six degrees Celsius (°C)) by 2100 for Switzerland and the entire Alps (FOEN 2018d).

The change in summer mean precipitation will have a marked impact on the hydrological cycle: on the Central Plateau and in the very south of Switzerland, small and medium watercourses will dry up more frequently and natural replenishment of groundwater will decrease accordingly (FOEN 2021j). Apart from changes to the mean temperature and precipitation, the nature of extreme events is also expected to change (CH2018 2018). More frequent, intense and longer-lasting summer warm spells and heat waves are expected, while the number of cold winter days and nights decrease in the projections for future climate in Switzerland. This is particularly relevant for alpine areas, tourism and forestry due to the risk of more frequent floods, landslides and debris flows.

The warming trend and changing precipitation patterns are expected to have significant effects on ecosystems. The Biodiversity Monitoring Switzerland reports that impacts of climate change are already being observed with indicators such as the phenological spring phases, flowering indices and animal specific indices (FOEN 2018g). They show significant changes in a wide range of ecosystems during the last decades. Generally, climate change is expected to affect species composition, distribution, their cycles, synchronicity, the overall genetic diversity and the provision of ecosystem services. It will raise the vulnerability of forests and impair their protective, productive and social functions. Species distribution shifts towards higher elevations, spread of thermophile species, colonisation by new species from warmer areas, and phenological shifts. In the driest areas, increasing droughts are affecting tree survival and fish species are suffering from warm temperatures in lowland regions. River ecosystems will be doubly affected by climate change, i.e. by both the higher air temperature and the seasonal redistribution of river flows. Higher air temperatures together with the associated higher water temperatures and lower water levels in summer are likely to put pressure on river ecology and thereby also on fishing (FOEN 2018d).

In general, climate change in Switzerland is expected to entail a shift of suitable areas for agricultural production, and to involve both positive (e.g. a longer vegetation period) and negative (e.g. increasing incidence of pest infestations owing to milder winters) aspects. Changes in the nature of extreme weather events, in particular more frequent, intense and longer-lasting summer heat waves, could also challenge agriculture, e.g. by reducing the reliability of harvests. The extent to which climate change will affect agriculture will depend, however, on the regional settings, the overall political framework and the specific economic situation of the farms. Economic considerations are expected to play a crucial role for the adoption of adaptation measures (FOEN 2018d).

Various sectors of the Swiss economy are likely to be affected by progressing climate change. In particular, the tourism industry will be hit, as the potentially beneficial effects for summer tourism will not compensate for the loss of income in mountain resorts during winter due to scarcity of snow. Cable car stations may suffer from loosening of their anchorage due to instabilities of thawing permafrost soils. Hydroelectric power stations may be affected by altered runoff and sediment transport regimes, and insurance companies may face increased losses due to winter storms and floods. Natural hazards and extreme weather events potentially pose a growing risk to infrastructure and human health. Heat waves and elevated tropospheric ozone levels are cause for serious concern, as evidenced by the impacts of the heat waves in 2003, 2015, and 2018 (FOEN 2016l, FOEN 2019j). Finally, it remains to be seen to what extent vector borne diseases spread due to changing climatic conditions. Switzerland has recently analysed these challenges in detail and developed an effective adaptation strategy in order to hedge against negative effects resulting from climate change in Switzerland (FOEN 2012b, FOEN 2020m).

### 1.1.2. Information on the greenhouse gas inventory

On 10 December 1993, Switzerland ratified the United Nations Framework Convention on Climate Change (UNFCCC) (UNFCCC 1992). Since 1996, the submission of its national greenhouse gas inventory has been based on IPCC guidelines. From 1998 onwards, the inventories have been submitted in the Common Reporting Format (CRF). In 2004, Switzerland started submitting annually its National Inventory Report (NIR) under the UNFCCC.

On 9 July 2003, Switzerland ratified the Kyoto Protocol under the UNFCCC (UNFCCC 1998). In November 2006 Switzerland submitted its Initial Report under Article 7, paragraph 4 of the Kyoto Protocol (FOEN 2006h). The Swiss National Inventory System (NIS) according to Article 5.1 of the Kyoto Protocol has been implemented in 2006 and is fully operational. On 6 December 2007, the NIS quality management system was certified to comply with ISO 9001:2000 requirements; it has been audited and recertified several times with the latest audit on 10$^{th}$ June 2021 (ISO 9001:2015, Swiss Safety Center 2019). The quality management system includes the accounting and reporting of the National Registry as well. The April 2008 submission of the Swiss GHG inventory (FOEN 2008) has been Switzerland’s first submission under both the UNFCCC and the Kyoto Protocol.

On 28 August 2015, Switzerland submitted its instrument of acceptance of the Doha amendment to the Kyoto Protocol (UNFCCC 2012) to the UNFCCC. The Initial Report for the second commitment period (FOEN 2016c) was submitted simultaneously with the inventory 2016. An update following the in-country review by an expert review team was submitted on 7$^{th}$ November 2016 to the UNFCCC secretariat (FOEN 2016d). In 2015, the inventory submission under the UNFCCC and under the Kyoto Protocol was restructured in accordance with the Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention (UNFCCC 2014a) and the Guidance for reporting information on activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol (UNFCCC 2014b).

The 2022 inventory submission under the UNFCCC and under the Kyoto Protocol includes the NIR on hand, the greenhouse gas inventory 1990 to 2020, the Kyoto Protocol LULUCF tables 2013 to 2020 in the Common Reporting Format (CRF) and the Standard Electronic Format (SEF) tables as well as the standard independent assessment report (SIAR) from the National Registry.

### 1.1.3. Supplementary information required under art. 7.1. KP

Supplementary information required under art. 7.1 of the Kyoto Protocol is provided in Part 2 of the NIR. Information on KP-LULUCF is provided in chp. 11.

Switzerland accounts for the mandatory activity Forest management under Article 3, paragraph 4 of the Kyoto Protocol (FOEN 2016c). In accordance with Annex I to Decision 2/CMP.7 (Annex I, Para 13), credits from Forest management are capped in the second commitment period. Thus, for Switzerland the cap amounts to 3.5% of the 1990 emissions (excluding LULUCF).

Switzerland will account over the entire commitment period for emissions and removals from activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol (FOEN 2016c, FOEN 2016d). In addition to the mandatory submission of the inventory years 2013–2020, selected data for the years 1990–2012 are shown in chp. 11.

## 1.2. National inventory arrangements

### 1.2.1. Institutional, legal and procedural arrangements

Based on the Organisation Ordinance for the Federal Department of the Environment, Transport, Energy and Communications (DETEC), the Federal Office for the Environment (FOEN) is the designated national authority for climate policy and environmental monitoring. According to the decree of the Federal Council of 8 November 2006, the FOEN is in charge of the National Inventory System (NIS) (Figure 1-1). The Swiss National Inventory System was formally set up in 2006 in compliance with the requirements of the UNFCCC and the Kyoto Protocol (FOEN 2006h). In this context, the FOEN established the process “Climate Reporting”, which covers maintaining the National Inventory System and fulfilling all reporting obligations under the UNFCCC and the Kyoto Protocol. The process, led and managed by the Climate division of the FOEN, is fully operational ever since and ensures timely fulfilment of Switzerland’s reporting obligations.

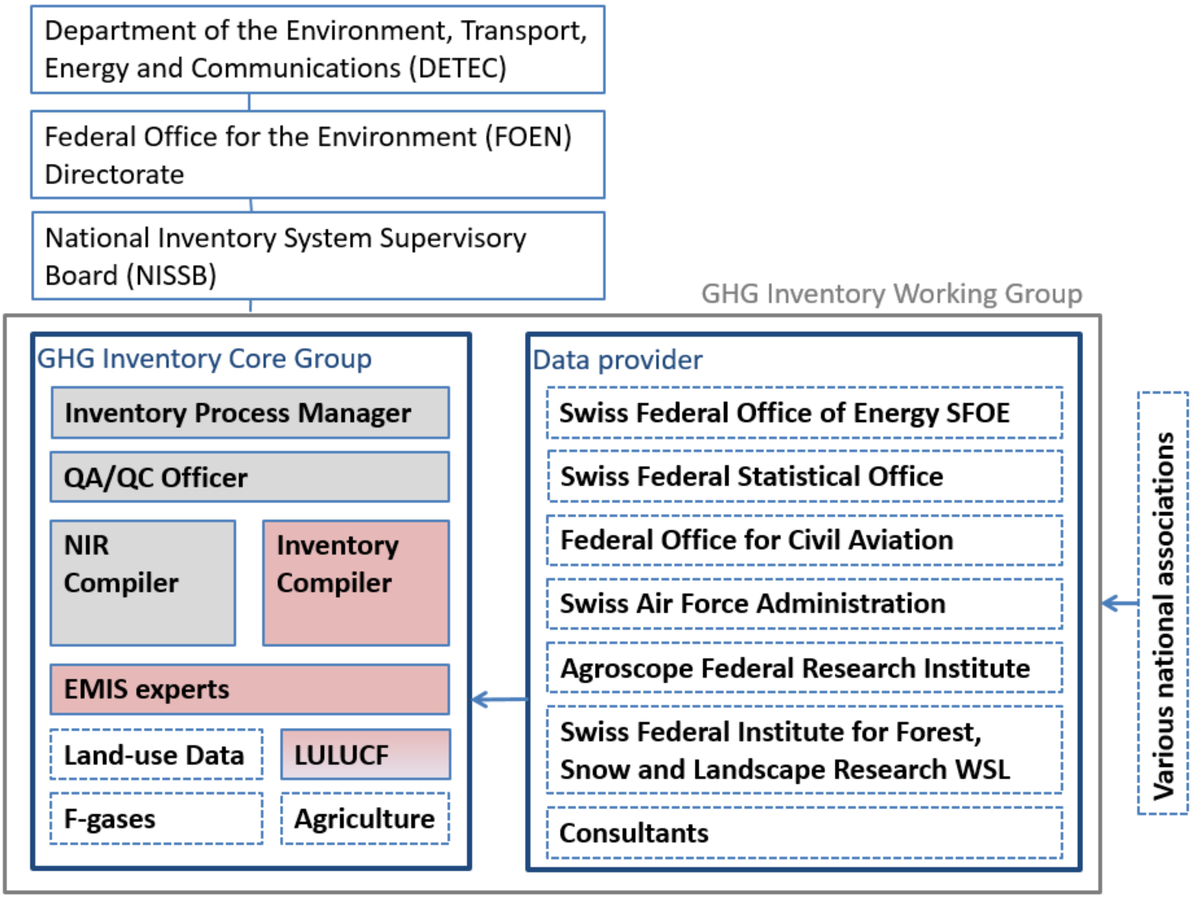


Figure 1-1 Institutional arrangements of the National Inventory System. Colours refer to divisions at FOEN. Grey: Climate division, red: Air Pollution Control and Chemicals division, Forest division. Boxes with dashed lines refer to external mandates.

### Legal arrangements

The $CO_2$ act (Swiss Confederation 2011) and the $CO_2$ ordinance (Swiss Confederation 2012) are the main legal instruments regarding climate policies. They also define the implementing bodies and, for all measures that are regulated at the national level, sanctions for non-compliance to climate policies and measures. The FOEN plays a central role in the development, evaluation and implementation of policies and measures.

With regard to statistical investigations, the legal basis is laid down in the Federal Statistics Act (Swiss Confederation 1992a) and the corresponding Ordinance on the Conduct of Federal Statistical Surveys (Swiss Confederation 1993). The greenhouse gas inventory, the institution responsible for it and the institutions contributing to it are explicitly listed in the ordinance.

### Institutional arrangements

There are well-established agreements and long-standing collaborations with institutions of the federal administration and private entities (Table 1-1) that guarantee the continuity of the National Inventory System (Figure 1-1). While agreements with institutions of the federal administration are normally open-ended, several large contracts with private entities are on a four-year basis, with an option for renewal for another four-year term. This enables continuous collaboration and ensures the technical competence and experience of the staff involved.

Table 1-1 Overview of the institutional arrangements and tasks

| Institutions of the federal administration | |
|---|---|
| FOEN Climate division | Overall responsibility for the greenhouse gas inventory |
| FOEN Air Pollution Control and Chemicals division | EMIS data base and data archiving |
| FOEN Forest division | Forestry emissions and removals |
| Swiss Federal Office of Energy (SFOE) | Energy statistics |
| Federal Office of Civil Aviation (FOCA) | Aviation emissions |
| Swiss Federal Statistical Office (SFSO) | Area surveys for (KP-) LULUCF |
| Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) | National forest inventory, forestry related modelling |
| Agroscope Federal Research Institute | Agriculture emissions and removals |
| **Private entities** | |
| Carbotech | Fluorinated gases emissions |
| Meteotest | Harvested Wood Products |
| Sigmaplan / Meteotest | (KP-) LULUCF |
| Meteotest / Infras | Data handling and NIR updating |

The overall responsibility for the greenhouse gas inventory lies with the Climate division of the FOEN. The Air Pollution Control and Chemicals division of the FOEN maintains and updates the emissions database (greenhouse gases and air pollutants), named EMIS, in very close collaboration with the Climate division. The national energy statistics from the Federal Office of Energy (SFOE) provides the basis for the Energy sector. The Federal Office for Civil Aviation (FOCA) delivers the domestic and international aviation emissions. A consultancy (Carbotech) is mandated to survey and model fluorinated gases use and emissions and to provide an annual update thereof. Agriculture emissions are compiled by the Federal Research Institute Agroscope. For LULUCF, detailed land use survey data are provided by the Federal Statistical Office (FSO). Two consultancies (Sigmaplan/Meteotest) are mandated to process the land use survey data to derive land-use and land-use change data and related emissions. The Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) is in charge of the national forest inventory and forestry-related modelling, providing the relevant input for the FOEN Forest division, who is compiling emissions and removals in Forest land. The LULUCF sector is coordinated by a member of the Climate division of the FOEN. A collaboration between two consultancies (Meteotest/Infras) is mandated to support data handling in EMIS and updating the National Inventory Report (NIR).

**Single national entity with overall responsibility for the inventory:**

Federal Office for the Environment (FOEN)
Climate Division, Climate Reporting and Adaptation Section
Dr. Regine Röthlisberger, process manager
CH-3003 Bern, Switzerland
+41 58 462 92 59
climate@bafu.admin.ch
www.climatereporting.ch

### 1.2.2. Overview of inventory planning, preparation and management

The process of inventory planning, preparation and management in Switzerland is well-established. Responsibilities and decision-making power are assigned to specific people or groups of people (Figure 1-1). The management responsibility for the NIS lies with the **National Inventory System Supervisory Board** (NISSB). The board consists of a member of the FOEN directorate and FOEN division heads of the relevant divisions (Climate, Forest, Air Pollution Control and Chemicals, International Affairs). In 2014 the NISSB, which originally covered the National Inventory System as well as the National Registry, was formally split into two separate boards with separate mandates and responsibilities. Since then, the NISSB is overseeing all aspects related to reporting obligations under the UNFCCC (including reporting of the National Registry in the NIR), while the Emission Registry Supervisory Board (ERSB) deals with management issues related to the National Registry.

At the operational level, the process of planning, preparation and management of the greenhouse gas inventory is led by the **process manager**. The **QA/QC officer** oversees design, development, and operation of the quality management system and is the primary contact point during the UN review process. The **Greenhouse gas (GHG) inventory core group** is the committee that combines all technical expertise required for greenhouse gas inventory planning, preparation and management. It consists of the process manager, the QA/QC officer, the inventory compiler, sectoral experts, as well as the NIR compiler. Additional experts join the core group as required. The GHG inventory core group ensures conformity of the inventory with the relevant UNFCCC reporting guidelines (UNFCCC 2014a), timely inventory preparation, and consideration and approval of methodological changes, choice of data and recalculations. The **GHG inventory working group** encompasses all technical personnel involved in the inventory preparation process or representing institutions that play a significant role as suppliers of data.

Inventory planning, preparation, and management follow an annual cycle according to a plan-do-check-act cycle (Table 1-2). Planning of the inventory cycle starts with the first meeting of the GHG inventory core group in May, where work is scheduled, priorities with regard to inventory development are set and decisions regarding planned improvements are taken. Data compilation usually starts in June with the first data sets for the preceding year becoming available. Quality control activities form part of the data acquisition process. They are routinely carried out by the EMIS (Swiss Emission Information System) experts and the sectoral experts. Usually, the UN review process in September provides further input to the inventory development plan (IDP). Recommendations and suggestions are discussed in the core group and future work is prioritized. The NIS supervisory board (NISSB) is provided with the management review in October and asked for formal approval of the planned way of proceeding. An important stage in inventory preparation is the preparation and quality control of the reporting tables (CRF) in December and January and the key category and uncertainty analyses towards end of January. The editing of the National Inventory Report (NIR) progresses alongside data compilation, with a draft of the NIR going into internal review in March. Suggestions from the internal review are dealt with before submission as far as possible. If the internal review suggests large revisions, they are taken up in the IDP for future improvements. The inventory is presented to the NISSB for official consideration and approval around end of March. Submission is coordinated by the process manager and carried out by the national inventory compiler. Archiving of inventory material is performed after submission by the EMIS and sectoral experts, by the contributing authors and by the QA/QC officer.

Table 1-2 Annual cycle of inventory planning, preparation and management

| | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Data compilation | | | | | | | | | | | | |
| QC EMIS Experts | | | | | | | | | | | | |
| QC Sectoral Experts | | | | | | | | | | | | |
| UN Review | | | | | | | | | | | | |
| Inventory Development Plan | | | | | | | | | | | | |
| CRF Tables | | | | | | | | | | | | |
| QC CRF Tables | | | | | | | | | | | | |
| KCA / Uncertainties | | | | | | | | | | | | |
| NIR | | | | | | | | | | | | |
| Internal review NIR and CRF Tables | | | | | | | | | | | | |
| Official consideration and approval | | | | | | | | | | | | |
| Submission | | | | | | | | | | | | x |
| Archiving | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| Meeting of Core Group | x | | | | x | | | x | | x | | |
| Meeting of Working Group | | | | | | | | | | | | x |
| Meeting of NIS Supervisory Board | | | | | | x | | | | | x | |

## 1.2.3. Quality assurance, quality control and verification plan

The national inventory system has an established quality management system (QMS) that complies with the requirements of ISO 9001:2015. Certification has been obtained in 2007 and is upheld since through annual audits (Swiss Safety Center 2019). The QMS is designed to comply with the UNFCCC reporting guidelines (UNFCCC 2014a) to ensure and continuously improve transparency, consistency, comparability, completeness, accuracy, and confidence in national GHG emission and removal estimates. The quality manual (FOEN 2022a) contains all relevant information regarding the QMS. It is updated annually and made available to everyone contributing to the GHG inventory.

### General QC procedures

The general QC activities as described in Table 6.1 of the IPCC reporting guidelines (IPCC 2006) are implemented in the annual cycle of inventory compilation (Table 1-2). Routine annual quality control procedures comprise checks related to new data and database operations, spot-checks for transcription errors, correct use of conversion factors and units, and correct calculations. There are checklists for the most important sectoral data suppliers and EMIS database experts.

Integrity of the database is ensured by creating a new database for every single submission and comparing the results from the new database with those from the previous version. Consistency of data between categories is to a large extent ensured by the design of the database, where specific emission factors and activity data that apply to various categories are used jointly by all categories to calculate emissions.

Checks regarding the correct aggregation are done on initial set-up of the various aggregations. There are also automated checks implemented in the database in order to identify incorrect internal aggregation processes.

Recalculations are compiled in a document and made available to the data compilers and the members of the GHG inventory core group, including the NIR authors. The recalculations file is of great importance in the QC procedures regarding the reporting tables (CRF) and in the preparation of the NIR. QC procedures regarding the reporting tables (CRF) comprise a detailed comparison of the reporting tables (CRF) of the previous submission with those of the latest submission for the base year and the latest common year. In addition, the time-series consistency is incrementally checked by comparing the latest inventory year with the preceding year. Any exceptional deviations are investigated by the sectoral or the EMIS database experts. These checks are performed in an iterative process: checks are done by collaborators of the Climate division and sectoral experts, providing feedback and comments to the EMIS database experts. Based on the comments, changes to the reporting tables or database are made as required. The process is repeated two times before producing the final reporting tables.

The NIR is subject to an internal review prior to submission. The review of every section is carried out by personnel not involved in the preparation of the reviewed section, but who is familiar with the reporting under the UNFCCC. Archiving of the database and related internal documentation is carried-out by the inventory compiler, while any other material is archived on the internal data management system by the QA/QC officer. Publicly available material is published after submission on the website owned by the FOEN (www.climatereporting.ch).

**Category-specific QC procedures**

Whenever new emission factors are considered, they are compared to the IPCC default values and to the values used in previous years. If the values are based on better or more appropriate data and compare reasonably well with the IPCC default values (or if differences can be explained), the new values are presented to the core group for adoption in future inventories. Similarly, if new activity data have become available for a particular category, a comparison between existing and new activity data is made and if the new data provide a more consistent or more reliable basis for the inventory, they are again presented to the core group for inclusion in future inventories. Quite often, sectoral and/or EMIS experts commission research to look into a particular topic in more detail. Results from these mid- to long-term projects are presented to the inventory core group. The core group decides on how to best implement the results and documents the agreed procedure in the inventory development plan. The general procedures regarding category-specific QC is also described in the quality manual (FOEN 2022a), while specific activities are documented in the corresponding sectoral chapters.

**Quality assurance procedures**

As required by ISO 9001 there are periodic internal audits covering all processes. In addition, an external organisation is mandated to do the annual audit of the ISO 9001 quality management system.

Apart from these audits, there are expert peer reviews for specific sectors commissioned on a case-by-case basis. The results and suggestions for improvements from these reviews are discussed in the core group and specific tasks for future implementation are taken up into the inventory development plan. In 2017, an expert peer review for Harvested wood products (HWP) has been conducted (Didion 2017). In 2018, an expert peer review for wastewater treatment was completed with experts by the Eawag (Eidgenössische Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz) (EAWAG 2018). In 2019, an expert peer review concerning F-gases has been conducted and results have been considered for submission 2020 (Reimann 2019). Werner (2019a) investigated the potential for improvement for Harvested wood products reporting with a focus on the reference scenarios using existing or yet to be collected data and parameters from the domestic industry. In 2021 an expert peer review concerning manure management has been conducted digitally (Fuß et al. 2021). Previous expert peer reviews covered the Industrial Processes (CSD 2013), LULUCF (VTI 2011) and Waste sector (Rytec 2010).

Likewise, recommendations and encouragements from the UNFCCC expert review teams (ERT) are also added to the inventory development plan, discussed in the core group and implemented in future submissions. Specific actions resulting from suggestions from the ERT are listed in chp. 10 Recalculations.

**Verification activities**

In the energy sector, the standard verification activity carried out on an annual basis is the reference approach, as documented in chp. 3.2.1 of the NIR and CRF Table1.A(b).

In addition, the FOEN supports a long-term monitoring programme carried out by the Swiss Federal Laboratories for Materials Science and Technology (Empa). In the frame of this programme, continuous measurements of atmospheric concentrations of various halogenated gases are made at the high-Alpine research station Jungfraujoch (3580 m a.s.l.), from which Swiss emissions of some fluorinated greenhouse gases can be estimated. These data are compared with the emissions reported in the greenhouse gas inventory. The results are briefly summarized in Annex A5.1.

Furthermore, an ongoing project is developing an independent estimate of $CH_4$ and $N_2O$ emissions in Switzerland based on atmospheric measurements and inverse modelling of atmospheric transport. The results show a very good agreement between modelled emissions and emission estimates according to the greenhouse gas inventory for $CH_4$ and reasonable agreement within the uncertainties for $N_2O$. A summary of the current state of these verification activities is provided in Annex A5.2.

**Treatment of Confidentiality Issues**

Nearly all of the data necessary to compile the Swiss GHG inventory are publicly available. There are, however, a few exceptions:

(1) Emission data that refer to a single enterprise are in general confidential.

(2) The reporting of disaggregated emissions from F-gases is confidential (not confidential as aggregated data).

(3) In the civil aviation sub-sector one data source (FOCA 1991) has been marked confidential by the Federal Office of Civil Aviation (FOCA).

(4) Unpublished AREA land use statistics raw data have been temporarily classified confidential by the Federal Statistical Office (FSO).

The FOEN collects the data needed for calculating emissions of HFCs, PFCs, $NF_3$ and $SF_6$ from private companies or industry associations. In the National Inventory Report, the activity data underlying emission estimates of HFCs, PFCs, $NF_3$ and $SF_6$ are only partly presented at the most disaggregated level for reasons of confidentiality. However, complete emissions are reported in aggregated tables.

Confidential data will be made available by the FOEN in line with the procedures agreed under the UNFCCC for the technical review of GHG inventories (UNFCCC 2015).

**Public access to the Swiss Greenhouse Gas Inventory**
FOEN operates a website (www.climatereporting.ch) where the Swiss GHG inventories (NIR, reporting tables, UNFCCC review reports), the Swiss National Communications and other reports submitted to the UNFCCC and the Kyoto Protocol may be downloaded. On this website, most papers, reports, domestic reviews, and other difficult-to-access materials (‘grey literature’) quoted in the Swiss GHG inventory are provided online. The climate reporting homepage thus provides the option for public review.

### 1.2.4. Changes in the national inventory arrangements since previous submission

**Changes to institutional, legal and procedural arrangements (24/CP.19, 22. (a)):**
No changes.

**Changes in staff and capacity (24/CP.19, 22. (b)):**
One person from the consultancy involved in data handling and updating of the NIR was added while another person reduced work load at the same time.

**Changes to national entity with overall responsibility for the inventory (24/CP.19, 22. (c)):**
No changes.

**Changes to the process of inventory planning (24/CP.19, 22.(d,e)/23./24.):**
No changes.

**Changes to the process of inventory preparation (24/CP.19, 25./26.):**
No changes.

**Changes to the process of inventory management (24/CP.19, 27.):**
No changes.

## 1.3. Inventory preparation and data collection, processing, and storage

An overview over the inventory preparation is given above and is schematically shown in Figure 1-1. Each sector has an assigned sectoral expert who is responsible for conformity with the relevant reporting guidelines, selection of appropriate methods and data sources, and collection, processing and updating of data (see Figure 1-2).

For the sectors Energy, IPPU (excl. fluorinated gases) and Waste, data collection and processing is done by the Air Pollution Control and Chemicals division of the FOEN. Emissions of road and non-road transportation are provided by INFRAS, a consultancy mandated by the Traffic section of FOEN. The use of fluorinated gases and related emissions in the corresponding source categories of the IPPU sector are provided by Carbotech, a consultancy mandated by FOEN to collect and process relevant data. For Agriculture, data collection and processing is provided by Agroscope, the Federal Research Institute for Agriculture. Land use and land-use change data from the Federal Statistical Office is compiled by Meteotest/Sigmaplan, in close collaboration with the FOEN Climate division. The Swiss Federal Institute for Forest, Snow and Landscape Research WSL provides data on Swiss forests, which are processed by the FOEN Forest division to obtain estimates on GHG emissions and removals from Forest land. Data on biomass and soil carbon dynamics for Cropland and Grassland are compiled or modelled at Agroscope and are incorporated into the GHG inventory via Meteotest. Data from other research institutes are used to calculate a complete GHG balance of the LULUCF sector.

All people responsible for data collection and processing in a particular sector are preparing their data for import into the National Air Pollution Database EMIS, which compiles all inventory data, including activity data and emission factors. EMIS was originally established in the late 1980s in order to record and monitor emissions of air pollutants, but it has since been extended to cover greenhouse gases and additional emission sources. The original EMIS database underwent a full redesign and a migration to a new software platform in 2005/2006. In preparation for the submission in 2015, all processes relevant to the GHG inventory have been restructured according to the 2006 IPCC Guidelines (IPCC 2006) and the revised reporting tables (CRF). The software in use is called “Mesap”, Release 5.5.38 by Seven2one information systems (Seven2one 2014); it is running on commonly used laptops or desktop computers as client. The EMIS database is stored as SQL database on a server.

The EMIS database as well as background information on activity data and emission factors are archived by the national inventory compiler for each submission. In the sectors where data collection is made by EMIS experts (e.g. Energy, IPPU, Waste), additional background information is compiled as appropriate (e.g. interim worksheets; references; rationale for choice of methods, data sources, activity data, emission factors). Whenever such documents are cited, they are labelled as “EMIS 2022/NFR-Code” in this report.

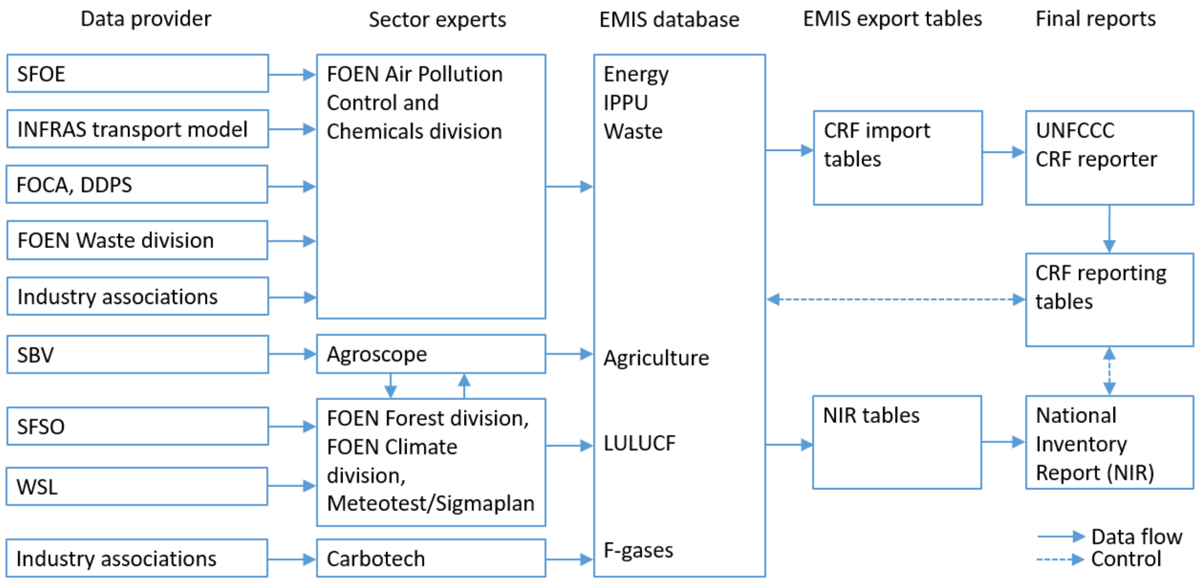


Figure 1-2 Schematic overview: Data collection and processing, compilation in EMIS database, import into CRF reporter and National Inventory Report (NIR). Abbreviations: see glossary.

## 1.4. Methodologies and data sources

According to the revised reporting guidelines under the UNFCCC (UNFCCC 2014a) and the Kyoto Protocol (UNFCCC 2014b), emissions are calculated based on standard methods and procedures provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) its 2019 Refinements (IPCC 2019), the 2013 KP Supplement (IPCC 2014), and the 2013 Wetlands supplement (IPCC 2014a). All key categories are estimated using approach 2 or higher or country-specific methods. The methodological tier used is described in detail in the sectoral chapters of the NIR and compiled in CRF Summary3s1 and CRF Summary3s2.

Various data suppliers contribute to the greenhouse gas inventory (Table 1-3). While most data stem from official statistics either from the FOEN or from other federal offices, some data is drawn from national associations or consultancies that maintain well-established models or data-bases. Details on activity data and emission factors are provided in the sectoral chapters of the NIR.

Table 1-3 Primary data providers for the various inventory categories. Generally, statistics are updated annually. However, the on-road and non-road emission models of INFRAS, the complete area survey by the SFSO as well as the national forest inventory by the WSL require large efforts and are therefore updated every couple of years. Coloured boxes mark those sectors to which each data provider contributes. Abbreviations: see glossary.

| Institution | Subject | Inventory category (numbering according to reporting tables) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1A1 | 1A2 | 1A3 | 1A4 | 1A5 | 1B | 2 | 3 | 4 / KP | 5 | 6 | indir. CO2/ N2O |
| FOEN, Air Pollution Control and Chemicals division | EMIS database | ■ | ■ | | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | ■ |
| FOEN, Climate division | Swiss ETS monitoring reports | ■ | ■ | | ■ | | ■ | ■ | | | | | |
| FOEN, Waste division | Waste statistics | ■ | ■ | | | | | | | | ■ | | |
| INFRAS | Road transportation emission model | | | ■ | | | | | | | | | |
| INFRAS | Non-road emission model | | ■ | ■ | ■ | ■ | | | | | | | |
| SFOE | Swiss overall energy statistics | ■ | ■ | ■ | ■ | | ■ | | | | ■ | | |
| SFOE | Swiss statistics of renewable energies | ■ | ■ | ■ | ■ | | | | | | ■ | | |
| SFOE | Swiss wood energy statistics | ■ | ■ | | ■ | | | | | | | | |
| SFOE | Energy consumption statistics in the industry and services sectors | | ■ | | | | | | | | | | |
| FOCA | Civil aviation | | | ■ | | | | | | | | | |
| Swiss Air Force Administration (DDPS) | Military aviation | | | | | ■ | | | | | | | |
| SGWA | Gas distribution losses | | | | | | ■ | | | | | | |
| Carbotech | F-gases, post-combustion of NMVOC | | | | | | | ■ | | | | | |
| Swissmem | National $SF_6$ balance | | | | | | | ■ | | | | | |
| SFSO | Agriculture, LULUCF | | | | | | | | ■ | ■ | | | |
| Agroscope | Agriculture, LULUCF | | | | | | | | ■ | ■ | | | |
| SBV | Agriculture | | | | | | | | ■ | | | | |
| FOEN, Forest division | Forest statistics | | | | | | | | | ■ | | | |
| WSL | National Forest Inventory | | | | | | | | | ■ | | | |
| Sigmaplan, Meteotest | LULUCF | | | | | | | | | ■ | | | |

## 1.5. Description of key categories

The aim of the key category analysis (KCA) is to identify relevant categories that have a strong influence on Switzerland's GHG inventory in terms of absolute emission and removal levels, trends and uncertainties (IPCC 2006, chp. 4). The KCA can be performed based on two approaches: in approach 1 of the KCA, categories are set out in decreasing order of contribution to the inventory emissions or trend. In approach 2, this ranking is weighted by the uncertainty assigned to each category. Approach 1 therefore highlights categories which mostly contribute to emissions or to emission changes, while approach 2 identifies categories mostly contributing to the inventory uncertainty. Data collection as well as quality assurance and control are prioritised for key categories during the inventory resource allocation (see also the planned improvements in chp. 10.4).

## 1.5.1. GHG inventory

### 1.5.1.1. Methodology

The key category analysis is performed according to the 2006 IPCC Guidelines (IPCC 2006, chp. 4) and Decision 24/CP.19 (UNFCCC 2014a, Annex 1, Para. 39) for 1990 and the latest reported year 2020 including all GHG ($CO_2$, $CH_4$, $N_2O$, HFCs, PFCs, $SF_6$ and $NF_3$). A total of 186 categories (including categories from the LULUCF sector) are used to disaggregate Switzerland's total GHG emissions for the purpose of this key category analysis (Table A – 1). The disaggregation level of the categories is selected based on country-specific relevance, i.e. the most important sources in Switzerland are disaggregated on a more detailed level.

Both approach 1 (with a threshold set at 95%) and approach 2 (with a threshold set at 90%) level and trend assessments are applied, including emissions from sector 4 LULUCF. For approach 2 of the KCA, uncertainties for emissions of each category are taken from the results of the Monte Carlo simulations (approach 2 uncertainty analysis, see details in chp. 1.6.2.2). Indirect $CO_2$ emissions are included in the key category analysis, indirect $N_2O$ emissions are not.

### 1.5.1.2. Results of the key category analysis (including LULUCF categories)

For the year 2020, there are 46 identified key categories among the 186 categories taken into account (see overview in Table 1-9). The large majority of the key categories are sources of $CO_2$ (see also Table 2-3 and discussion in chp. 2.2), a few of $CH_4$ and $N_2O$, only one of HFCs and also one of PFC. There are no key categories for neither $SF_6$ nor $NF_3$.

Compared to the previous submission, indirect $CO_2$ emissions in sector 2 are now split into sub-categories of which two are key categories for $CO_2$ indirect emissions resulting from NMVOC: 2D Non-energy products from fuels and solvent use and 2G Other product manufacture and use. For the year 2020, a much larger uncertainty was assigned to category 4B1 Cropland remaining cropland ($CO_2$ emissions, see Annex 2), compared to the year 2019 in the previous submission. For this reason, fewer categories are needed to reach a threshold of 90% for approach 2 of the KCA. For this submission, there is one newly identified key category: 4F2 Land converted to other land. It is a key category for the level assessment, approaches 1 and 2, albeit with a minor contribution in both cases (see chp. 6.9.1 for an explanation).

The detailed results of the key category analyses, approaches 1 and 2, level and trend assessments, are reported in Table 1-4 to Table 1-8. For level assessments, columns are labelled A to G according to Table 4-2 in the IPCC guidelines (IPCC, 2006, chp. 4) and for trend assessments, columns are labelled A to H according to Table 4-3 in the same guidelines. The following abbreviations are used:

- $E_{x,0}$: base year emission/removal estimate.
- $E_{x,t}$: reporting year emission/removal estimate.
- $L_{x,0}$, $L_{x,t}$: level assessment for the base year and the reporting year, respectively.
- $T_{x,t}$: trend assessment for the trend between base year and reporting year.

**Approach 1**

For 2020, among the total of 186 categories, 31 are identified as level key categories under approach 1 (see Table 1-4).

Fifteen of these key categories belong to sector 1 Energy, accounting for the largest share of $CO_2$ equivalent emissions in 2020 (see Table 2-1 for emission share per sector). Sector 2 Industrial processes and product use (3 key categories) and sector 3 Agriculture (5 key categories) are also significant contributors to the emissions for the year 2020 (Table 2-1), while sector 5 Waste (2 key categories) and sector 6 Other (no key category) have only marginal contributions. Sector 4 LULUCF (6 key categories) has a net negative contribution to the emissions for the year 2020.

Within the ten most relevant key categories (level contribution), only 3A Enteric fermentation, 4A1 Forest land remaining forest land and 2A1 Cement production are not part of sector 1 Energy. Note that category 4A1 has a net negative emission contribution.

For the base year 1990, 34 categories are identified as level key categories under approach 1 (see Table 1-5). The following categories are key according to level in the base year 1990, but not anymore in the latest reported year:

- 1A3a Civil aviation, liquid fuels, $CO_2$
- 1A3b Road transportation, gasoline, $N_2O$
- 1A5 Other (military), liquid fuels, $CO_2$
- 2A4 Other process uses of carbonates, $CO_2$
- 2D Non-energy products from fuels and solvent use, NMVOC (indirect), $CO_2$
- 3B1-4 Manure management, all livestock, direct, $N_2O$
- 4B1 Cropland remaining cropland, $CO_2$.
- 4G HWP Harvested wood products, $CO_2$

On the other hand, the following categories are key according to level in the latest reported year, but not in the base year 1990:

- 2F1 Refrigeration and air conditioning, HFC
- 4C1 Grassland remaining grassland, $CO_2$
- 4C2 Land converted to grassland, $CO_2$
- 4F2 Land converted to other land, $CO_2$
- 5D Wastewater treatment and discharge, $CH_4$

Regarding the trend assessment between the base year 1990 and the latest reported year, 34 categories are identified as trend key categories under approach 1 (see Table 1-6). Among these, 14 have an increasing trend and 20 a decreasing trend. See chp. 2.2 Emission trends by gas and chp. 2.3 Emission trends by sources and sinks for a further discussion.

Table 1-4 Switzerland's key categories according to approach 1 level assessment for the year 2020, including LULUCF categories and indirect $CO_2$ emissions, sorted by decreasing contribution. Categories in grey are not key and are given for information only.

| KCA APPROACH 1 LEVEL ASSESSMENT FOR 2020 | | | | | | |
|---|---|---|---|---|---|---|
| A | B | C | D | E | F | G |
| Code | IPCC category | Gas | Ex, t (kt CO2 equ.) | \|Ex, t\| (kt CO2 equ.) | Lx, t (%) | Cumu-lative Total (%) |
| 1A3b | Road Transportation; Diesel oil | CO2 | 6'946 | 6'946 | 14.6 | 14.6 |
| 1A3b | Road Transportation; Gasoline | CO2 | 6'211 | 6'211 | 13.1 | 27.7 |
| 1A4b | Residential; Liquid Fuels | CO2 | 4'387 | 4'387 | 9.2 | 36.9 |
| 3A | Enteric Fermentation | CH4 | 3'254 | 3'254 | 6.8 | 43.8 |
| 1A4b | Residential; Gaseous Fuels | CO2 | 2'652 | 2'652 | 5.6 | 49.3 |
| 1A1 | Energy Industries; Other Fuels | CO2 | 2'480 | 2'480 | 5.2 | 54.6 |
| 4A1 | Forest Land Remaining Forest Land | CO2 | -2'180 | 2'180 | 4.6 | 59.1 |
| 1A2 | Manufacturing Industries and Construction; Gaseous Fuels | CO2 | 2'141 | 2'141 | 4.5 | 63.7 |
| 1A4a | Commercial; Liquid Fuels | CO2 | 2'052 | 2'052 | 4.3 | 68.0 |
| 2A1 | Cement Production | CO2 | 1'679 | 1'679 | 3.5 | 71.5 |
| 1A2 | Manufacturing Industries and Construction; Liquid Fuels | CO2 | 1'535 | 1'535 | 3.2 | 74.7 |
| 2F1 | Refrigeration and Air Conditioning | HFC | 1'346 | 1'346 | 2.8 | 77.6 |
| 1A4a | Commercial; Gaseous Fuels | CO2 | 1'183 | 1'183 | 2.5 | 80.1 |
| 3Da | Direct Emissions from Managed Soils | N2O | 1'111 | 1'111 | 2.3 | 82.4 |
| 4A2 | Land Converted to Forest Land | CO2 | -628 | 628 | 1.3 | 83.7 |
| 2B10 | Chemical Industry, Other | N2O | 574 | 574 | 1.2 | 84.9 |
| 3B1-4 | Manure Management, all Livestock, direct | CH4 | 568 | 568 | 1.2 | 86.1 |
| 1A1 | Energy Industries; Gaseous Fuels | CO2 | 499 | 499 | 1.1 | 87.2 |
| 1A4c | Agriculture and Forestry; Liquid Fuels | CO2 | 454 | 454 | 1.0 | 88.1 |
| 1A2 | Manufacturing Industries and Construction; Other Fuels | CO2 | 444 | 444 | 0.9 | 89.1 |
| 4C1 | Grassland Remaining Grassland | CO2 | 401 | 401 | 0.8 | 89.9 |
| 3Db | Indirect Emissions from Managed Soils | N2O | 397 | 397 | 0.8 | 90.7 |
| 1A2 | Manufacturing Industries and Construction; Solid Fuels | CO2 | 339 | 339 | 0.7 | 91.4 |
| 1A1 | Energy Industries; Liquid Fuels | CO2 | 273 | 273 | 0.6 | 92.0 |
| 5A | Solid Waste Disposal | CH4 | 272 | 272 | 0.6 | 92.6 |
| 3B5 | Manure Management, indirect | N2O | 260 | 260 | 0.5 | 93.1 |
| 4C2 | Land Converted to Grassland | CO2 | 256 | 256 | 0.5 | 93.7 |
| 4E2 | Land Converted to Settlements | CO2 | 214 | 214 | 0.4 | 94.1 |
| 5D | Wastewater Treatment and Discharge | CH4 | 192 | 192 | 0.4 | 94.5 |
| 1B2 | Oil and Natural Gas Energy Production; All Fuels | CH4 | 185 | 185 | 0.4 | 94.9 |
| 4F2 | Land Converted to Other Land | CO2 | 130 | 130 | 0.3 | 95.2 |
| 2G | Other Product Manufacture and Use | SF6 | 127 | 127 | 0.3 | 95.5 |
| 1A4c | Agriculture and Forestry; Gaseous Fuels | CO2 | 123 | 123 | 0.3 | 95.7 |
| 3B1-4 | Manure Management, all Livestock, direct | N2O | 122 | 122 | 0.3 | 96.0 |
| 1A5 | Non-Specified; Liquid Fuels | CO2 | 118 | 118 | 0.2 | 96.2 |
| 1A3d | Water-borne Navigation; Liquid Fuels | CO2 | 111 | 111 | 0.2 | 96.5 |
| 5D | Wastewater Treatment and Discharge | N2O | 104 | 104 | 0.2 | 96.7 |
| 2B8 | Petrochemical and Carbon Black Production | CO2 | 98 | 98 | 0.2 | 96.9 |
| 1A3b | Road Transportation; Diesel oil | N2O | 95 | 95 | 0.2 | 97.1 |

Table 1-5 Switzerland's key categories according to approach 1 level assessment for the year 1990, including LULUCF categories and indirect $CO_2$ emissions, sorted by decreasing contribution. Categories in grey are not key and are given for information only.

| KCA APPROACH 1 LEVEL ASSESSMENT FOR 1990 | | | | | | |
|---|---|---|---|---|---|---|
| A | B | C | D | E | F | G |
| Code | IPCC category | Gas | Ex, 0 (kt CO2 equ.) | \|Ex, 0\| (kt CO2 equ.) | Lx, 0 (%) | Cumu-lative Total (%) |
| 1A3b | Road Transportation; Gasoline | CO2 | 11'342 | 11'342 | 19.6 | 19.6 |
| 1A4b | Residential; Liquid Fuels | CO2 | 10'099 | 10'099 | 17.4 | 37.0 |
| 1A2 | Manufacturing Industries and Construction; Liquid Fuels | CO2 | 3'974 | 3'974 | 6.9 | 43.9 |
| 1A4a | Commercial; Liquid Fuels | CO2 | 3'918 | 3'918 | 6.8 | 50.7 |
| 3A | Enteric Fermentation | CH4 | 3'544 | 3'544 | 6.1 | 56.8 |
| 1A3b | Road Transportation; Diesel oil | CO2 | 2'632 | 2'632 | 4.5 | 61.3 |
| 2A1 | Cement Production | CO2 | 2'581 | 2'581 | 4.5 | 65.8 |
| 1A1 | Energy Industries; Other Fuels | CO2 | 1'492 | 1'492 | 2.6 | 68.4 |
| 1A4b | Residential; Gaseous Fuels | CO2 | 1'451 | 1'451 | 2.5 | 70.9 |
| 3Da | Direct Emissions from Managed Soils | N2O | 1'276 | 1'276 | 2.2 | 73.1 |
| 1A2 | Manufacturing Industries and Construction; Solid Fuels | CO2 | 1'275 | 1'275 | 2.2 | 75.3 |
| 4G | HWP Harvested Wood Products | CO2 | -1'169 | 1'169 | 2.0 | 77.3 |
| 4A1 | Forest Land Remaining Forest Land | CO2 | -1'110 | 1'110 | 1.9 | 79.2 |
| 1A2 | Manufacturing Industries and Construction; Gaseous Fuels | CO2 | 1'091 | 1'091 | 1.9 | 81.1 |
| 1A4a | Commercial; Gaseous Fuels | CO2 | 920 | 920 | 1.6 | 82.7 |
| 5A | Solid Waste Disposal | CH4 | 770 | 770 | 1.3 | 84.0 |
| 1A4c | Agriculture and Forestry; Liquid Fuels | CO2 | 742 | 742 | 1.3 | 85.3 |
| 3B1-4 | Manure Management, all Livestock, direct | CH4 | 706 | 706 | 1.2 | 86.5 |
| 1A1 | Energy Industries; Liquid Fuels | CO2 | 686 | 686 | 1.2 | 87.7 |
| 3Db | Indirect Emissions from Managed Soils | N2O | 583 | 583 | 1.0 | 88.7 |
| 4A2 | Land Converted to Forest Land | CO2 | -547 | 547 | 0.9 | 89.7 |
| 2B10 | Chemical Industry, Other | N2O | 432 | 432 | 0.7 | 90.4 |
| 1B2 | Oil and Natural Gas Energy Production; All Fuels | CH4 | 336 | 336 | 0.6 | 91.0 |
| 4B1 | Cropland Remaining Cropland | CO2 | 289 | 289 | 0.5 | 91.5 |
| 4E2 | Land Converted to Settlements | CO2 | 256 | 256 | 0.4 | 91.9 |
| 1A3a | Civil Aviation; Kerosene | CO2 | 253 | 253 | 0.4 | 92.4 |
| 1A1 | Energy Industries; Gaseous Fuels | CO2 | 243 | 243 | 0.4 | 92.8 |
| 3B5 | Manure Management, indirect | N2O | 235 | 235 | 0.4 | 93.2 |
| 1A5 | Non-Specified; Liquid Fuels | CO2 | 218 | 218 | 0.4 | 93.6 |
| 2D | Non-Energy Products from Fuels and Solvent Use; NMVOC (indirect) | CO2 | 193 | 193 | 0.3 | 93.9 |
| 1A2 | Manufacturing Industries and Construction; Other Fuels | CO2 | 192 | 192 | 0.3 | 94.2 |
| 3B1-4 | Manure Management, all Livestock, direct | N2O | 189 | 189 | 0.3 | 94.6 |
| 2A4 | Other Process Uses of Carbonates | CO2 | 160 | 160 | 0.3 | 94.8 |
| 1A3b | Road Transportation; Gasoline | N2O | 159 | 159 | 0.3 | 95.1 |
| 2C3 | Aluminium Production | CO2 | 139 | 139 | 0.2 | 95.4 |
| 2G | Other Product Manufacture and Use | SF6 | 137 | 137 | 0.2 | 95.6 |
| 2G | Other Product Manufacture and Use; NMVOC (indirect) | CO2 | 129 | 129 | 0.2 | 95.8 |
| 5D | Wastewater Treatment and Discharge | CH4 | 129 | 129 | 0.2 | 96.0 |
| 2C3 | Aluminium Production | PFC | 116 | 116 | 0.2 | 96.2 |
| 1A3b | Road Transportation; Gasoline | CH4 | 115 | 115 | 0.2 | 96.4 |
| 1A3d | Water-borne Navigation; Liquid Fuels | CO2 | 114 | 114 | 0.2 | 96.6 |
| 2G | Other Product Manufacture and Use | N2O | 104 | 104 | 0.2 | 96.8 |
| 4C1 | Grassland Remaining Grassland | CO2 | -103 | 103 | 0.2 | 97.0 |

Table 1-6 Switzerland's key categories according to approach 1 trend assessment for 1990–2020, including LULUCF categories and indirect $CO_2$ emissions, sorted by decreasing contribution. Categories in orange have increased emissions in 2020 compared to 1990. Categories in grey are not key and are given for information only.

| KCA APPROACH 1 TREND ASSESSMENT 1990 - 2020 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| A | B | C | D | E | | F | G | H |
| Code | IPCC category | Gas | Ex, 0 (kt CO2 equ.) | Ex, t (kt CO2 equ.) | Category trend (%) | Trend Assess-ment | Contri-bution to trend (%) | Cumu-lative Total (%) |
| 1A3b | Road Transportation; Diesel oil | CO2 | 2'632 | 6'946 | 164 | 0.083 | 16.9 | 16.9 |
| 1A4b | Residential; Liquid Fuels | CO2 | 10'099 | 4'387 | -57 | 0.064 | 13.0 | 29.9 |
| 1A3b | Road Transportation; Gasoline | CO2 | 11'342 | 6'211 | -45 | 0.050 | 10.1 | 40.1 |
| 1A2 | Manufacturing Industries and Construction; Liquid Fuels | CO2 | 3'974 | 1'535 | -61 | 0.029 | 5.8 | 45.9 |
| 1A4b | Residential; Gaseous Fuels | CO2 | 1'451 | 2'652 | 83 | 0.026 | 5.2 | 51.1 |
| 4G | HWP Harvested Wood Products | CO2 | -1'169 | -51 | 96 | 0.023 | 4.7 | 55.8 |
| 2F1 | Refrigeration and Air Conditioning | HFC | 0 | 1'346 | 5'431'939 | 0.023 | 4.7 | 60.5 |
| 1A1 | Energy Industries; Other Fuels | CO2 | 1'492 | 2'480 | 66 | 0.022 | 4.5 | 65.0 |
| 1A2 | Manufacturing Industries and Construction; Gaseous Fuels | CO2 | 1'091 | 2'141 | 96 | 0.022 | 4.4 | 69.4 |
| 1A4a | Commercial; Liquid Fuels | CO2 | 3'918 | 2'052 | -48 | 0.019 | 3.8 | 73.2 |
| 4A1 | Forest Land Remaining Forest Land | CO2 | -1'110 | -2'180 | -96 | 0.015 | 3.0 | 76.2 |
| 1A2 | Manufacturing Industries and Construction; Solid Fuels | CO2 | 1'275 | 339 | -73 | 0.012 | 2.4 | 78.6 |
| 4C1 | Grassland Remaining Grassland | CO2 | -103 | 401 | 489 | 0.009 | 1.8 | 80.4 |
| 1A4a | Commercial; Gaseous Fuels | CO2 | 920 | 1'183 | 29 | 0.008 | 1.6 | 82.0 |
| 3A | Enteric Fermentation | CH4 | 3'544 | 3'254 | -8 | 0.007 | 1.4 | 83.4 |
| 2A1 | Cement Production | CO2 | 2'581 | 1'679 | -35 | 0.007 | 1.4 | 84.8 |
| 5A | Solid Waste Disposal | CH4 | 770 | 272 | -65 | 0.006 | 1.2 | 86.0 |
| 1A1 | Energy Industries; Gaseous Fuels | CO2 | 243 | 499 | 105 | 0.005 | 1.1 | 87.1 |
| 1A2 | Manufacturing Industries and Construction; Other Fuels | CO2 | 192 | 444 | 131 | 0.005 | 1.0 | 88.1 |
| 1A1 | Energy Industries; Liquid Fuels | CO2 | 686 | 273 | -60 | 0.005 | 1.0 | 89.0 |
| 4B1 | Cropland Remaining Cropland | CO2 | 289 | -8 | -103 | 0.004 | 0.8 | 89.9 |
| 2B10 | Chemical Industry, Other | N2O | 432 | 574 | 33 | 0.004 | 0.8 | 90.7 |
| 4C2 | Land Converted to Grassland | CO2 | 94 | 256 | 173 | 0.003 | 0.6 | 91.3 |
| 1A4c | Agriculture and Forestry; Liquid Fuels | CO2 | 742 | 454 | -39 | 0.002 | 0.5 | 91.8 |
| 1A3a | Civil Aviation; Kerosene | CO2 | 253 | 79 | -69 | 0.002 | 0.4 | 92.2 |
| 2D | Non-Energy Products from Fuels and Solvent Use; NMVOC (indirect) | CO2 | 193 | 34 | -82 | 0.002 | 0.4 | 92.7 |
| 2C3 | Aluminium Production | CO2 | 139 | 0 | -100 | 0.002 | 0.4 | 93.0 |
| 1A3b | Road Transportation; Gasoline | N2O | 159 | 18 | -89 | 0.002 | 0.4 | 93.4 |
| 2C3 | Aluminium Production | PFC | 116 | 0 | -100 | 0.002 | 0.3 | 93.8 |
| 1A3b | Road Transportation; Diesel oil | N2O | 6 | 95 | 1'452 | 0.002 | 0.3 | 94.1 |
| 5D | Wastewater Treatment and Discharge | CH4 | 129 | 192 | 49 | 0.002 | 0.3 | 94.4 |
| 3Da | Direct Emissions from Managed Soils | N2O | 1'276 | 1'111 | -13 | 0.001 | 0.3 | 94.7 |
| 1B2 | Oil and Natural Gas Energy Production; All Fuels | CH4 | 336 | 185 | -45 | 0.001 | 0.3 | 95.0 |
| 1A3b | Road Transportation; Gasoline | CH4 | 115 | 12 | -89 | 0.001 | 0.3 | 95.3 |
| 3Db | Indirect Emissions from Managed Soils | N2O | 583 | 397 | -32 | 0.001 | 0.3 | 95.5 |
| 3B5 | Manure Management, indirect | N2O | 235 | 260 | 11 | 0.001 | 0.3 | 95.8 |
| 1A4c | Agriculture and Forestry; Gaseous Fuels | CO2 | 70 | 123 | 75 | 0.001 | 0.2 | 96.0 |
| 2A4 | Other Process Uses of Carbonates | CO2 | 160 | 65 | -60 | 0.001 | 0.2 | 96.2 |
| 4F2 | Land Converted to Other Land | CO2 | 88 | 130 | 48 | 0.001 | 0.2 | 96.4 |
| 1A5 | Non-Specified; Liquid Fuels | CO2 | 218 | 118 | -46 | 0.001 | 0.2 | 96.6 |
| 2G | Other Product Manufacture and Use; NMVOC (indirect) | CO2 | 129 | 47 | -63 | 0.001 | 0.2 | 96.8 |
| 2B2 | Nitric Acid Production | N2O | 65 | 0 | -100 | 0.001 | 0.2 | 97.0 |

### Approach 2

Given that the threshold is set at 90%, the number of key categories is smaller under approach 2 compared to approach 1 for both level and trend assessment.

Concerning the level assessment, 27 out of 186 categories are identified as key categories for the latest reported year (see Table 1-7). Regarding the trend assessment between the base year 1990 and the latest reported year 2020, 7 categories are identified as trend key categories under approach 2 (see Table 1-8).

Contrary to approach 1 of the KCA, highlighting significant emission contributions from the Energy sector, approach 2 is dominated by contributions from categories having a large uncertainty, mostly from sector 3 Agriculture, sector 4 LULUCF and sector 2 IPPU.

Table 1-7 Switzerland's key categories according to approach 2 level assessment for the year 2020, including LULUCF categories and indirect $CO_2$ emissions, sorted by uncertainty-weighted emission contribution (col. F). Categories in grey are not key and are given for information only. Compare also with results of the sensitivity study for the year 2020, see bottom panel of Figure 1-4.

| KCA APPROACH 2, UNCERTAINTY APPROACH 2, LEVEL ASSESSMENT FOR 2020 | | | | | | |
|---|---|---|---|---|---|---|
| A | B | C | D | E | F | G |
| Code | IPCC category | Gas | Ex, t (kt CO2 equ.) | \|Ex, t\| (kt CO2 equ.) | Lx, t (%) | Cumu-lative Total (%) |
| 3Da | Direct Emissions from Managed Soils | N2O | 1'111 | 1'111 | 13.0 | 13.0 |
| 4C1 | Grassland Remaining Grassland | CO2 | 401 | 401 | 12.3 | 25.3 |
| 4A1 | Forest Land Remaining Forest Land | CO2 | -2'180 | 2'180 | 10.6 | 35.9 |
| 3A | Enteric Fermentation | CH4 | 3'254 | 3'254 | 6.8 | 42.7 |
| 3Db | Indirect Emissions from Managed Soils | N2O | 397 | 397 | 6.6 | 49.3 |
| 3B5 | Manure Management, indirect | N2O | 260 | 260 | 5.4 | 54.7 |
| 4B1 | Cropland Remaining Cropland | CO2 | -8 | 8 | 5.0 | 59.7 |
| 1A1 | Energy Industries; Other Fuels | CO2 | 2'480 | 2'480 | 4.6 | 64.2 |
| 2B10 | Chemical Industry, Other | N2O | 574 | 574 | 3.6 | 67.8 |
| 3B1-4 | Manure Management, all Livestock, direct | CH4 | 568 | 568 | 3.2 | 71.0 |
| 4A2 | Land Converted to Forest Land | CO2 | -628 | 628 | 3.1 | 74.1 |
| 2F1 | Refrigeration and Air Conditioning | HFC | 1'346 | 1'346 | 2.6 | 76.7 |
| 5D | Wastewater Treatment and Discharge | N2O | 104 | 104 | 1.4 | 78.1 |
| 1A4b | Residential; Gaseous Fuels | CO2 | 2'652 | 2'652 | 1.4 | 79.5 |
| 4C2 | Land Converted to Grassland | CO2 | 256 | 256 | 1.2 | 80.6 |
| 1A2 | Manufacturing Industries and Construction; Gaseous Fuels | CO2 | 2'141 | 2'141 | 1.1 | 81.7 |
| 4E2 | Land Converted to Settlements | CO2 | 214 | 214 | 1.1 | 82.9 |
| 5D | Wastewater Treatment and Discharge | CH4 | 192 | 192 | 1.0 | 83.8 |
| 5A | Solid Waste Disposal | CH4 | 272 | 272 | 0.9 | 84.7 |
| 3B1-4 | Manure Management, all Livestock, direct | N2O | 122 | 122 | 0.8 | 85.5 |
| 4D1 | Wetland Remaining Wetland | CO2 | 66 | 66 | 0.8 | 86.3 |
| 2A1 | Cement Production | CO2 | 1'679 | 1'679 | 0.8 | 87.1 |
| 2G | Other Product Manufacture and Use; NMVOC (indirect) | CO2 | 47 | 47 | 0.7 | 87.8 |
| 5C | Incineration and Open Burning of Waste | N2O | 55 | 55 | 0.7 | 88.6 |
| 2D | Non-Energy Products from Fuels and Solvent Use; NMVOC (indirect) | CO2 | 34 | 34 | 0.7 | 89.3 |
| 4F2 | Land Converted to Other Land | CO2 | 130 | 130 | 0.7 | 90.0 |
| 4III | Direct N2O from Disturbance | N2O | 41 | 41 | 0.7 | 90.6 |
| 1A3b | Road Transportation; Diesel oil | CO2 | 6'946 | 6'946 | 0.6 | 91.3 |
| 1A4a | Commercial; Gaseous Fuels | CO2 | 1'183 | 1'183 | 0.6 | 91.9 |
| 2G | Other Product Manufacture and Use | SF6 | 127 | 127 | 0.6 | 92.5 |

Table 1-8 Switzerland's key categories according to approach 2 trend assessment for 1990–2020, including LULUCF categories and indirect $CO_2$ emissions, sorted by decreasing uncertainty-weighted contribution to the trend assessment (col. G). Categories in orange have an increased emission in 2020 compared to 1990. Categories in grey are not key and are given for information only.

| KCA APPROACH 2, UNCERTAINTY APPROACH 2, TREND ASSESSMENT 1990 - 2020 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| A | B | C | D | E | | F | G | H |
| Code | IPCC category | Gas | Ex, 0 (kt CO2 equ.) | Ex, t (kt CO2 equ.) | Category trend (%) | Trend Assess-ment | Contri-bution to trend (%) | Cumu-lative Total (%) |
| 4B1 | Cropland Remaining Cropland | CO2 | 289 | -8 | -103 | 0.004 | 72.7 | 72.7 |
| 4C1 | Grassland Remaining Grassland | CO2 | -103 | 401 | 489 | 0.009 | 8.0 | 80.7 |
| 4G | HWP Harvested Wood Products | CO2 | -1'169 | -51 | 96 | 0.023 | 3.9 | 84.7 |
| 4A1 | Forest Land Remaining Forest Land | CO2 | -1'110 | -2'180 | -96 | 0.015 | 2.1 | 86.8 |
| 2F1 | Refrigeration and Air Conditioning | HFC | 0 | 1'346 | 5'431'939 | 0.023 | 1.3 | 88.0 |
| 2D | Non-Energy Products from Fuels and Solvent Use; NMVOC (indirect) | CO2 | 193 | 34 | -82 | 0.002 | 1.3 | 89.3 |
| 1A1 | Energy Industries; Other Fuels | CO2 | 1'492 | 2'480 | 66 | 0.022 | 1.2 | 90.5 |
| 3B5 | Manure Management, indirect | N2O | 235 | 260 | 11 | 0.001 | 0.7 | 91.2 |
| 2B10 | Chemical Industry, Other | N2O | 432 | 574 | 33 | 0.004 | 0.7 | 91.9 |
| 3Db | Indirect Emissions from Managed Soils | N2O | 583 | 397 | -32 | 0.001 | 0.6 | 92.5 |

### 1.5.1.3. Summary of combined KCA including LULUCF categories

A summary of the key category analysis including LULUCF categories and indirect $CO_2$ emissions is shown in Table 1-9, considering the level assessment for 2020 and the trend assessment for 1990–2020, for both approach 1 and approach 2. Note that a category is counted multiple times as key category if it is a key category for multiple gases.

Table 1-9 Summary of Switzerland key category analysis, including LULUCF categories. L: Level (2020); T: Trend (1990–2020); 1: KCA approach 1; 2: KCA approach 2. $SF_6$ and $NF_3$ are not emitted from any key category. Note that categories which are key for the level assessment for the base year only are not reported in this table.

| SUMMARIES TO IDENTIFY KEY CATEGORIES | | | | | | |
|---|---|---|---|---|---|---|
| A | B | C & D | | | | |
| Code | IPCC category | CO2 | CH4 | N2O | HFC | PFC |
| 1A1 | Energy Industries; Gaseous Fuels | L1, T1 | | | | |
| 1A1 | Energy Industries; Liquid Fuels | L1, T1 | | | | |
| 1A1 | Energy Industries; Other Fuels | L1, T1, L2, T2 | | | | |
| 1A2 | Manufacturing Industries and Construction; Gaseous Fuels | L1, T1, L2 | | | | |
| 1A2 | Manufacturing Industries and Construction; Liquid Fuels | L1, T1 | | | | |
| 1A2 | Manufacturing Industries and Construction; Other Fuels | L1, T1 | | | | |
| 1A2 | Manufacturing Industries and Construction; Solid Fuels | L1, T1 | | | | |
| 1A3a | Civil Aviation; Kerosene | T1 | | | | |
| 1A3b | Road Transportation; Diesel oil | L1, T1 | | T1 | | |
| 1A3b | Road Transportation; Gasoline | L1, T1 | T1 | T1 | | |
| 1A4a | Commercial; Gaseous Fuels | L1, T1 | | | | |
| 1A4a | Commercial; Liquid Fuels | L1, T1 | | | | |
| 1A4b | Residential; Gaseous Fuels | L1, T1, L2 | | | | |
| 1A4b | Residential; Liquid Fuels | L1, T1 | | | | |
| 1A4c | Agriculture and Forestry; Liquid Fuels | L1, T1 | | | | |
| 1B2 | Oil and Natural Gas Energy Production; All Fuels | | L1, T1 | | | |
| 2A1 | Cement Production | L1, T1, L2 | | | | |
| 2B10 | Chemical Industry, Other | | | L1, T1, L2 | | |
| 2C3 | Aluminium Production | T1 | | | | T1 |
| 2D | Non-Energy Products from Fuels and Solvent Use; NMVOC (indirect) | T1, L2, T2 | | | | |
| 2F1 | Refrigeration and Air Conditioning | | | | L1, T1, L2, T2 | |
| 2G | Other Product Manufacture and Use; NMVOC (indirect) | L2 | | | | |
| 3A | Enteric Fermentation | | L1, T1, L2 | | | |
| 3B1-4 | Manure Management, all Livestock, direct | | L1, L2 | L2 | | |
| 3B5 | Manure Management, indirect | | | L1, L2 | | |
| 3Da | Direct Emissions from Managed Soils | | | L1, T1, L2 | | |
| 3Db | Indirect Emissions from Managed Soils | | | L1, L2 | | |
| 4A1 | Forest Land Remaining Forest Land | L1, T1, L2, T2 | | | | |
| 4A2 | Land Converted to Forest Land | L1, L2 | | | | |
| 4B1 | Cropland Remaining Cropland | T1, L2, T2 | | | | |
| 4C1 | Grassland Remaining Grassland | L1, T1, L2, T2 | | | | |
| 4C2 | Land Converted to Grassland | L1, T1, L2 | | | | |
| 4D1 | Wetland Remaining Wetland | L2 | | | | |
| 4E2 | Land Converted to Settlements | L1, L2 | | | | |
| 4F2 | Land Converted to Other Land | L1, L2 | | | | |
| 4G | HWP Harvested Wood Products | T1, T2 | | | | |
| 4III | Direct N2O from Disturbance | | | L2 | | |
| 5A | Solid Waste Disposal | | L1, T1, L2 | | | |
| 5C | Incineration and Open Burning of Waste | | | L2 | | |
| 5D | Wastewater Treatment and Discharge | | L1, T1, L2 | L2 | | |

## 1.5.2. KP-LULUCF inventory

Switzerland identified 2 key categories for activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol (Forest management and Deforestation). The approach relies on full inventory KCA (including LULUCF), KP – CRF association and qualitative assessment. A detailed description is presented in chp. 11.6.1.

# 1.6. General uncertainty evaluation

Specific input uncertainty estimates for KP-LULUCF activities are presented in chp. 11.3.1.5. We hereafter present the input uncertainty estimates for the greenhouse gas inventory under the UNFCCC and the obtained results.

### 1.6.1. Data used

Input uncertainty values are mostly given for activity data and emissions factors. For categories concerning indirect $CO_2$ emissions and F-gases, uncertainty values are available for emissions only.

Input uncertainty values are selected and/or computed based on available data and according to the following order of preference:

- As a first choice, specific uncertainty information from studies or from data suppliers is used, if available. This is the case for most key categories.
- As a second choice, authors of the NIR chapters, FOEN experts involved and several data suppliers derived estimates of uncertainties based on the 2006 IPCC Guidelines (IPCC 2006) default values and on information concerning the process of data collection for activity data and emission factors (import or sales statistics, surveys or modelling). Several experts from data suppliers were contacted for further information on some of the uncertainties. Industry associations/sources also provided published or unpublished uncertainty estimates for their data.
- As a last choice, for categories with no quantitative uncertainty data available, the NIR provides qualitative estimates of uncertainties. The elaboration of a quantitative uncertainty assessment for these categories would present a large effort with only limited effect on the overall uncertainty and therefore it has been decided to realize a semi-quantitative assessment. This includes the definition of a list of the combined uncertainties for all gases and three uncertainty levels: low, medium and high (see Table 1-10). These values are motivated by the comparison of uncertainty analyses of several countries carried out by de Keizer et al. (2007), as presented at the 2nd International Workshop on Uncertainty in Greenhouse Gas Inventories (Vienna 27–28 September 2007), and by expert judgement from sectoral experts and authors.

The following sources of uncertainties are not taken into account:

- Uncertainties in the GWP values.
- Uncertainty due to unknown bias.
- Uncertainty due to neglected temporal variability when assuming constant parameters over time (e.g. emission factors).

Several uncertainty values have been changed for submission 2022 (see detailed input values in Annex A2.1):

- The uncertainty for the emission factor of category 1A1 Other fuels $CO_2$ was updated.
- The uncertainties assigned to emissions of HFCs, PFCs, $SF_6$ and $NF_3$ in sector 2 IPPU were updated (yearly update).
- The uncertainties assigned to activity data and emission factors in sector 3 Agriculture for $CH_4$ and $N_2O$ emissions were updated (yearly update).
- The uncertainties for the emission factors for categories 4B1, 4B2, 4C1, 4C2, 4D2 and 4F2 were updated (yearly update).
- In sector 1 Energy, emission factors with an uncertainty value > 100% were assigned a gamma distribution (instead of a normal distribution).

The detailed data sources can be found in the relevant chapters on “Uncertainties and time-series consistency” in each of the sectoral chapters (chp. 3 to 9) below.

Table 1-10 Semi-quantitative (combined) uncertainties (U) for the emission of categories with no quantitative uncertainty data available. Note that there is no source of HFC, PFC, $SF_6$ or $NF_3$ for which a semi-quantitative uncertainty value is required.

| Gas | Uncertainty category | Combined uncertainty |
|---|---|---|
| $CO_2$ | low | 2% |
| | medium | 10% |
| | high | 40% |
| $CH_4$ | low | 15% |
| | medium | 30% |
| | high | 60% |
| $N_2O$ | low | 40% |
| | medium | 80% |
| | high | 150% |

## 1.6.2. Methodology

The uncertainty aggregation for the greenhouse gases is carried out for the latest submission according to approach 1 (uncertainty propagation) and approach 2 (Monte Carlo simulations).

Input uncertainty values for activity data and emission factors at the same aggregation level as required for the key category analysis are used for the computation. A total of 186 categories were considered, including LULUCF and indirect $CO_2$ emissions. Indirect $N_2O$ emissions are not included in the uncertainty analysis.

Uncertainties are assessed in accordance with the IPCC Guidelines 2006 (IPCC 2006). The Monte Carlo simulations follow the recommendations by JCGM (2008, Supplement 1).

The following assumptions were applied to both approaches:

- Full correlation or no correlation can be set between the base year and the reporting year for the same input variable.
- The following statistical distributions are used: normal, triangular, gamma. If a variable cannot physically have negative values and has an uncertainty >100%, a gamma distribution is preferred in order to not generate negative values during Monte Carlo simulations. This is particularly relevant for emission factors.
- Asymmetric distribution: in approach 1, this is taken into account by computing the uncertainty propagation separately for each side of the mean. In approach 2, each distribution can be simulated, and asymmetric distributions are not an issue.

The following factors are not accounted for:

- Partial correlation between the base year and the reporting year for the same input variable.
- Correlations between categories (for different input variables).

For both approaches, all uncertainty results represent a 95% confidence interval. For a symmetrical distribution, this interval is centered on the mean, from 2.5% up to 97.5% of the distribution. For non-symmetrical distributions obtained by Monte Carlo simulations, the reported uncertainties represent the narrowest 95% interval, in agreement with JCGM (2008, S1). This has consequences in particular for combined uncertainties strongly influenced by input gamma distributions, with the narrowest interval having the tendency to be shifted towards the lower end of the distribution (for example, from 1% up to 96% of the distribution). Uncertainties are given for the lower range (from the lower edge to the mean) and the upper range (from the mean to the upper edge), expressed as a percentage of the mean.

#### 1.6.2.1. Aggregation of uncertainties using approach 1: uncertainty propagation

The uncertainty propagation is computed using the open source software Python (version 3.6.1, https://www.python.org/), in which the equations given in the guidelines (IPCC 2006) are programmed. Results of approach 1 for the reporting year and for the trend are summarised in Table 1-11.

#### 1.6.2.2. Aggregation of uncertainties using approach 2: Monte Carlo simulations

The Monte Carlo simulations were performed for the base year 1990, the reporting year 2020 and the trend at the aggregation level required for the KCA. All input variables can be found in Annex A2.1. Results for each gas are summarized in Table 1-13.

The main strategy in Monte Carlo analysis is to simulate a probability distribution for each input variable (distribution type, mean and standard deviation) and propagate these probability distributions to the final value of the model, in order to obtain a realistic uncertainty envelope for the final quantity. In practice, this is achieved by generating a large set of random numbers for each input quantity according to its distribution probability and by computing the intermediate (if any) and final values according to the equations of the model. The strength of this method is to propagate uncertainties accurately even if the equations of the model are non-linear and even if the final uncertainty envelope is non-symmetric. Another advantage is that a distribution is produced to represent the final quantity, while this information is not available from approach 1.

In our settings, each input quantity is, for each year, an activity data value associated with an emission factor or if applicable, a direct emission. The final quantity is the emission at the inventory level and the mathematical model is the sum of emissions from each process.

**Modelling framework**

The Monte Carlo simulations are programmed using the open source software Python (version 3.6.1, https://www.python.org/). Python is run through the Anaconda installation (https://www.anaconda.com/, version 4.4.0 (64 bit)) on a Windows PC.

To generate random numbers corresponding to the selected distributions, mean and variances, the Python function `random` is used. In practice, for each input emission factor and activity data value (or direct emission, if applicable), random numbers are generated according to the input parameters. The final uncertainty envelope is obtained by computing the emissions as the product of simulated activity data and emission factors and by then adding up all simulated emissions. Intermediate sums can also be obtained, for example the sum for a given sector.

For each input quantity, 1'000'000 random values were generated resulting in equal numbers of values for the base year, the reporting year and the trend.

The average offset between the simulated mean for each process and the input mean is 0.15%. This reflects the uncertainty introduced by the Monte Carlo method itself. This computational uncertainty remains small compared to the uncertainty introduced by activity data and emission factors.

**Correlation**

If two variables representing the base year (BY) and the reporting year (RY) for the same process are fully correlated, a random number is generated for the base year only, written $BY_{random}$. The random value for the reporting year $RY_{random}$ is then computed as:

$$RY_{random} = BY_{random} * RY_{input,\ mean}/BY_{input,\ mean},$$

where $RY_{input,\ mean}$ and $BY_{input,\ mean}$ are the input mean values for the variables in the reporting year and the base year, respectively.

This method implicitly assumes that the uncertainty for the base year and the reporting year, expressed in percentage of the mean value, stays the same.

No correlation between activity data (or emission factors) resulting from different processes for the same year is programmed.

**Sensitivity analysis**

The sensitivity analysis investigates how sensitive the total emission is to each input emission. This analysis was conducted for the base year and the reporting year.

The sensitivity of a total value (total base year emission, total reporting year emission) to the variability of input quantities is computed as the correlation coefficient between total and input values, using in Python the function `corrcoef` from the `numpy` package. Each sensitivity value is computed on 1'000'000 pairs of points.

The sensitivity therefore has a value between -1 and +1, where a negative value indicates a negative correlation, and a positive value a positive correlation. For emissions, since the total values are a sum of input values, we expect only positive correlations.

Intuitively, the variability in the total value will be very sensitive to a process with also a high variability, compared to other processes with a smaller variability. In other words, the inventory total is expected to be mostly sensitive to processes with a high uncertainty (expressed in absolute values or in the same unit as the emissions).

**Source code availability**

The Python source code is available on request. For the next submission, we plan to make the code available on a public repository.

## 1.6.3. Results of approaches 1 and 2 uncertainty evaluation

Table 1-11 shows the results of the uncertainty evaluations using approaches 1 and 2 for the base year, the reporting year and the trend, excluding and including the LULUCF sector.

Table 1-11 Relative uncertainties, expressed in percentage of the mean, for Switzerland's national total greenhouse gas emissions and removals excluding and including the LULUCF sector. Uncertainties are obtained by approach 1 (uncertainty propagation) and 2 (Monte Carlo simulations) for emission levels in 1990, 2020 and for the trend (1990–2020) and are detailed by negative, positive and mean uncertainty. The uncertainty analysis is based on emissions and removals including indirect $CO_2$ emissions.

| Inventory | Level uncertainty 1990 | | | Level uncertainty 2020 | | | Trend uncertainty 1990-2020 | | |
|---|---|---|---|---|---|---|---|---|---|
| | (-)% | (+)% | mean % | (-)% | (+)% | mean % | (-)% | (+)% | mean % |
| Approach 2 Uncertainty analysis | | | | | | | | | |
| excl. LULUCF | 4.6 | 5.7 | 5.2 | 4.3 | 4.8 | 4.6 | 5.7 | 5.4 | 5.6 |
| incl. LULUCF | 6.0 | 6.8 | 6.4 | 6.1 | 6.4 | 6.2 | 6.7 | 6.8 | 6.7 |
| Approach 1 Uncertainty analysis | | | | | | | | | |
| excl. LULUCF | 3.2 | 7.4 | 5.3 | 3.3 | 5.9 | 4.6 | 3.5 | 3.6 | 3.6 |
| incl. LULUCF | 4.6 | 8.3 | 6.4 | 5.3 | 7.3 | 6.3 | 5.3 | 5.3 | 5.3 |

In general, mean uncertainties resulting from approaches 1 and 2 are in concordance. For the lower range uncertainty, approach 1 may result in a smaller estimate in cases where the inventory probability distribution is asymmetric. We therefore recommend to take into consideration the uncertainty estimate provided by approach 2 (Monte Carlo simulations). Uncertainties including the LULUCF sector are in each case larger than excluding the LULUCF sector, as processes in the LULUCF sector have comparatively large uncertainties.

Uncertainty estimates can be summarized as follow:

- The level uncertainty according to approach 2 for the year 2020 including LULUCF is [-6.1%; +6.4%] and excluding LULUCF [-4.3%; + 4.9%].
- The trend uncertainty according to approach 2 for the trend 1990–2020 including LULUCF is [-6.7%; +6.7%] and excluding LULUCF [-5.7%; +5.4%].

As a comparison, the results of the previous inventory, according to approach 1, were (FOEN 2021):

- The level uncertainty for the year 2019 was 7.1% including LULUCF and 5.8% excluding LULUCF.
- The trend uncertainty 1990–2019 was 4.3% including LULUCF and 1.9% excluding LULUCF.

While level uncertainties are similar for the latest submission compared to the previous one, trend uncertainties are larger for the latest submission. This is due to the fact that by model construction, variables with non-identical uncertainties for the base year and the reporting year cannot be treated as correlated. As a consequence, about ten processes were newly treated as not correlated for this submission, for both approaches 1 and 2.

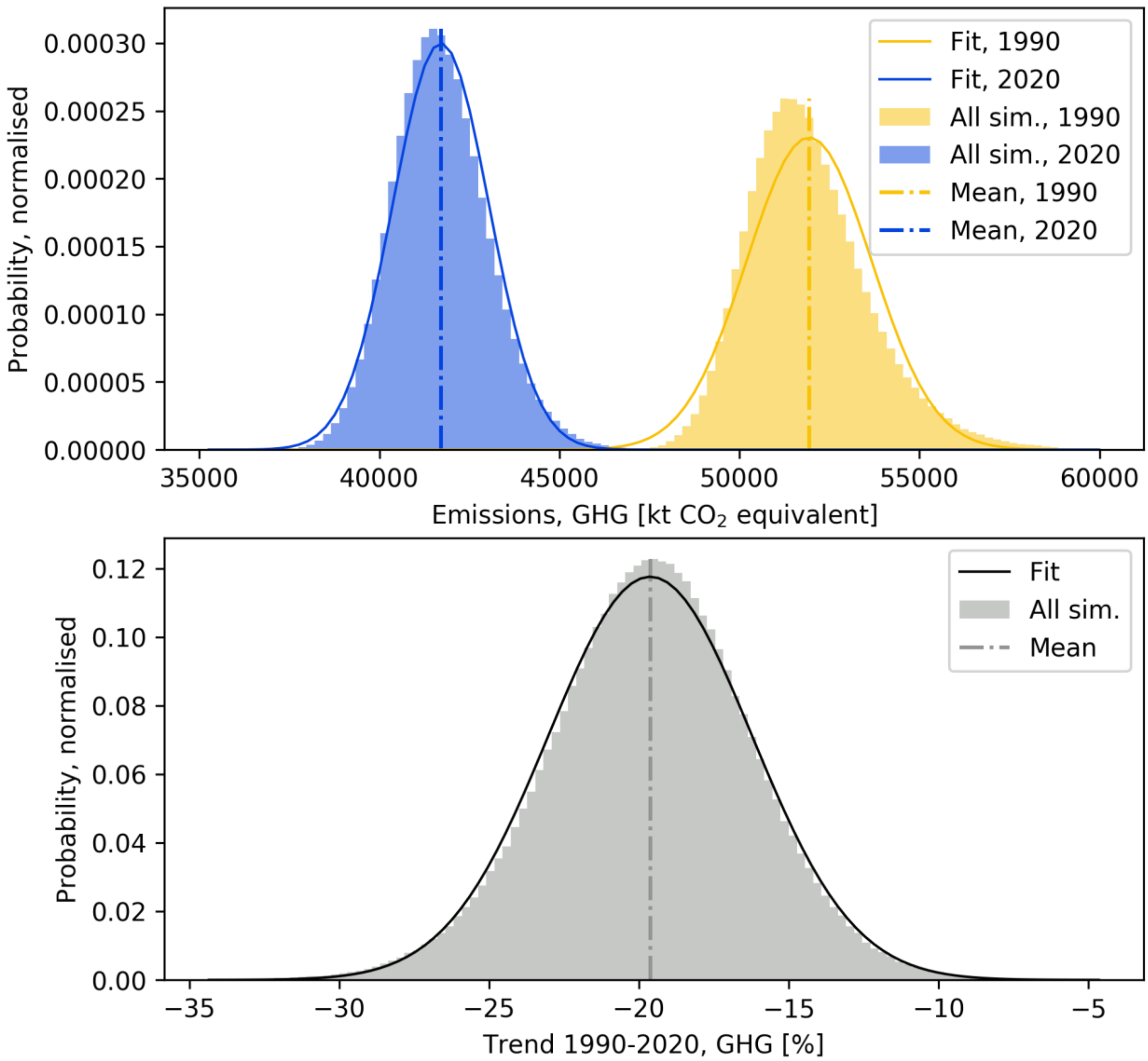


Figure 1-3 Results of Monte Carlo simulations: Distributions obtained for the inventory mean emission for all greenhouse gases, for the base year 1990 (top panel, yellow), the reporting year 2020 (top panel, blue) and the trend 1990–2020 (bottom panel, grey). All sim.: all simulations (1’000‘000 values for each distribution). Fit: fit of the distribution using a normal distribution. By definition, the integral of the fit (or area) is one. Mean: mean inventory emission obtained from the simulations.

Table 1-12 Overview of sector contributions to inventory uncertainties for the reporting year emissions and removals and for the trend, including indirect $CO_2$ emissions. Uncertainties are computed using approach 2 (Monte Carlo simulations).

| Sector | Emissions or removals in base year (1990) | Emissions or removals in reporting year (2020) | Contribution to total uncertainty by sector in reporting year | Contribution to total trend uncertainty by sector |
|---|---|---|---|---|
| | kt CO2 equ. | kt CO2 equ. | % | % |
| 1: Energy | 41'917 | 32'675 | 3 | 3 |
| 2: Industrial Processes and Product Use | 4'348 | 4'292 | 3 | 3 |
| 3: Agriculture | 6'582 | 5'757 | 54 | 68 |
| 4: Land Use, Land Use Change and forestry | -2'044 | -1'705 | 39 | 26 |
| 5: Waste | 1'120 | 675 | 0.7 | 0.2 |
| 6: Other | 13 | 13 | 0.0 | 0.0 |
| Total | 51'936 | 41'706 | 100 | 100 |

Table 1-13 For each gas, net emission levels for 1990 and 2020, trend (1990–2020), and associated uncertainties obtained from Monte Carlo simulations and from uncertainty propagation, including indirect $CO_2$ emissions and LULUCF categories. Note that the trend and its associated uncertainty are expressed in the same unit, in percent. As an example, for a trend of -10% with uncertainties of 2%, the trend is comprised between -12% and -8%.

| Gas | Base year (1990) | | | Reporting year (2020) | | | Trend (1990-2020) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Emissions, kt CO2 equ. | U(-) % | U(+) % | Emissions, kt CO2 equ. | U(-) % | U(+) % | Trend, % | U(-) % | U(+) % |
| Monte Carlo simulations (approach 2) | | | | | | | | | |
| CO2 | 42'446 | 4 | 4 | 32'594 | 5 | 5 | -23 | 4 | 4 |
| CH4 | 5'820 | 13 | 14 | 4'599 | 16 | 16 | -21 | 15 | 16 |
| N2O | 3'416 | 62 | 85 | 2'953 | 53 | 63 | -14 | 75 | 93 |
| HFC | 0.025 | 18 | 18 | 1'387 | 17 | 18 | 5'597'702 | 1'361'727 | 1'458'167 |
| SF6 | 137.0 | 41 | 45 | 137.6 | 39 | 42 | 0 | 5 | 6 |
| PFC | 116.5 | 9 | 9 | 34.44 | 25 | 27 | -70 | 8 | 8 |
| NF3 | 0.000 | | | 0.412 | 87 | 108 | | | |
| Uncertainty propagation (approach 1) | | | | | | | | | |
| CO2 | 42'446 | 4 | 4 | 32'594 | 5 | 5 | -23 | 5 | 5 |
| CH4 | 5'820 | 13 | 14 | 4'599 | 15 | 16 | -21 | 17 | 17 |
| N2O | 3'416 | 41 | 113 | 2'953 | 38 | 80 | -14 | 45 | 46 |
| HFC | 0.025 | 17 | 0.0 | 1'387 | 17 | 18 | 5'597'702 | 1'320'721 | 1'450'382 |
| SF6 | 137.0 | 39 | 0.0 | 137.6 | 36 | 45 | 0 | 6 | 9 |
| PFC | 116.5 | 0.0 | 0.0 | 34.44 | 22 | 30 | -70 | 9 | 13 |
| NF3 | 0.000 | | | 0.412 | 77 | 133 | | | |

Changes in total level and trend uncertainties are on one hand due to changes in uncertainties assigned to emission factors and activity data in the different categories. On the other hand, changes in activity data and emission factor values cause changes in the contribution to the total level and trend uncertainty of each category.

Contribution to level uncertainty and the uncertainty introduced to the trend in total national emissions of each category are shown in Annex A2.2 for approach 1 (uncertainty propagation) and in Annex A2.3 for approach 2 (Monte Carlo simulations).

The Monte Carlo simulations provide data to conduct a sensitivity analysis between emissions from each category and the inventory (total) emission. This analysis quantifies the influence of a change in the emission of a given category on the inventory total. The results of the sensitivity analysis for the base year and the reporting year are shown in Figure 1-4. The processes ranked in descending order of importance according to the sensitivity analysis follow almost the same order as the processes ranked according to approach 2 of the key category analysis. In both cases, results are dominated by categories from sectors 3 Agriculture and 4 LULUCF. Both methods highlight categories with large uncertainties, expressed in absolute values. The sensitivity analysis therefore confirms the results obtained by approach 2 of the KCA.

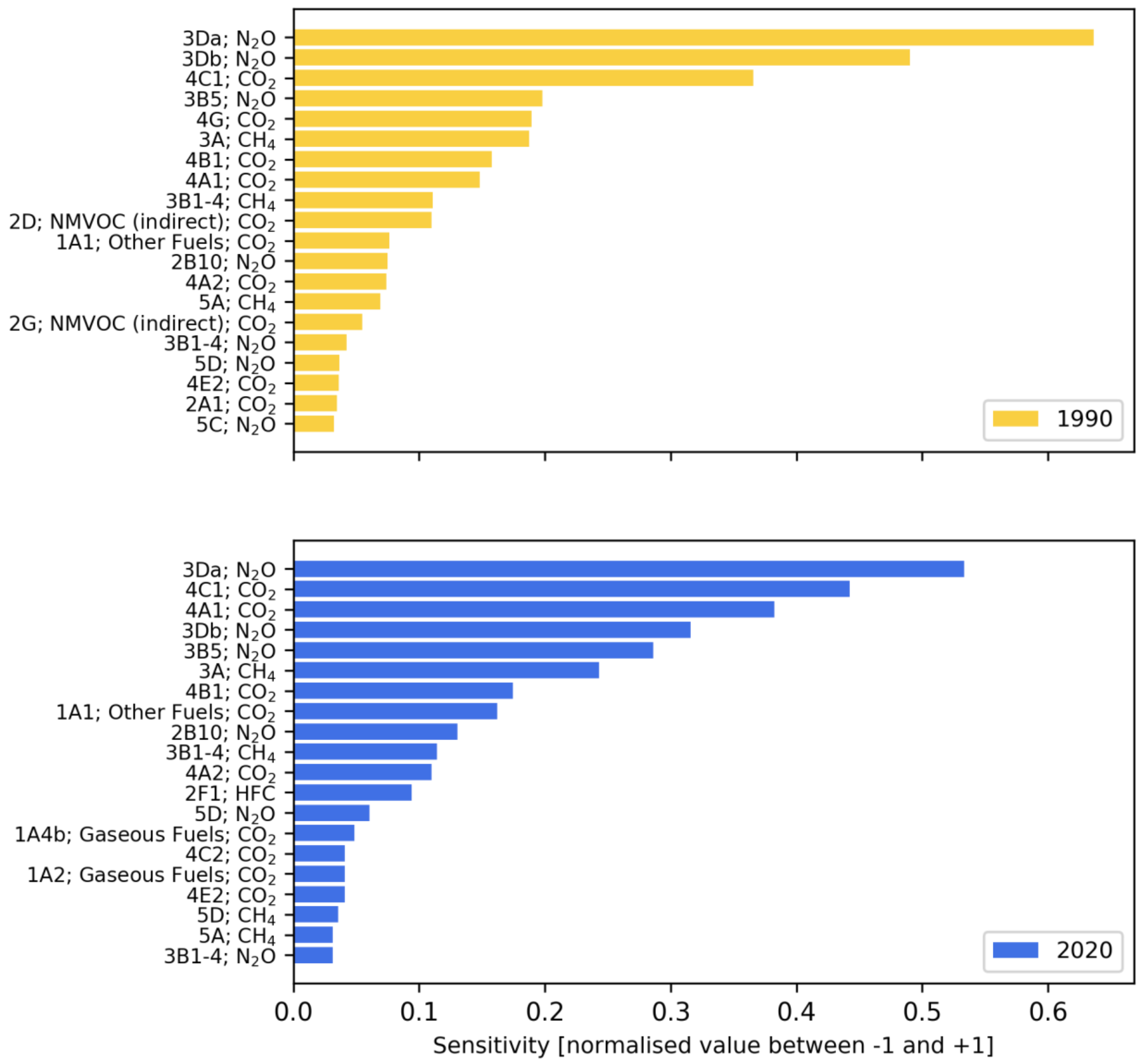


Figure 1-4 Results of the sensitivity analysis between emissions and removals from each category and inventory emissions and removals for all greenhouse gases, for the base year 1990 and the reporting year 2020. Only the twenty categories ranked first are listed. See chp. 1.6.2.2 for details and compare also with Table 1-7 (results for the key category analysis approach 2, i.e. using uncertainties).

Based on the analysis of the predominant contributions to the uncertainty of the Swiss greenhouse gas inventory, the FOEN commissions and/or supports various projects.

Planned improvements are given in the sectoral chapters and an overview list is reported in chp. 10.4.

## 1.7. General assessment of completeness

### 1.7.1. GHG inventory

For the following categories, the notation key "not estimated" (NE) is used:

- $CH_4$ emissions from 1A1a iv Other / Municipal and special waste incineration plants / Other Fossil Fuels. Based on measurements of the exhaust gas (Mohn 2013), $CH_4$ emissions are below detection limit and thus considered insignificant (see chp. 3.2.5.2.1).
- Potential $CO_2$ emissions from 2A4b Other uses of soda ash are estimated to be clearly below the significance threshold of 0.05% of the national total GHG emissions (excluding LULUCF; decision 24/CP.19, annex I, paragraph 37(b)) (see chp. 4.2.2.4). The share was highest in 1990 (0.02%) and has remained more or less constant (0.01%) since 2003.
- Carbon stock changes in living biomass and in dead wood for land converted to unproductive forest land (4.A.2.1, 4.A.2.2, 4.A.2.3, 4.A.2.4, 4.A.2.5). The Tier 1 approach assumes carbon stock change is zero, but the numerical value 0 cannot be included in the reporting tables; therefore the notation key NE is used.
- Net carbon stock changes in dead wood and in litter for land converted to forest land – afforestation (4.A.2.1, 4.A.2.2, 4.A.2.3, 4.A.2.4, 4.A.2.5). The Tier 1 approach assumes carbon stock change is zero, but the numerical value 0 cannot be included in the reporting tables; therefore the notation key NE is used.
- Net carbon stock changes in living biomass, in dead wood, in litter and in mineral soils in unproductive forest land remaining unproductive forest land (4.A.1 "CC13"). The Tier 1 approach assumes carbon stock change is zero, but the numerical value 0 cannot be included in the reporting tables; therefore the notation key NE is used.
- Activity data for 4.Gs2 Harvested wood products. The FAO database does not provide data for years prior to 1961.
- $CH_4$ emissions from drainage and rewetting and other management of organic and mineral soils 4.A Forest Land/4(II), 4.B Cropland/4(II), 4.C Grassland/4(II), 4.D3 Other wetlands/4(II). Reporting for these source categories is not mandatory.
- $N_2O$ emissions from drainage and rewetting and other management of organic and mineral soils 4.D Wetlands/4(II), 4.D.2 Flooded lands. Reporting for this source category is not mandatory.

For the following categories, the notation key "included elsewhere" (IE) is used:

- 1A1b Petroleum refining / Gaseous fuels: Emissions are reported under 1A1b Petroleum refining / Liquid fuels for reasons of confidentiality (see chp. 3.2.5.2.2).
- 1A2c Chemicals/Other fossil fuels: Emissions are reported under 1A2f Non-metallic minerals / Other fossil fuels for reasons of confidentiality (see chp. 3.2.6.2.4).
- 1A2d Pulp, paper and print/Biomass and 1A2e Food processing, beverages and tobacco/Biomass: Emissions are partly or totally reported under 1A2gviii due to lack

of statistical data to disaggregate wood consumption in the relevant categories (see chp. 3.2.4.5.2).

- 1A2f Non-metallic minerals/Biomass: $CH_4$ emissions from cement production are reported under 1A2f Non-metallic minerals/Other fossil fuels, as the emission factor in the cement industry is based on direct exhaust measurements at the chimneys of the cement plants (see chp. 3.2.6.2.7).
- 1A3a Domestic aviation/Aviation gasoline and 1D International aviation/Aviation gasoline: Emissions are reported together with Jet kerosene, as only negligible amounts of aviation gasoline are consumed and no detailed modelling for aviation gasoline exists.
- 1.A(b) Reference approach, liquid fuels: Imports of refinery feedstocks are included in crude oil.
- 1.A(b) Reference approach, liquid fuels: Imports of other kerosene are included in jet kerosene.
- 1.A(b) Reference approach, liquid fuels: Carbon stored of liquefied petroleum gas, naphtha and petroleum coke are included in other oil.
- 1.A(b) Reference approach, solid fuels: Import and stock change of anthracite and coke oven/gas coke are included in other bituminous coal.
- 1.A(d) Feedstock, reductants and other non-energy use of fuels, liquid fuels: fuel quantity, C excluded from reference approach and $CO_2$ emissions for liquefied petroleum gas, naphtha and petroleum coke are included in other oil.
- 2B1 Ammonia production: $CO_2$ emissions are reported under 2B8b Ethylene because Ammonia production is part of an integrated production chain (see chp. 4.3.2.1).
- 4D1.2 Flooded land remaining flooded land: $CO_2$ emissions and removals are reported for all Wetlands remaining wetlands under 4D1.3 Other wetlands remaining other wetlands (unproductive wetland/surface water).
- 4D2.2.2 Land converted to flooded land: $CO_2$ emissions and removals are reported for all land converted to wetlands under 4D2.3 Land converted to other wetlands.
- 4.E Settlements / 4(I) Direct $N_2O$ emissions from nitrogen inputs to managed soils: Emissions are reported together with 3.D.a Agriculture because no data are available for a further disaggregation of fertiliser use.
- 4.A-D / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils: All carbon stock changes ($CO_2$ emissions and removals) are reported as carbon stock changes in tables 4.A to 4.D.
- 4.C.1 Grasslands remaining grasslands / 4(III) Direct $N_2O$ from N mineralisation/immobilisation: $N_2O$ emissions are reported under 3.D.a.5 Agriculture, as grasslands are considered part of the agricultural area.
- 4(IV).1 Indirect $N_2O$ emissions from managed soils/Atmospheric deposition: Emissions are reported under 3.D.b.1 Agriculture because no data are available for a further disaggregation.
- 4(V) Biomass Burning: $CO_2$, $CH_4$ and $N_2O$ emissions from 4.A.2 Land converted to forest land and 4.C.2 Land converted to grassland are reported under biomass burning of 4.A.1 Forest land remaining forest land and 4.C.1 Grassland remaining grassland, respectively, because no data are available for a further disaggregation. $CO_2$ emissions from controlled burning and wildfires in 4.A.1 and from wildfires in 4.C.1 are covered by the carbon changes reported under 4.A and 4.C respectively.

- 5B2 Anaerobic digestion at industrial and agricultural biogas facilities: Amount of $CH_4$ recovered and emissions from its use in stationary motors (CHP) and boilers are reported under 1A2gviii Other / Biomass (CHP at industrial biogas plants) and 1A4ci Agriculture/forestry/fishing / Stationary / Biomass (CHP and boilers at agricultural biogas plants).
- 5C1 Waste Incineration Biogenic: Emission factors for $CH_4$ and $N_2O$ cannot be separated into biogenic and non-biogenic fraction. Therefore, emissions are reported together with 5C1 Waste Incineration non-biogenic $CH_4$ and $N_2O$ emissions (NIR chp. 7.4.2).
- 5D2 Industrial wastewater: $CH_4$ and $N_2O$ emissions are reported under 5D1 Domestic wastewater, because industrial wastewater is merged and treated together with domestic wastewater (see chp. 7.5.1).

### 1.7.2. KP-LULUCF inventory

For all known GHG sources and sinks, complete estimates are accomplished for the latest submission. Notation keys for the activity coverage and the reported carbon pools are displayed in CRF NIR-1. A detailed justification for the reported methods is given in chp. 11.3.1.2.

# 2. Trends in greenhouse gas emissions and removals

| Responsibilities for Trends in greenhouse gas emissions and removals | |
|---|---|
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This chapter provides an overview of Switzerland's GHG emissions and removals in 2020 as well as trends for the period 1990–2020. Values in chp. 2.1–2.4 are relevant for reporting under the UNFCCC, values in chp. 2.5 refer to accounting under the Kyoto Protocol.

## 2.1. Aggregated greenhouse gas emissions 2020 (UNFCCC)

Table 2-1 shows the aggregated emissions of all greenhouse gases (GHG) 2020 for each sector and the relative shares of the sectors. Furthermore, emission data on international aviation and marine bunkers are provided. As the table indicates, $CO_2$ is the main contributor to total GHG emissions followed by $CH_4$, $N_2O$ and F-gases. Sector 1 Energy is the main source concerning climate-related emissions followed by sectors 3 Agriculture, 2 IPPU, 5 Waste and 6 Other. In contrast, sector 4 LULUCF is a net sink regarding GHG net emissions and removals in 2020.

Table 2-1 Switzerland's GHG emissions in $CO_2$ equivalent (kt) by gas and sector in 2020 (without indirect emissions).

| Sectors | $CO_2$ | $CH_4$ | $N_2O$ | HFCs | PFCs | $SF_6$ | $NF_3$ | Total | Share |
|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | | | | | |
| 1 Energy | 32'150 | 262 | 239 | | | | | 32'651 | 75% |
| 2 IPPU | 2'026 | 6.4 | 605 | 1'387 | 34 | 138 | 0.41 | 4'198 | 9.7% |
| 3 Agriculture | 45 | 3'822 | 1'890 | | | | | 5'757 | 13% |
| 5 Waste | 8.9 | 496 | 168 | | | | | 674 | 1.6% |
| 6 Other | 11 | 0.57 | 0.47 | | | | | 12 | 0.027% |
| **Total (excluding LULUCF)** | 34'241 | 4'588 | 2'903 | 1'387 | 34 | 138 | 0.41 | **43'291** | 100% |
| 4 LULUCF | -1'768 | 12 | 50 | | | | | -1'705 | -3.9% |
| **Total (including LULUCF)** | 32'473 | 4'599 | 2'953 | 1'387 | 34 | 138 | 0.41 | **41'586** | 96% |
| *International aviation bunkers* | 2'051 | 0.17 | 17 | | | | | *2'068* | |
| *International marine bunkers* | 14 | 0.0029 | 0.13 | | | | | *14* | |

A breakdown of Switzerland's total emissions by gas (excluding LULUCF) is given in Figure 2-1. Figure 2-2 charts the relative contributions of the individual sectors (excluding LULUCF) to the emissions of each GHG. Trends in GHG emissions are given in chp. 2.2 to 2.5

The national total of 43'291 kt of $CO_2$ equivalent (excluding LULUCF, excluding indirect $CO_2$; see Table 2-1) corresponds to 5.0 tonnes of $CO_2$ equivalent per capita ($CO_2$: 4.0 tonnes per capita) emitted to the atmosphere in 2020. Emissions per capita are calculated based on population statistics from the Swiss Federal Statistical Office (SFSO).

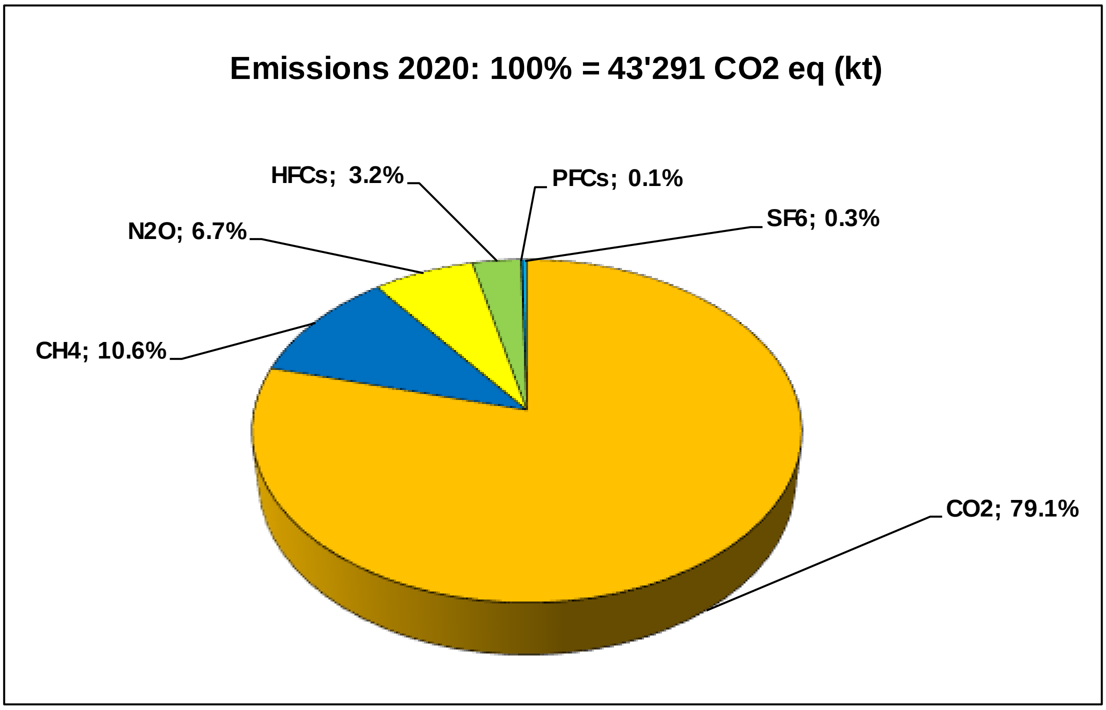


Figure 2-1 Contribution of individual gases to total greenhouse gas emissions in 2020 (excluding LULUCF, excluding indirect $CO_2$).

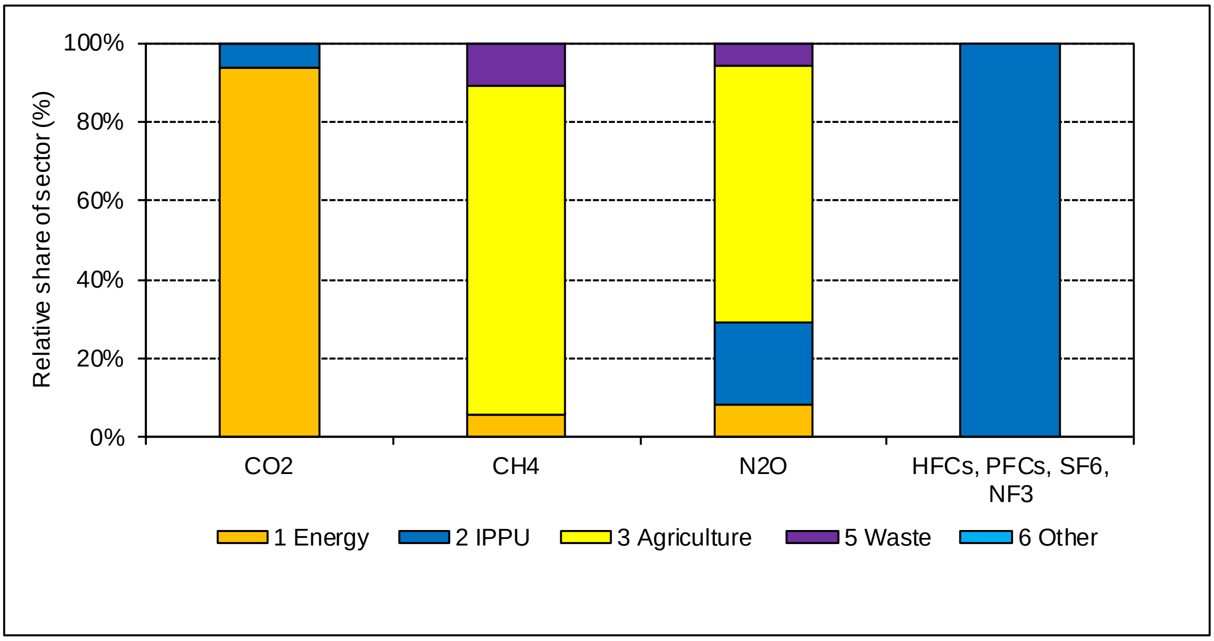


Figure 2-2 Relative contributions of the individual sectors (excluding LULUCF, excluding indirect $CO_2$) to GHG emissions in 2020.

A clear dominance of $CO_2$ emissions in 2020 is related to source category 1A Fuel combustion within sector 1 Energy. $CH_4$ and $N_2O$ emissions mainly originate from sector 3 Agriculture, while F-gas emissions by definition only originate from sector 2 Industrial processes and product use.

## 2.2. Emission trends by gas

Emission trends by gas for the period 1990–2020 are summarized in Table 2-2.

Table 2-2 Greenhouse gas emissions in $CO_2$ equivalent (kt) by gas (without indirect emissions). The last column of the lower panel indicates the percentage change in emissions in the latest year compared to the base year 1990. HFC emissions increased by more than 5 million percent when compared to 1990 levels.

| Greenhouse Gas Emissions | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | |
| $CO_2$ emissions including net $CO_2$ from LULUCF | 42'032 | 39'410 | 48'749 | 42'843 | 42'053 |
| $CO_2$ emissions excluding net $CO_2$ from LULUCF | 44'160 | 43'419 | 43'622 | 45'779 | 45'046 |
| $CH_4$ emissions including $CH_4$ from LULUCF | 5'820 | 5'535 | 5'155 | 5'091 | 5'031 |
| $CH_4$ emissions excluding $CH_4$ from LULUCF | 5'792 | 5'517 | 5'141 | 5'077 | 5'019 |
| $N_2O$ emissions including $N_2O$ from LULUCF | 3'416 | 3'381 | 3'323 | 3'179 | 3'134 |
| $N_2O$ emissions excluding $N_2O$ from LULUCF | 3'361 | 3'331 | 3'276 | 3'132 | 3'085 |
| HFCs | 0.025 | 244 | 636 | 1'048 | 1'308 |
| PFCs | 117 | 17 | 61 | 50 | 38 |
| $SF_6$ | 137 | 93 | 152 | 213 | 161 |
| $NF_3$ | NO | NO | NO | NO | 13 |
| **Total (including LULUCF)** | **51'522** | **48'680** | **58'076** | **52'424** | **51'737** |
| **Total (excluding LULUCF)** | **53'566** | **52'622** | **52'889** | **55'299** | **54'670** |

| Greenhouse Gas Emissions | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2020 vs.1990 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | | | | | | | % |
| $CO_2$ emissions including net $CO_2$ from LULUCF | 39'677 | 39'704 | 41'105 | 38'868 | 36'502 | 36'987 | 36'220 | 35'906 | 34'555 | 32'473 | -22.7% |
| $CO_2$ emissions excluding net $CO_2$ from LULUCF | 40'985 | 42'253 | 43'188 | 39'234 | 38'732 | 39'185 | 38'179 | 36'874 | 36'733 | 34'241 | -22.5% |
| $CH_4$ emissions including $CH_4$ from LULUCF | 4'981 | 4'958 | 4'887 | 4'878 | 4'851 | 4'819 | 4'760 | 4'724 | 4'645 | 4'599 | -21.0% |
| $CH_4$ emissions excluding $CH_4$ from LULUCF | 4'967 | 4'946 | 4'874 | 4'865 | 4'838 | 4'804 | 4'747 | 4'712 | 4'633 | 4'588 | -20.8% |
| $N_2O$ emissions including $N_2O$ from LULUCF | 3'056 | 3'029 | 3'037 | 3'019 | 3'024 | 2'957 | 3'110 | 2'977 | 3'044 | 2'953 | -13.6% |
| $N_2O$ emissions excluding $N_2O$ from LULUCF | 3'006 | 2'980 | 2'987 | 2'969 | 2'974 | 2'905 | 3'059 | 2'926 | 2'994 | 2'903 | -13.6% |
| HFCs | 1'380 | 1'453 | 1'432 | 1'469 | 1'508 | 1'481 | 1'504 | 1'525 | 1'429 | 1'387 | see caption |
| PFCs | 36 | 39 | 28 | 23 | 26 | 20 | 32 | 36 | 32 | 34 | -70.4% |
| $SF_6$ | 169 | 230 | 276 | 285 | 278 | 236 | 233 | 183 | 152 | 138 | 0.4% |
| $NF_3$ | 9.3 | 0.54 | 0.14 | 0.60 | 0.73 | 0.77 | 0.80 | 0.50 | 0.54 | 0.41 | - |
| **Total (including LULUCF)** | **49'309** | **49'414** | **50'765** | **48'542** | **46'188** | **46'500** | **45'859** | **45'352** | **43'858** | **41'586** | **-19.3%** |
| **Total (excluding LULUCF)** | **50'552** | **51'901** | **52'786** | **48'845** | **48'355** | **48'631** | **47'754** | **46'257** | **45'974** | **43'291** | **-19.2%** |

As shown in Table 2-2, Table 2-3, and Figure 2-3, total emissions excluding LULUCF in 2020 are clearly below base year emissions. There is no discernible trend of overall emissions in the period 1990–2005. Only from 2005 onwards, a decreasing trend starts to develop. Compared to 2019, emissions have strongly decreased in 2020 (by 5.8%). The emission maximum occurred in 1991. Also when including LULUCF categories, a decreasing trend is visible compared to the base year 1990, although the net $CO_2$ eq removals generated by LULUCF categories were generally smaller after 1997 (see Figure 2-8, Figure 2-9 and Figure 6-3). Total emissions reached a minimum in 2020, for both cases including and excluding LULUCF, which was 19.3% and 19.2% below base year emissions in 1990, respectively.

The strong decrease of emissions between 2019 and 2020 may be interpreted as a consequence of the lockdown and subsequent measures associated with the COVID-19 pandemic that affected Switzerland from March 2020 onwards. In particular, the measures to contain the pandemic mainly led to reduced traffic volumes, which reduced $CO_2$ emissions from source category 1A3b Road transportation. Furthermore, mild winter temperatures led to reduced emissions from source category 1A4 Other sectors.

The trends of the different greenhouse gases can be described as follows:

- There is a strong correlation between **$CO_2$** emissions and winter climatic conditions (number of heating degree days; see box 1 on page 68 for further information) in the period 1990–2020. However, the relative developments of heating degree days and $CO_2$ emissions are clearly drifting apart in the years since 2002, which indicates that additional effects like reduction measures contribute to emission reductions (see Figure 2-7).
- Between 1990 and 2020, **$CH_4$** emissions (excluding LULUCF) decreased. One major reason for this decrease was a reduction of livestock in the years 1990 to 2004 that led to a reduction of emissions from enteric fermentation in the agricultural sector (see Table 5-8). Moreover, from 2000 onwards, a change in waste legislation banning the disposal of municipal solid waste in landfills contributed to this trend.
- As a consequence of the declining livestock population and reduced input of synthetic fertilisers, **$N_2O$** emissions that mainly stem from manure management and agricultural soils decrease between 1990 und 2020 as well.
- **HFC** emissions are significantly higher in 2020 compared to the base year due to their application as substitutes for CFCs, while **PFC** emissions declined (mainly due to the decrease and stop of aluminium production). Decreasing tendencies are found for HFC emissions since 2018 due to restrictions of HFC use in mobile air-conditioning and stationary refrigeration. **$SF_6$** emissions show relatively large fluctuations between 1990 and 2020. This effect bases on annual fluctuations of the market volumes in the production of electrical equipment as well as on changes in other applications. The temporary increase of $SF_6$ emissions between 2010 and 2013 is mainly due the disposal of sound proof windows. Although soundproof windows containing $SF_6$ are not produced or installed in Switzerland anymore, the disposal of old windows still leads to emissions. On the other hand, the $SF_6$ emissions from electrical equipment (2G1) are decreasing due to the agreement of SWISSMEM and FOEN on the reduction of $SF_6$ emissions since 2008. Furthermore, the import of $SF_6$ for magnesium foundries (2C4) is prohibited in Switzerland since 2017, leading to an additional decrease of $SF_6$ emissions over the past couple of years. **$NF_3$** has mainly been used only short-term in the photovoltaic industry (around 2010).

Table 2-3 Contribution of individual gases to total emissions (excluding LULUCF, excluding indirect $CO_2$) in $CO_2$ equivalent (kt) and (%).

| **Greenhouse Gas Emissions** | **1990** | | **1995** | | **2000** | | **2005** | | **2010** | |
|---|---|---|---|---|---|---|---|---|---|---|
| (excluding LULUCF) | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % |
| $CO_2$ | 44'160 | 82.4% | 43'419 | 82.5% | 43'622 | 82.5% | 45'779 | 82.8% | 42'253 | 81.4% |
| $CH_4$ | 5'792 | 10.8% | 5'517 | 10.5% | 5'141 | 9.7% | 5'077 | 9.2% | 4'946 | 9.5% |
| $N_2O$ | 3'361 | 6.3% | 3'331 | 6.3% | 3'276 | 6.2% | 3'132 | 5.7% | 2'980 | 5.7% |
| HFCs | 0.025 | 0.0% | 244 | 0.5% | 636 | 1.2% | 1'048 | 1.9% | 1'453 | 2.8% |
| PFCs | 117 | 0.2% | 17 | 0.0% | 61 | 0.1% | 50 | 0.1% | 39 | 0.1% |
| $SF_6$ | 137 | 0.3% | 93 | 0.2% | 152 | 0.3% | 213 | 0.4% | 230 | 0.4% |
| $NF_3$ | NO | - | NO | - | NO | - | NO | - | 0.54 | 0.0% |
| **Total (excluding LULUCF)** | **53'566** | **100%** | **52'622** | **100%** | **52'889** | **100%** | **55'299** | **100%** | **51'901** | **100%** |

| **Greenhouse Gas Emissions** | **2016** | | **2017** | | **2018** | | **2019** | | **2020** | |
|---|---|---|---|---|---|---|---|---|---|---|
| (excluding LULUCF) | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % |
| $CO_2$ | 39'185 | 80.6% | 38'179 | 79.9% | 36'874 | 79.7% | 36'733 | 79.9% | 34'241 | 79.1% |
| $CH_4$ | 4'804 | 9.9% | 4'747 | 9.9% | 4'712 | 10.2% | 4'633 | 10.1% | 4'588 | 10.6% |
| $N_2O$ | 2'905 | 6.0% | 3'059 | 6.4% | 2'926 | 6.3% | 2'994 | 6.5% | 2'903 | 6.7% |
| HFCs | 1'481 | 3.0% | 1'504 | 3.2% | 1'525 | 3.3% | 1'429 | 3.1% | 1'387 | 3.2% |
| PFCs | 20 | 0.0% | 32 | 0.1% | 36 | 0.1% | 32 | 0.1% | 34 | 0.1% |
| $SF_6$ | 236 | 0.5% | 233 | 0.5% | 183 | 0.4% | 152 | 0.3% | 138 | 0.3% |
| $NF_3$ | 0.77 | 0.0% | 0.80 | 0.0% | 0.50 | 0.0% | 0.54 | 0.0% | 0.41 | 0.0% |
| **Total (excluding LULUCF)** | **48'631** | **100%** | **47'754** | **100%** | **46'257** | **100%** | **45'974** | **100%** | **43'291** | **100%** |

Figure 2-3 shows Switzerland's relative GHG emission trends by gas. The base year 1990 is set to 100%.

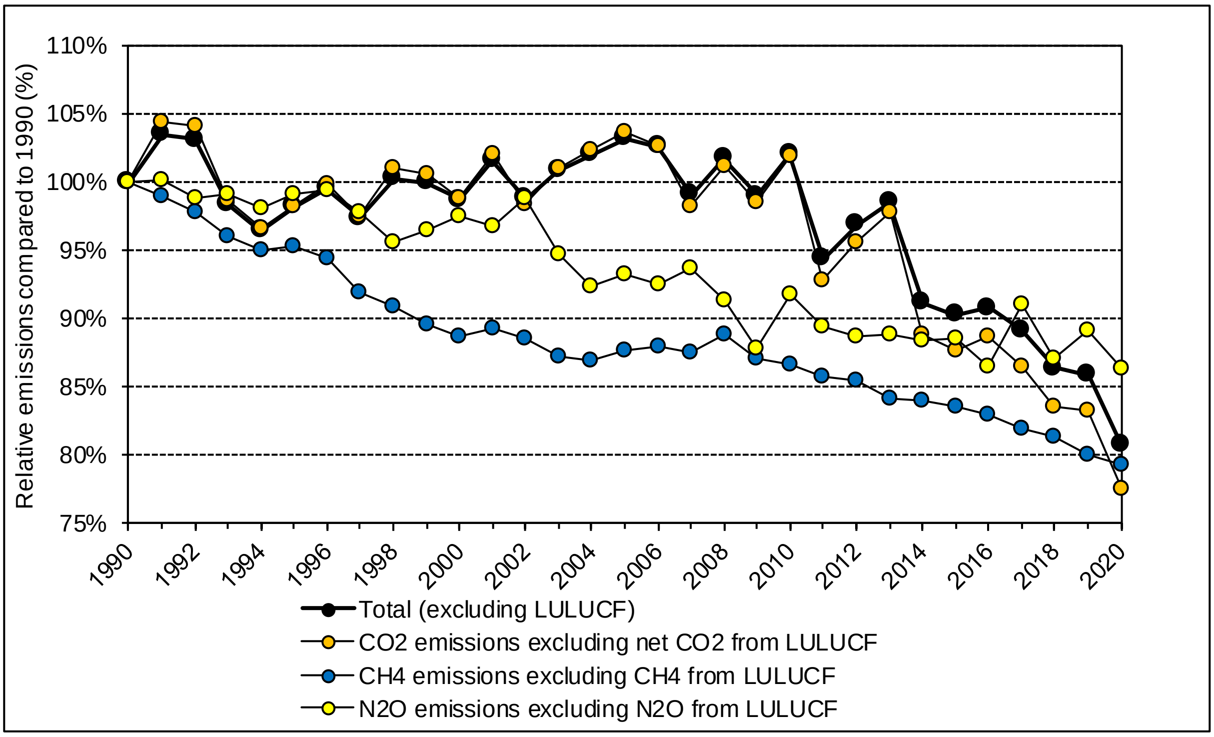


Figure 2-3 Relative trends of Switzerland's main greenhouse gas emissions (excluding LULUCF, excluding indirect $CO_2$). The base year 1990 represents 100%. F-gases are not illustrated here (see Figure 4-3).

## 2.3. Emission trends by sources and sinks

Table 2-4 shows the emission trends for all major source and sink categories. As the largest share of emissions originates from sector 1 Energy, the table includes further information concerning the contributions of energy-related source categories.

### 2.3.1. Overview

In order to understand trends within the sector 1 Energy, the individual source categories are considered separately (see chp. 2.3.2 and Figure 2-6 below).

In line with economic development, overall emissions in sector 2 Industrial processes and product use (IPPU) show a decreasing trend in the early 1990s and a gradual increase between 1997 and 2010, except for the economically difficult year 2009. Since 2010, emissions from the sector have stagnated. The Chemical Risk Reduction Ordinance (Swiss Confederation 2005) was put in place in 2005 and regulates the use of F-gases since then. The dominant source category of sector 2 is 2A Mineral industry although the emissions decreased by approximately one third since 1990. If sources are analysed in more detail, 2A1 Cement production is the most relevant emitter in this category. Emissions of 2F Product uses as substitutes for ozone-depleting substances (ODS), the second most important source in sector 2, increased by some orders of magnitude since 1990 due to the replacement of CFCs with HFCs. The third-most important source category from the IPPU sector is 2B Chemical industry, in particular due to $N_2O$ emissions from category 2B10 Niacin production. Source category 2G Other product manufacture and use, another important source category, contains in particular $SF_6$ and PFC emissions from electrical equipment and other product use, as well as $N_2O$ emissions from the application in households and hospitals. Other source categories in sector 2 are of minor importance with regard to the overall greenhouse gas emissions.

GHG emissions in sector 3 Agriculture are driven by populations of cattle and swine and by fertiliser use. Both factors have been declining (see Table 5-8 and Table 5-24, respectively), thus leading to a decrease in $CH_4$ and $N_2O$ emissions until 2004. Subsequently, emissions remained more or less stable with some fluctuations mainly due to the evolution of the cattle population.

Total emissions from the source category 5 Waste continuously decrease between 1990 and 2020, with a short increasing and fluctuating phase from 1999 until 2004. The main driver of the decreasing trend is the emission reduction in solid waste disposal, which was reinforced through a change of legislation in 2000 that banned disposal of combustible waste in landfills. Therefore, an increasing amount of municipal solid waste is being incinerated, with emissions reported under source 1A1 Energy industries rather than sector 5 Waste. Altogether, “waste-related” emissions (including emissions from all waste management activities reported in 1 Energy, 3 Agriculture, and 5 Waste) are increasing since 1994 and show a stagnation since 2006 (see Figure 7-3 in chp. 7.1).

The total emissions from sector 6 Other (fire damages) show fluctuations within a range of about 15% throughout the reporting period. Emissions from sector 6 Other account for well below 1‰ of total emissions and are not accounted for under the Kyoto Protocol.

Table 2-4 Greenhouse gas emissions (excluding indirect $CO_2$) in $CO_2$ equivalent (kt) by individual source (positive numbers) and sink (negative numbers) categories.

| Source and Sink Categories | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | |
| 1 Energy | 41'842 | 41'899 | 42'219 | 43'981 | 43'212 |
| 1A1 Energy industries | 2'519 | 2'642 | 3'172 | 3'816 | 3'846 |
| 1A2 Manufacturing industries and construction | 6'570 | 6'295 | 6'007 | 6'041 | 5'865 |
| 1A3 Transport | 14'690 | 14'314 | 15'981 | 15'855 | 16'336 |
| 1A4 Other sectors | 17'481 | 18'056 | 16'550 | 17'819 | 16'751 |
| 1A5 Other | 220 | 163 | 151 | 139 | 137 |
| 1B Fugitive emissions from fuels | 362 | 429 | 358 | 311 | 278 |
| 2 Industrial processes and product use | 4'012 | 3'421 | 3'784 | 4'432 | 4'530 |
| 3 Agriculture | 6'582 | 6'371 | 5'984 | 5'934 | 6'053 |
| 5 Waste | 1'118 | 919 | 892 | 938 | 862 |
| 6 Other | 12 | 12 | 13 | 14 | 12 |
| Total (excluding LULUCF) | 53'566 | 52'622 | 52'892 | 55'299 | 54'670 |
| 4. Land use, land-use change and forestry | -2'044 | -3'941 | 5'187 | -2'875 | -2'932 |
| Total (including LULUCF) | 51'522 | 48'680 | 58'079 | 52'424 | 51'737 |

| Source and Sink Categories | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | *2020 vs. 1990* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | | | | | | | *%* |
| 1 Energy | 39'155 | 40'546 | 41'472 | 37'423 | 37'090 | 37'489 | 36'503 | 35'210 | 35'087 | 32'651 | *-22.0%* |
| 1A1 Energy industries | 3'598 | 3'640 | 3'735 | 3'605 | 3'291 | 3'376 | 3'294 | 3'357 | 3'366 | 3'276 | *30.0%* |
| 1A2 Manufacturing industries and construction | 5'436 | 5'433 | 5'499 | 5'097 | 4'979 | 4'986 | 4'950 | 4'792 | 4'705 | 4'499 | *-31.5%* |
| 1A3 Transport | 16'159 | 16'273 | 16'188 | 16'081 | 15'344 | 15'182 | 14'920 | 14'926 | 14'883 | 13'577 | *-7.6%* |
| 1A4 Other sectors | 13'555 | 14'808 | 15'682 | 12'275 | 13'124 | 13'587 | 12'992 | 11'793 | 11'799 | 10'968 | *-37.3%* |
| 1A5 Other | 125 | 132 | 133 | 139 | 135 | 139 | 128 | 127 | 115 | 119 | *-45.6%* |
| 1B Fugitive emissions from fuels | 282 | 259 | 235 | 225 | 218 | 219 | 219 | 216 | 219 | 212 | *-41.5%* |
| 2 Industrial processes and product use | 4'533 | 4'517 | 4'524 | 4'533 | 4'479 | 4'423 | 4'586 | 4'454 | 4'406 | 4'198 | *4.6%* |
| 3 Agriculture | 6'011 | 6'013 | 5'954 | 6'069 | 5'994 | 5'957 | 5'936 | 5'882 | 5'783 | 5'757 | *-12.5%* |
| 5 Waste | 840 | 810 | 821 | 809 | 780 | 749 | 716 | 697 | 687 | 674 | *-39.8%* |
| 6 Other | 13 | 14 | 14 | 12 | 12 | 12 | 13 | 14 | 11 | 12 | *-4.9%* |
| Total (excluding LULUCF) | 50'552 | 51'901 | 52'786 | 48'845 | 48'355 | 48'631 | 47'754 | 46'257 | 45'974 | 43'291 | *-19.2%* |
| 4. Land use, land-use change and forestry | -1'244 | -2'488 | -2'021 | -303 | -2'167 | -2'132 | -1'895 | -905 | -2'116 | -1'705 | *-16.6%* |
| Total (including LULUCF) | 49'309 | 49'414 | 50'765 | 48'542 | 46'188 | 46'500 | 45'859 | 45'352 | 43'858 | 41'586 | *-19.3%* |

The percentage shares of source categories are shown for selected years in Table 2-5 whereas Figure 2-4 to Figure 2-6 are graphical representations of the data in Table 2-4. For the time series of the source categories of sector 1 Energy see chp. 3.

Table 2-5 Greenhouse gas emissions (excluding LULUCF, excluding indirect $CO_2$) in $CO_2$ equivalent (kt) and the relative contribution (%) of individual source categories.

| **Source and Sink Categories** | **1990** | | **1995** | | **2000** | | **2005** | | **2010** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % |
| 1 Energy | 41'842 | 78.1% | 41'899 | 79.6% | 42'219 | 79.8% | 43'981 | 79.5% | 43'212 | 79.0% |
| *1A1 Energy industries* | 2'519 | *4.7%* | 2'642 | *5.0%* | 3'172 | *6.0%* | 3'816 | *6.9%* | 3'846 | 7.0% |
| *1A2 Manufacturing industries and construction* | 6'570 | *12.3%* | 6'295 | *12.0%* | 6'007 | *11.4%* | 6'041 | *10.9%* | 5'865 | *10.7%* |
| *1A3 Transport* | 14'690 | *27.4%* | 14'314 | *27.2%* | 15'981 | *30.2%* | 15'855 | *28.7%* | 16'336 | *29.9%* |
| *1A4 Other sectors* | 17'481 | *32.6%* | 18'056 | *34.3%* | 16'550 | *31.3%* | 17'819 | *32.2%* | 16'751 | *30.6%* |
| *1A5 Other* | 220 | *0.4%* | 163 | *0.3%* | 151 | *0.3%* | 139 | *0.3%* | 137 | *0.3%* |
| *1B Fugitive emissions from fuels* | 362 | *0.7%* | 429 | *0.8%* | 358 | *0.7%* | 311 | *0.6%* | 278 | *0.5%* |
| 2 Industrial processes and product use | 4'012 | 7.5% | 3'421 | 6.5% | 3'784 | 7.2% | 4'432 | 8.0% | 4'530 | 8.3% |
| 3 Agriculture | 6'582 | 12.3% | 6'371 | 12.1% | 5'984 | 11.3% | 5'934 | 10.7% | 6'053 | 11.1% |
| 5 Waste | 1'118 | 2.1% | 919 | 1.7% | 892 | 1.7% | 938 | 1.7% | 862 | 1.6% |
| 6 Other | 12 | 0.0% | 12 | 0.0% | 13 | 0.0% | 14 | 0.0% | 12 | 0.0% |
| Total (excluding LULUCF) | 53'566 | 100.0% | 52'622 | 100.0% | 52'892 | 100.0% | 55'299 | 100.0% | 54'670 | 100.0% |

| **Source and Sink Categories** | **2016** | | **2017** | | **2018** | | **2019** | | **2020** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % | kt $CO_2$ eq | % |
| 1 Energy | 37'489 | 77.1% | 36'503 | 76.4% | 35'210 | 76.1% | 35'087 | 76.3% | 32'651 | 75.4% |
| *1A1 Energy industries* | 3'376 | *6.9%* | 3'294 | *6.9%* | 3'357 | *7.3%* | 3'366 | *7.3%* | 3'276 | *7.6%* |
| *1A2 Manufacturing industries and construction* | 4'986 | *10.3%* | 4'950 | *10.4%* | 4'792 | *10.4%* | 4'705 | *10.2%* | 4'499 | *10.4%* |
| *1A3 Transport* | 15'182 | *31.2%* | 14'920 | *31.2%* | 14'926 | *32.3%* | 14'883 | *32.4%* | 13'577 | *31.4%* |
| *1A4 Other sectors* | 13'587 | *27.9%* | 12'992 | *27.2%* | 11'793 | *25.5%* | 11'799 | *25.7%* | 10'968 | *25.3%* |
| *1A5 Other* | 139 | *0.3%* | 128 | *0.3%* | 127 | *0.3%* | 115 | *0.3%* | 119 | *0.3%* |
| *1B Fugitive emissions from fuels* | 219 | *0.4%* | 219 | *0.5%* | 216 | *0.5%* | 219 | *0.5%* | 212 | *0.5%* |
| 2 Industrial processes and product use | 4'423 | 9.1% | 4'586 | 9.6% | 4'454 | 9.6% | 4'406 | 9.6% | 4'198 | 9.7% |
| 3 Agriculture | 5'957 | 12.2% | 5'936 | 12.4% | 5'882 | 12.7% | 5'783 | 12.6% | 5'757 | 13.3% |
| 5 Waste | 749 | 1.5% | 716 | 1.5% | 697 | 1.5% | 687 | 1.5% | 674 | 1.6% |
| 6 Other | 12 | 0.0% | 13 | 0.0% | 14 | 0.0% | 11 | 0.0% | 12 | 0.0% |
| Total (excluding LULUCF) | 48'631 | 100.0% | 47'754 | 100.0% | 46'257 | 100.0% | 45'974 | 100.0% | 43'291 | 100.0% |

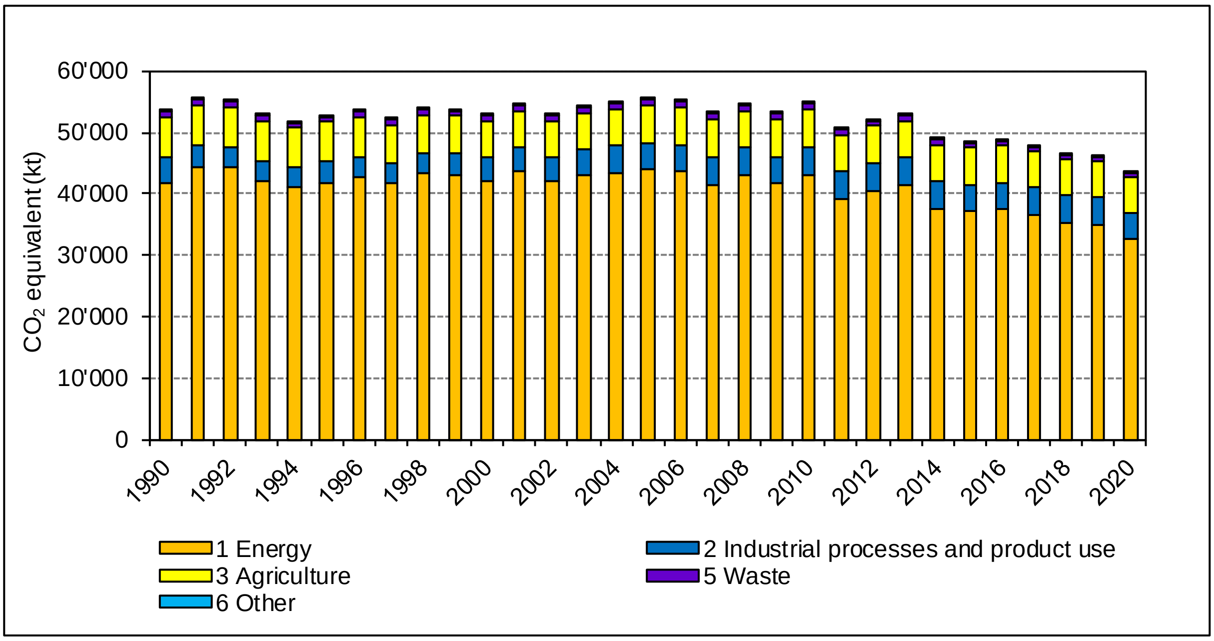


Figure 2-4 Greenhouse gas emissions in $CO_2$ equivalent (kt) by sectors (excluding LULUCF, excluding indirect $CO_2$).

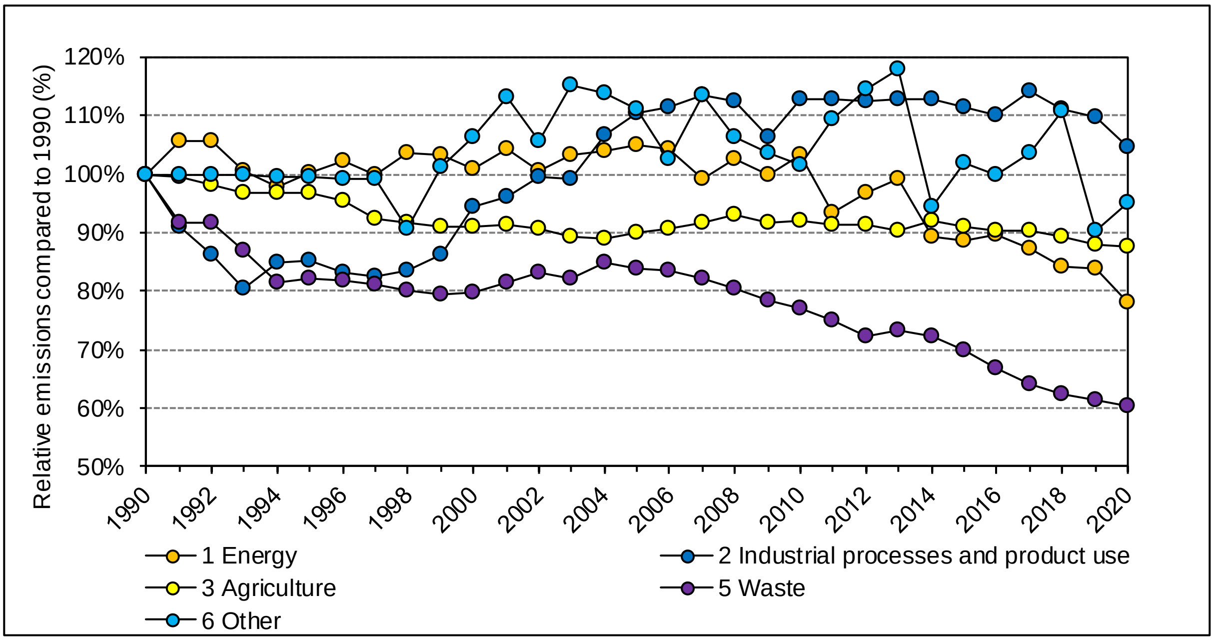


Figure 2-5 Relative emission trends ($CO_2$ eq; excluding indirect $CO_2$) by main source categories (base year 1990 = 100%).

## 2.3.2. Emission trends in sector 1 Energy

The main source categories within sector 1 Energy – representing the major sources of Switzerland's GHG emissions – are shown in Figure 2-6 and Table 2-5.

The following emission trends emerge within the sector 1 Energy:

- Despite differing trends of individual source categories, the overall emissions from the sector 1 Energy remain at a relatively constant level (orange/bold line in Figure 2-6) in the period 1990–2006. Afterwards, the trend is determined by a combination of effective reduction measures and a decreasing trend of heating degree days (see Figure 2-7; see further details below under 1A1 Energy industries and 1A4 Other sectors).
- It is noteworthy that due to Switzerland's electricity production structure (mainly hydroelectric and nuclear power in 2020; see SFOE (2021), Table 24), category 1A1 Energy industries plays only a minor role. It does not represent thermal power stations as in many other countries, but primarily waste incineration plants. The increase in waste incineration is the reason why overall emissions from source category 1A1 Energy industry are higher in 2020 than in 1990. The time series shows an increase until 2006 and a slight decrease thereafter. Fluctuations are caused by varying combustion activities for district heating. The stepwise emission reduction in 2015 was due to the closure of one of two refineries (see Figure 2-6 and values in Table 2-5).
- Emissions from 1A2 Manufacturing industries show a decreasing trend since 1990, mainly due to continuous changes in the use of fuel types for stationary combustion (see table 3-43).
- The increasing trend of emissions in source category 1A3 Transport between 1990 and 2008 is based on increasing traffic volumes (in all different types of transport). The effect of increasing energy efficiency of vehicles was unable to counterbalance the substantial growth in transport. The decrease of transport emissions since 2008

as well as the drop from 2014 to 2015 is largely caused by decreasing fuel tourism (EV 2015a) (see chp. 3.2.9.2.2). The strong decrease between 2019 and 2020 can be attributed to the COVID-19 pandemic, when a lockdown and further measures reduced traffic volumes, in particular of passenger cars.

- The trend for source category 1A4 Other sectors reflects the impact of climatic variations on energy demand for heating in stationary source-categories (1A4ai/bi/ci). The strong correlation with the number of "heating degree days" (see box 1 on page 68) – used as an index of cold weather conditions over the year – is apparent from Figure 2-7, which shows $CO_2$ emissions from source category 1A4 Other sectors (only stationary sources) and the number of heating degree days. Since 2002, heating degree days and $CO_2$ emissions are clearly drifting apart, which indicates that additional effects like reduction measures contribute to emission reductions (see Figure 2-7). In the period 1990–2020, the number of buildings and apartments increased as well as the average floor space per person and workplace. Both phenomena result in an increase in the total area heated by more than forty percent (FOEN 2021l). Over the same period, however, higher standards were specified for insulation and for combustion equipment efficiency for both new and renovated buildings, compensating for the emissions from the additional area heated.
- $CO_2$ emissions from 1A5 Other mainly stem from military aircraft and therefore show almost the same decreasing trend as the use of jet kerosene within this source-category (see Table 3-93).
- The development of $CO_2$ equivalent emissions in 1B are dominated by the trend of the $CH_4$ emissions from leakage in the natural gas distribution network. From 1990 to 1994, emissions increased due to network expansion. Thereafter, emissions decreased substantially due to gradual replacement of old pipelines.

**Box 1: Heating degree days**

Heating degree days: a standardized measure for linking heating demand and weather conditions. Number of degrees per day calculated as the difference between 20°C (room temperature) and the daily average outdoor temperature for such days where the daily average temperature is below 12°C (e.g. daily outdoor average equals 7°C, then for that day 20 - 7 = 13). The number of degrees per day are summed up for a year t to yield the heating degree days of year t.

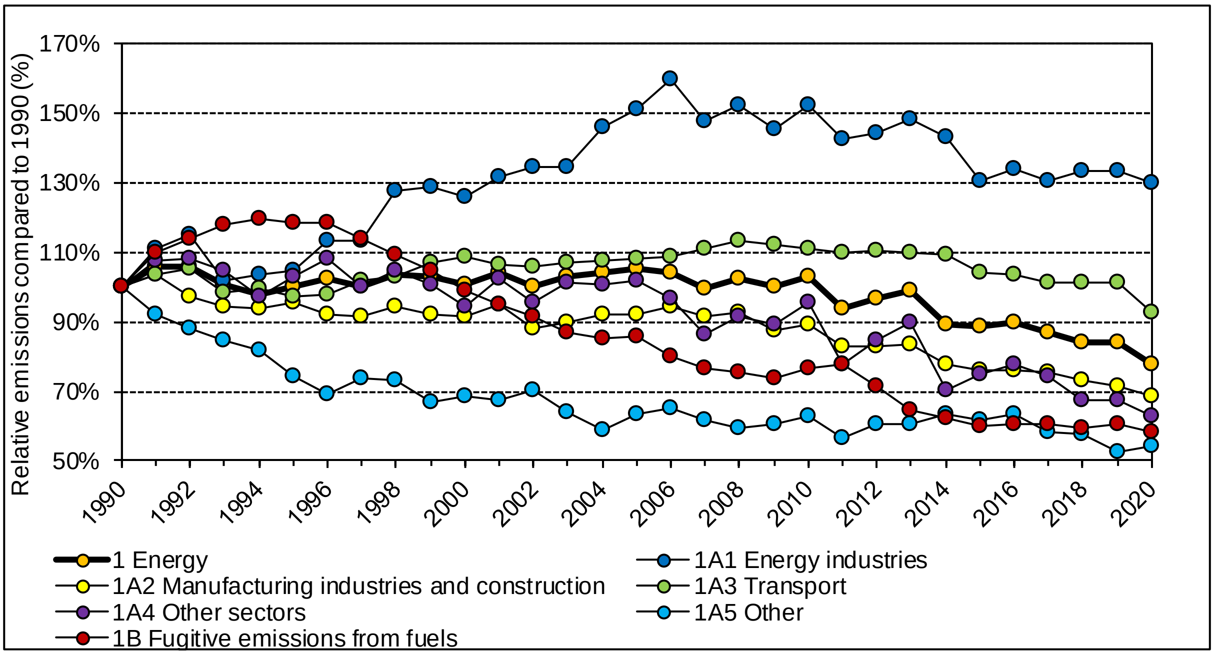


Figure 2-6 Emission trends ($CO_2$ eq) for the source categories in sector 1 Energy. The trend for the entire sector 1 Energy is represented by the bold line with orange bullets.

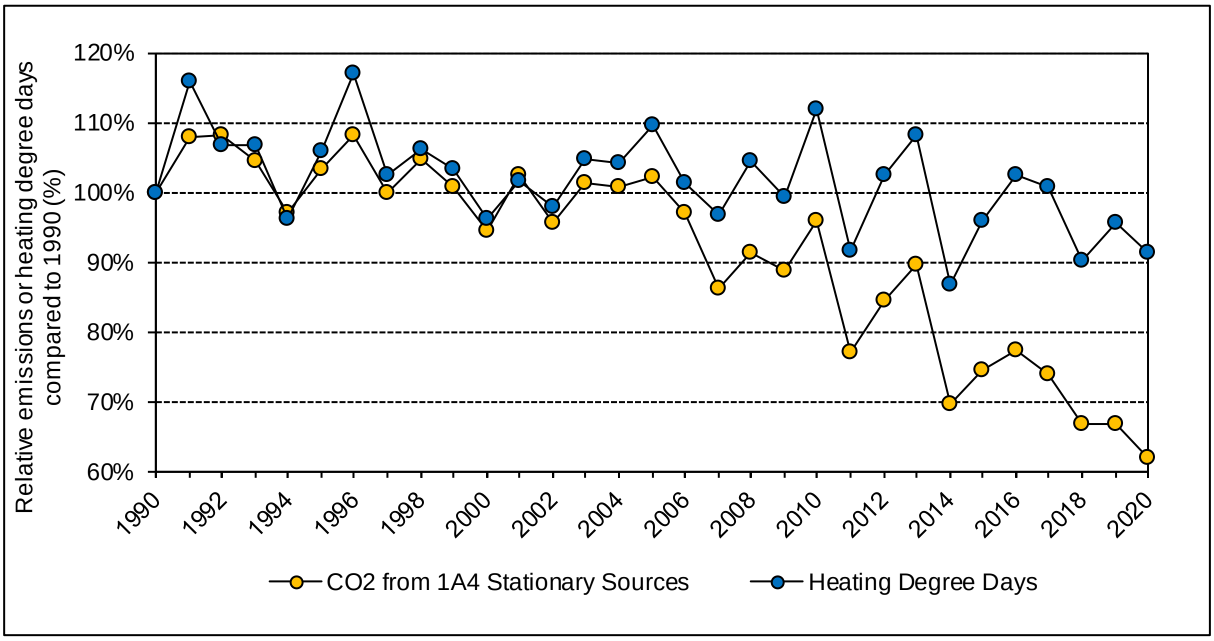


Figure 2-7 Relative trend for $CO_2$ emissions from 1A4 Fuel Combustion – Other Sectors (stationary sources only) compared with the number of heating degree days.

### 2.3.3. Emission trends in sector 4 LULUCF

Figure 2-8 illustrates the net $CO_2$ eq emissions and removals in sector 4 LULUCF. Associated data are given in Table 2-4.

The GHG fluxes are reported for six land-use categories: 4A Forest land, 4B Cropland, 4C Grassland, 4D Wetlands, 4E Settlements and 4F Other land. The carbon stock of 4G

Harvested wood products made from Swiss wood is also recorded. $CO_2$ is the most important greenhouse gas by far in the LULUCF sector. $CH_4$ and $N_2O$ from fires, soil organic matter decomposition, reservoirs and drained organic soils make a minor contribution to the emissions (see Figure 6-2). With the exception of 2000, Switzerland's land use resulted in more $CO_2$ eq being absorbed from the atmosphere by the soil and vegetation than were emitted (Figure 2-8, see also Figure 2-9, Figure 6-1 and Figure 6-3). Quantitatively, most $CO_2$ eq removals were achieved in the decade between 1990 and 1999.

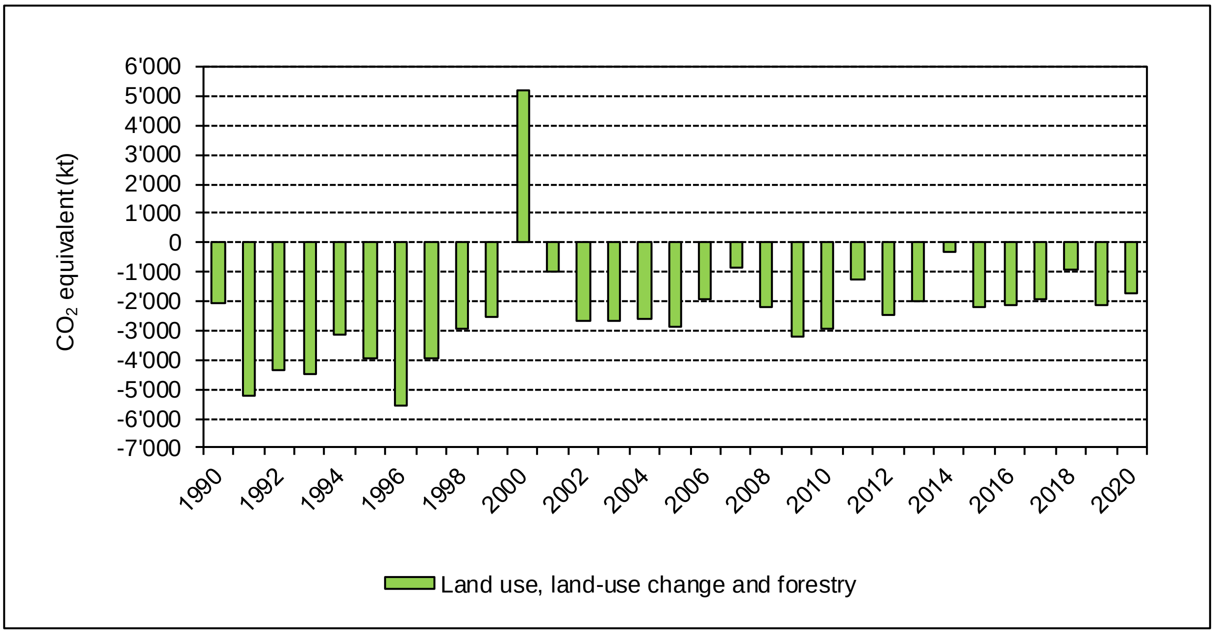


Figure 2-8 Net GHG ($CO_2$, $CH_4$, $N_2O$) emissions and removals of sector 4 Land use, land-use change and forestry (LULUCF), in kt $CO_2$ eq. Positive values refer to net emissions, negative values refer to net removals.

4A: Forest land dominates the GHG balance of Switzerland's land use. Most years, management of Forest land resulted in a distinct increase in the total carbon stocks in living biomass, dead wood, litter and forest soils (i.e. a net removal of $CO_2$ from the atmosphere; Figure 2-9). Salvage logging following severe storms (Vivian in February 1990, Lothar in December 1999) and the rise in harvested volumes in some years (e.g. 2006, 2007) are clearly recognisable. In 2008 harvesting rates dropped (Table 6-14) due to the international and domestic economic framework conditions and remained relatively constant thereafter with interannual fluctuation of ca. 2 to 8%. These fluctuations are reflected in the year-to-year variability of the removals from Forest management. The relatively small net removals in 2011, 2014 and 2018 are due to comparably high harvesting rates in conjunction with above-average carbon losses in the litter pool related to climatic circumstances (see Figure 6-6).

4G: In terms of climate policy, sustainable forest management can be achieved by using the wood grown in a cascade, firstly for long-lived harvested wood products and subsequently for energy purposes. In almost all years since 1990, more wood has been incorporated into new products (such as construction timber or wood panels) than has been released from old ones. However, the size of the annual net $CO_2$ removals from harvested wood products decreased clearly since 2011. In 2013 and 2019 HWP fluxes resulted in net $CO_2$ emissions (see Figure 2-9 and Figure 6-14 for details).

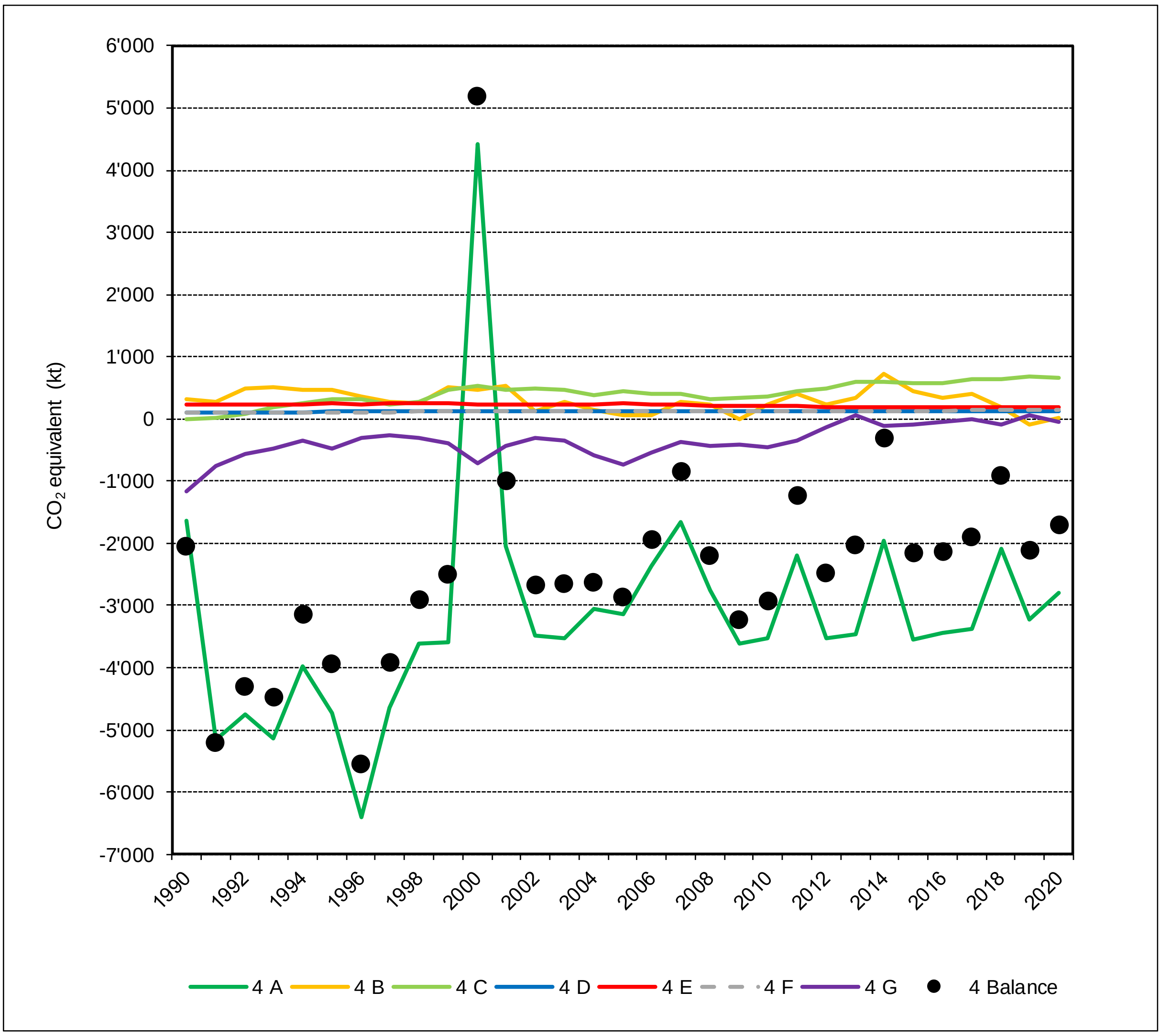


Figure 2-9 Net GHG ($CO_2$, $CH_4$, $N_2O$) emissions and removals in the LULUCF sector (in kt $CO_2$ eq) broken down by categories 4A-4G. "Balance" reflects the annual mean. Positive values refer to net emissions, negative values refer to net removals.

4B, 4C:The agricultural use of Cropland and Grassland affects the carbon stocks of the soil. For example, ploughing promotes the decomposition of soil organic matter, whereas spreading farmyard manure or leaving harvest residues on the fields increases soil carbon stocks. As well as the farming method, the main factors influencing the annual fluctuations are the crops grown and the climatic conditions. The case of drained former peatlands is a special one. When subjected to intense agricultural use, these organic soils release large amounts of $CO_2$ and $N_2O$. In both category 4B Cropland and category 4C Grassland, the 1990–2020 patterns of net $CO_2$ eq emissions and removals caused by carbon dynamics in living biomass and in mineral soils are pushed towards an overall net $CO_2$ eq source by persistently high emissions from organic soils. As a consequence, categories 4B and 4C show weakly to moderately fluctuating net $CO_2$ eq emissions at an intermediate level over most of the inventory period (Figure 2-9).

4D: Unproductive wetlands only account for a small part of the land area. As most remaining peatland are impaired by the consequences of previous use (particularly drainage), many organic soils are now net GHG sources. $CO_2$ eq emissions in category 4D are comparatively low and increased by 24.5% over the inventory period (Figure 2-9).

4E: The development of new settlements and infrastructure resulted in comparatively low and slowly fluctuating $CO_2$ eq emissions since 1990 (-18.0% change from 1990 to 2020) (Figure 2-9). Emissions in category 4E are mainly produced by loss of plant biomass and soil organic carbon during construction work.

4F: $CO_2$ eq emissions in 4F2 Land converted to other land increased by 47.0% between 1990 and 2020 (Figure 2-9). Mudflows, erosion, landslides, and dynamic changes in stream beds were identified as the main processes causing these land-use changes. The contribution to the GHG balance of the LULUCF sector remains small.

## 2.4. Emission trends for precursor gases

The methodologies concerning calculation of emissions of the precursor gases $NO_x$, CO, NMVOC and $SO_2$ are provided in detail in Switzerland's Informative Inventory Report (FOEN 2022b). Emission trends for precursor gases (IPCC 2006, Volume 1, Chapter 7) show a very pronounced decline (see Table 2-6 and Figure 2-10). A strict air pollution control policy and the implementation of a large number of emission reduction measures led to decreasing emissions of precursor gases over the period 1990–2020.

Overall, the most effective reduction measures were the abatement of exhaust emissions from road vehicles and stationary installations and the incentive taxes on VOC (since 2000) and on fossil combustible fuels (since 2008). The latter measure was (jointly) responsible for the significant shift in the fuel mix of standard fossil fuels in industry from solid and liquid fuels to natural gas and the almost complete disappearance of residual fuel oil. As a result, $NO_x$, NMVOC and CO emissions clearly declined between 1980 and 2020.

Furthermore, due to legal restriction of sulphur content in liquid fuels and decrease in coal consumption, a decreasing trend can also be observed for $SO_x$ emissions. The lowering of the maximum sulphur content in liquid fuels is shown in Table A – 13, whereas the time series of Switzerland's decreasing coal consumption is given in Table 3-12. Both trends resulted in a considerable reduction of the $SO_x$ emissions. Annual fluctuations of $SO_x$ emissions occur mainly due to annual variations of heating degree days, which affects the consumption of gas oil.

Table 2-6 Emissions of precursor gases (kt) (excluding NOx, CO and NMVOC from LULUCF).

| Precursor gases and $SO_2$ | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | kt | | | | |
| $NO_x$ | 144 | 115 | 102 | 93 | 84 |
| CO | 817 | 532 | 418 | 320 | 255 |
| NMVOC | 302 | 205 | 154 | 113 | 99 |
| $SO_2$ | 37 | 26 | 16 | 14 | 10 |

| Precursor gases and $SO_2$ | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | *2020 vs. 1990* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | kt | | | | | | | | | | *%* |
| $NO_x$ | 80 | 80 | 80 | 76 | 71 | 70 | 66 | 62 | 59 | 53 | *-63%* |
| CO | 231 | 223 | 215 | 194 | 185 | 185 | 178 | 169 | 168 | 152 | *-81%* |
| NMVOC | 95 | 92 | 90 | 86 | 83 | 81 | 80 | 79 | 78 | 76 | *-75%* |
| $SO_2$ | 8.3 | 8.5 | 7.9 | 7.2 | 5.5 | 5.1 | 4.9 | 4.7 | 4.3 | 3.8 | *-90%* |

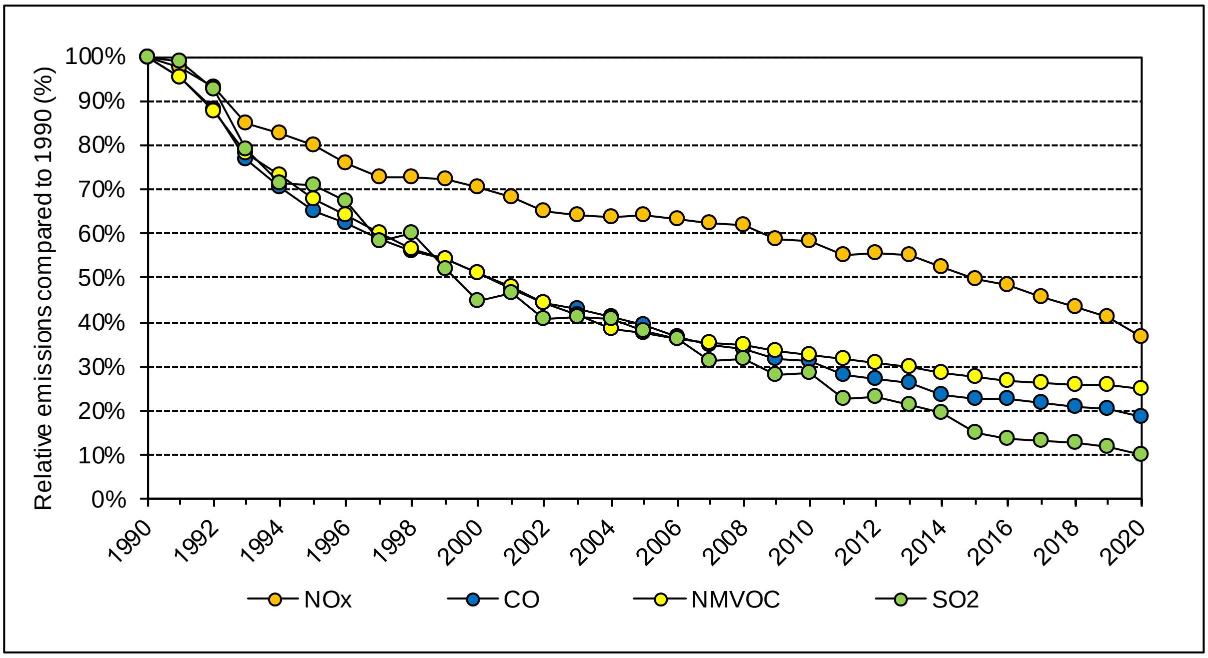


Figure 2-10: Relative trends for precursor gas emissions (excluding $NO_x$, CO and NMVOC from LULUCF; base year 1990 = 100%).

Sector 1 Energy is by far the largest source of precursor gas emissions (see Table 2-7), with the only exception being NMVOC, where sector 4 LULUCF is the dominant source followed by sector 2 Industrial processes and product use (see Figure 2-11).

Table 2-7: Precursor gas emissions (kt) by source category in 2020. Totals include LULUCF emissions.

| **Sectors** | **$NO_x$** | | **CO** | | **NMVOC** | | **$SO_2$** | |
|---|---|---|---|---|---|---|---|---|
| | kt | % | kt | % | kt | % | kt | % |
| 1 Energy | 49 | 92.3% | 142 | 92.8% | 15 | 10.6% | 3.2 | 85.0% |
| 2 IPPU | 0.23 | 0.4% | 8.4 | 5.5% | 40 | 27.3% | 0.52 | 13.9% |
| 3 Agriculture | 3.7 | 7.0% | NA | NA | 19 | 13.1% | NA | NA |
| 4 LULUCF | 0.016 | 0.0% | 0.54 | 0.4% | 69 | 47.8% | 0.00085 | 0.023% |
| 5 Waste | 0.12 | 0.2% | 1.5 | 1.0% | 1.7 | 1.2% | 0.030 | 0.8% |
| 6 Other sources | 0.014 | 0.0% | 0.63 | 0.4% | 0.10 | 0.1% | 0.010 | 0.3% |
| **Total** | **53** | **100.0%** | **153** | **100.0%** | **145** | **100.0%** | **3.8** | **100.0%** |

Figure 2-11 shows the relative contributions of the various sectors for each individual precursor gas excluding LULUCF (data deduced from Table 2-7).

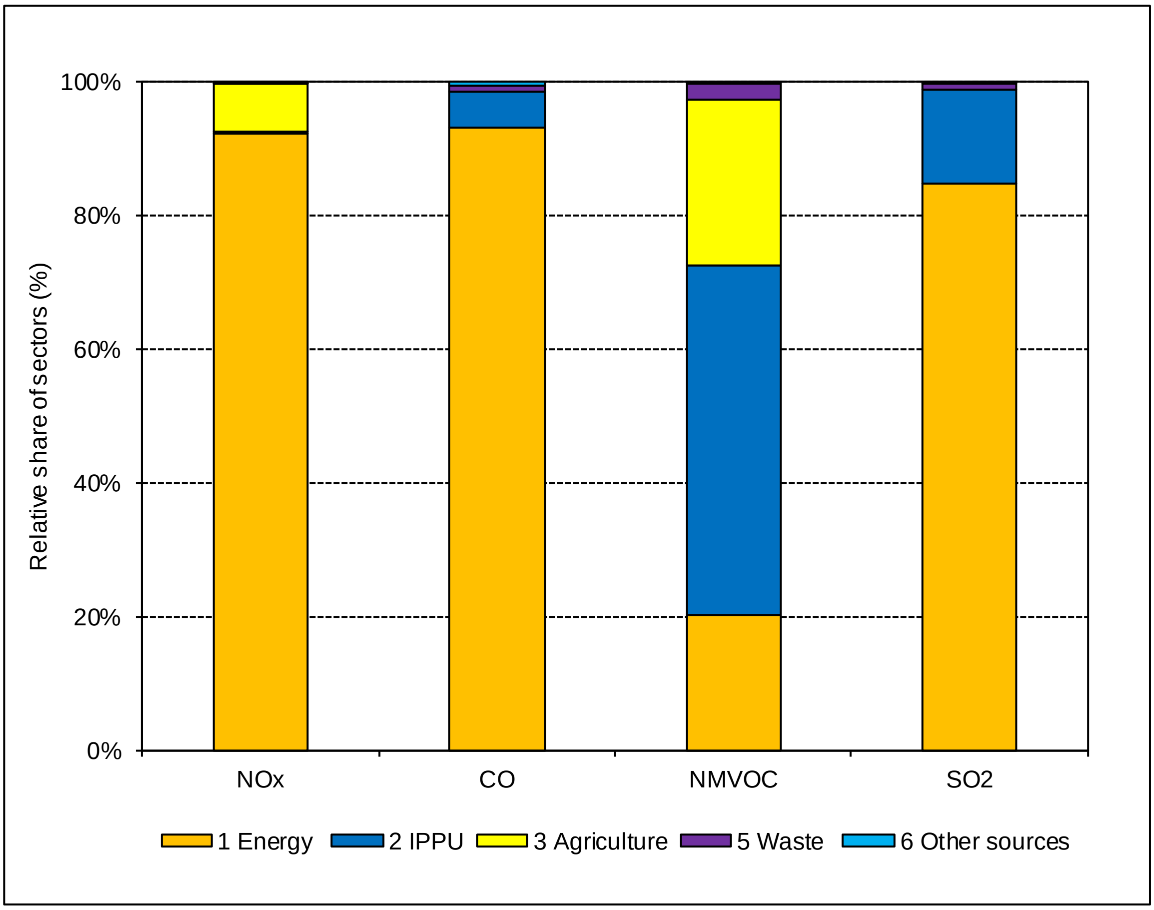


Figure 2-11: Relative contributions of individual sectors to precursor gas emissions in 2020 (excluding LULUCF, note data given in Table 2-7 especially for NMVOC).

## 2.5. Emission trends (Kyoto Protocol)

Relevant emissions and removals as accounted for under the Kyoto Protocol by sectors and GHG are shown in Table 2-8 and Table 2-9. Base year emissions for the second commitment period are reported in Switzerland's second Initial Report (FOEN 2016c) and the update to the report following the UNFCCC in-country review (FOEN 2016d).

Total emissions reported under the Kyoto Protocol differ from those reported under the UNFCCC because sectors 4 LULUCF and 6 Other and international bunkers are not accounted for under the Kyoto Protocol. However, activities under Article 3, paragraph 3 (Afforestation and Reforestation, Deforestation) and Article 3, paragraph 4 (Forest management, Cropland management, Grazing land management, Revegetation and Wetland drainage and rewetting) are taken into account. Under the activities of Article 3, paragraph 4 of the Kyoto Protocol, Switzerland only accounts for the mandatory activity Forest management.

Table 2-8 Summary of greenhouse gas emissions in $CO_2$ equivalent (kt) as well as emissions and removals under KP-LULUCF by sectors. Excluded are emissions and removals from sectors 4 LULUCF, 6 Other, and from International bunkers.

| | | **Sector** | **Base year** | **1991** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $CO_2$ equivalent (kt) | | | | | | | | | |
| Annex A sources | | 1 Energy + indirect $CO_2$ from this sector | 41'881 | 44'312 | 44'359 | 42'183 | 41'067 | 41'964 | 42'836 | 41'922 | 43'488 | 43'277 |
| | | 2 Industrial processes and product use + indirect $CO_2$ from this sector | 3'887 | 3'971 | 3'751 | 3'491 | 3'659 | 3'659 | 3'554 | 3'514 | 3'545 | 3'641 |
| | | 3 Agriculture | 6'804 | 6'551 | 6'466 | 6'378 | 6'364 | 6'371 | 6'293 | 6'082 | 6'046 | 5'999 |
| | | 5 Waste + indirect $CO_2$ from this sector | 1'135 | 1'027 | 1'026 | 974 | 913 | 920 | 917 | 908 | 898 | 889 |
| | | **Total (Annex A sources)** | **53'707** | **55'861** | **55'601** | **53'026** | **52'003** | **52'914** | **53'600** | **52'427** | **53'977** | **53'805** |

| | | **Sector** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $CO_2$ equivalent (kt) | | | | | | | | | |
| Annex A sources | | 1 Energy + indirect $CO_2$ from this sector | 42'269 | 43'672 | 43'662 | 43'264 | 43'586 | 44'019 | 43'640 | 41'594 | 42'982 | 41'879 |
| | | 2 Industrial processes and product use + indirect $CO_2$ from this sector | 3'955 | 4'018 | 4'143 | 4'121 | 4'408 | 4'552 | 4'585 | 4'672 | 4'621 | 4'382 |
| | | 3 Agriculture | 5'984 | 6'019 | 5'969 | 5'883 | 5'861 | 5'934 | 5'972 | 6'031 | 6'125 | 6'028 |
| | | 5 Waste + indirect $CO_2$ from this sector | 893 | 914 | 933 | 921 | 950 | 939 | 937 | 919 | 900 | 878 |
| | | **Total (Annex A sources)** | **53'101** | **54'623** | **54'706** | **54'189** | **54'805** | **55'444** | **55'134** | **53'216** | **54'629** | **53'168** |
| KP-LULUCF | Art.3.3 | Afforestation & Reforestation | | | | | | | | | -25 | -26 |
| | | Deforestation | | | | | | | | | 177 | 181 |
| | Art.3.4 | Forest management | | | | | | | | | -2763 | -3'613 |
| | | Cropland management | | | | | | | | | NA | NA |
| | | Grazing land management | | | | | | | | | NA | NA |
| | | Revegetation | | | | | | | | | NA | NA |
| | | Wetland drainage and rewetting | | | | | | | | | NA | NA |

| | | **Sector** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | ***2020 vs. base year*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $CO_2$ equivalent (kt) | | | | | | | | | | | *%* |
| Annex A sources | | 1 Energy + indirect $CO_2$ from this sector | 43'244 | 39'186 | 40'576 | 41'499 | 37'450 | 37'116 | 37'515 | 36'528 | 35'234 | 35'112 | 32'675 | *-16%* |
| | | 2 Industrial processes and product use + indirect $CO_2$ from this sector | 4'643 | 4'644 | 4'624 | 4'626 | 4'633 | 4'576 | 4'522 | 4'685 | 4'547 | 4'502 | 4'292 | *16%* |
| | | 3 Agriculture | 6'053 | 6'011 | 6'013 | 5'954 | 6'069 | 5'994 | 5'957 | 5'936 | 5'882 | 5'783 | 5'757 | *-15%* |
| | | 5 Waste + indirect $CO_2$ from this sector | 864 | 842 | 812 | 823 | 810 | 781 | 750 | 717 | 699 | 688 | 675 | *-39%* |
| | | **Total (Annex A sources)** | **54'804** | **50'682** | **52'025** | **52'903** | **48'962** | **48'467** | **48'745** | **47'866** | **46'362** | **46'085** | **43'399** | ***-14%*** |
| KP-LULUCF | Art.3.3 | Afforestation & Reforestation | -24 | -22 | -21 | -20 | -17 | -18 | -18 | -17 | -15 | -17 | -16 | |
| | | Deforestation | 184 | 185 | 186 | 187 | 187 | 186 | 186 | 193 | 194 | 195 | 196 | |
| | Art.3.4 | Forest management | -3'565 | -2'083 | -3'209 | -2'965 | -1'593 | -3'147 | -3'018 | -2'916 | -1'679 | -2'659 | -2'330 | |
| | | Cropland management | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | |
| | | Grazing land management | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | |
| | | Revegetation | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | |
| | | Wetland drainage and rewetting | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | |

Table 2-9 Contribution of individual gases to total emissions (excluding 4 LULUCF, 6 Other, and International bunkers) in $CO_2$ equivalent (kt), as well as net emissions and removals under KP-LULUCF. HFC emissions increased by more than 5 million percent when compared to 1990 levels.

| | | GHG | Base year | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $CO_2$ equivalent (kt) | | | | | | | | | |
| Annex A sources | | $CO_2$ + indirect $CO_2$ | 44'516 | 46'522 | 46'378 | 43'944 | 42'992 | 43'713 | 44'384 | 43'305 | 44'863 | 44'669 |
| | | $CH_4$ | 6'086 | 5'731 | 5'666 | 5'564 | 5'505 | 5'516 | 5'469 | 5'327 | 5'267 | 5'185 |
| | | $N_2O$ | 2'852 | 3'368 | 3'320 | 3'330 | 3'298 | 3'330 | 3'340 | 3'289 | 3'213 | 3'242 |
| | | HFCs | 0.025 | 1.5 | 16 | 33 | 80 | 244 | 296 | 360 | 456 | 533 |
| | | PFCs | 117 | 99 | 81 | 35 | 21 | 17 | 20 | 21 | 24 | 32 |
| | | $SF_6$ | 137 | 139 | 141 | 121 | 107 | 93 | 90 | 125 | 153 | 140 |
| | | $NF_3$ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| | | **Total (Annex A sources)** | **53'707** | **55'861** | **55'601** | **53'026** | **52'003** | **52'914** | **53'600** | **52'427** | **53'975** | **53'802** |

| | | GHG | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $CO_2$ equivalent (kt) | | | | | | | | | |
| Annex A sources | | $CO_2$ + indirect $CO_2$ | 43'833 | 45'273 | 43'647 | 44'816 | 45'391 | 45'925 | 45'518 | 43'509 | 44'847 | 43'671 |
| | | $CH_4$ | 5'140 | 5'173 | 5'128 | 5'050 | 5'036 | 5'077 | 5'090 | 5'071 | 5'146 | 5'044 |
| | | $N_2O$ | 3'276 | 3'253 | 3'322 | 3'181 | 3'105 | 3'132 | 3'107 | 3'149 | 3'071 | 2'949 |
| | | HFCs | 636 | 736 | 826 | 910 | 1'009 | 1'048 | 1'160 | 1'253 | 1'275 | 1'272 |
| | | PFCs | 61 | 37 | 36 | 67 | 69 | 50 | 62 | 52 | 45 | 35 |
| | | $SF_6$ | 152 | 151 | 161 | 166 | 195 | 213 | 197 | 182 | 245 | 188 |
| | | $NF_3$ | NO | NO | NO | NO | NO | NO | NO | NO | 0.12 | 7.6 |
| | | **Total (Annex A sources)** | **53'099** | **54'623** | **53'120** | **54'189** | **54'805** | **55'444** | **55'134** | **53'216** | **54'629** | **53'168** |
| KP-LULUCF | Art.3.3 | $CO_2$ | | | | | | | | | 149 | 153 |
| | | $CH_4$ | | | | | | | | | NO | NO |
| | | $N_2O$ | | | | | | | | | 2.9 | 3.1 |
| | Art.3.4 | $CO_2$ | | | | | | | | | -2766.7 | -3'617 |
| | | $CH_4$ | | | | | | | | | 2.7 | 2.7 |
| | | $N_2O$ | | | | | | | | | 1.2 | 1.2 |

| | | GHG | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | ***2020 vs. base year*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $CO_2$ equivalent (kt) | | | | | | | | | | | *%* |
| Annex A sources | | $CO_2$ + indirect $CO_2$ | 45'181 | 41'116 | 42'378 | 43'306 | 39'351 | 38'844 | 39'300 | 38'292 | 36'980 | 36'845 | 34'350 | *-17%* |
| | | $CH_4$ | 5'018 | 4'967 | 4'946 | 4'874 | 4'865 | 4'838 | 4'804 | 4'746 | 4'711 | 4'632 | 4'587 | *-24%* |
| | | $N_2O$ | 3'085 | 3'005 | 2'980 | 2'987 | 2'968 | 2'973 | 2'904 | 3'058 | 2'926 | 2'994 | 2'902 | *5%* |
| | | HFCs | 1'308 | 1'380 | 1'453 | 1'432 | 1'469 | 1'508 | 1'481 | 1'504 | 1'525 | 1'429 | 1'387 | *see caption* |
| | | PFCs | 38 | 36 | 39 | 28 | 23 | 26 | 20 | 32 | 36 | 32 | 34 | *-73%* |
| | | $SF_6$ | 161 | 169 | 230 | 276 | 285 | 278 | 236 | 233 | 183 | 152 | 138 | *11%* |
| | | $NF_3$ | 13 | 9.3 | 0.54 | 0.14 | 0.60 | 0.73 | 0.77 | 0.80 | 0.50 | 0.54 | 0.41 | *NA* |
| | | **Total (Annex A sources)** | **54'804** | **50'682** | **52'025** | **52'903** | **48'962** | **48'467** | **48'745** | **47'866** | **46'362** | **46'085** | **43'399** | ***-14%*** |
| KP-LULUCF | Art.3.3 | $CO_2$ | 158 | 160 | 162 | 165 | 166 | 164 | 165 | 172 | 175 | 174 | 176 | |
| | | $CH_4$ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | |
| | | $N_2O$ | 3.2 | 3.3 | 3.3 | 3.4 | 3.5 | 3.5 | 3.6 | 3.6 | 3.7 | 3.7 | 3.7 | |
| | Art.3.4 | $CO_2$ | -3'568 | -2'089 | -3'212 | -2'968 | -1'596 | -3'151 | -3'025 | -2'921 | -1'683 | -2'662 | -2'333 | |
| | | $CH_4$ | 2.3 | 4.0 | 2.2 | 2.2 | 2.4 | 2.4 | 5.0 | 3.1 | 2.5 | 2.0 | 1.9 | |
| | | $N_2O$ | 0.98 | 2.1 | 0.97 | 0.95 | 1.1 | 1.1 | 2.8 | 1.6 | 1.2 | 0.85 | 0.80 | |

# 3. Energy

| Responsibilities for sector Energy | |
|---|---|
| Overall responsibility | Anouk-Aimée Bass (FOEN) |
| Experts for source-categories | Anouk-Aimée Bass (FOEN; Overview, Stationary sources in 1A1, 1A4, Bunker fuels, Country-specific issues, Mobile sources in 1A2-1A5), Daiana Leuenberger (FOEN; Waste related processes), Benedict Notter (INFRAS; Non-road and Road transportation), Sabine Schenker (FOEN; Sectoral/Reference Approach, Feedstocks and non-energy use of fuels, Wood combustion, 1A2 (stationary)), Adrian Schilt (FOEN; Country-specific issues Fuel consumption, Industry Model), Theo Rindlisbacher (FOCA; Civil Aviation) |
| EMIS database operation | Anouk-Aimée Bass (FOEN), Sabine Schenker (FOEN) |
| Annual updates (NIR text, tables, figures) | Dominik Eggli (Meteotest), Anna Ehrler (INFRAS), Pascal Graf (Meteotest), Beat Rihm (Meteotest), Regine Röthlisberger (FOEN), Adrian Schilt (FOEN), Felix Weber (INFRAS) |
| Quality control NIR (annual updates) | Dominik Eggli (Meteotest), Benedict Notter (INFRAS; Non-road and Road transportation), Regine Röthlisberger (FOEN), Adrian Schilt (FOEN), Felix Weber (INFRAS) |
| Internal review | Anouk-Aimée Bass (FOEN), Daiana Leuenberger (FOEN; Waste related processes), Theo Rindlisbacher (FOCA; Civil Aviation), Regine Röthlisberger (FOEN), Sabine Schenker (FOEN), Adrian Schilt (FOEN) |

## 3.1. Overview

This chapter provides information on the estimation of the greenhouse gas emissions from the sector 1 Energy. The following source categories are reported:

- 1A Fuel combustion
- 1B Fugitive emissions from fuels

In Switzerland, the sector 1 Energy is the most relevant source of greenhouse gases. The emissions of the period 1990–2020 are illustrated in Figure 3-1 and Table 3-1.

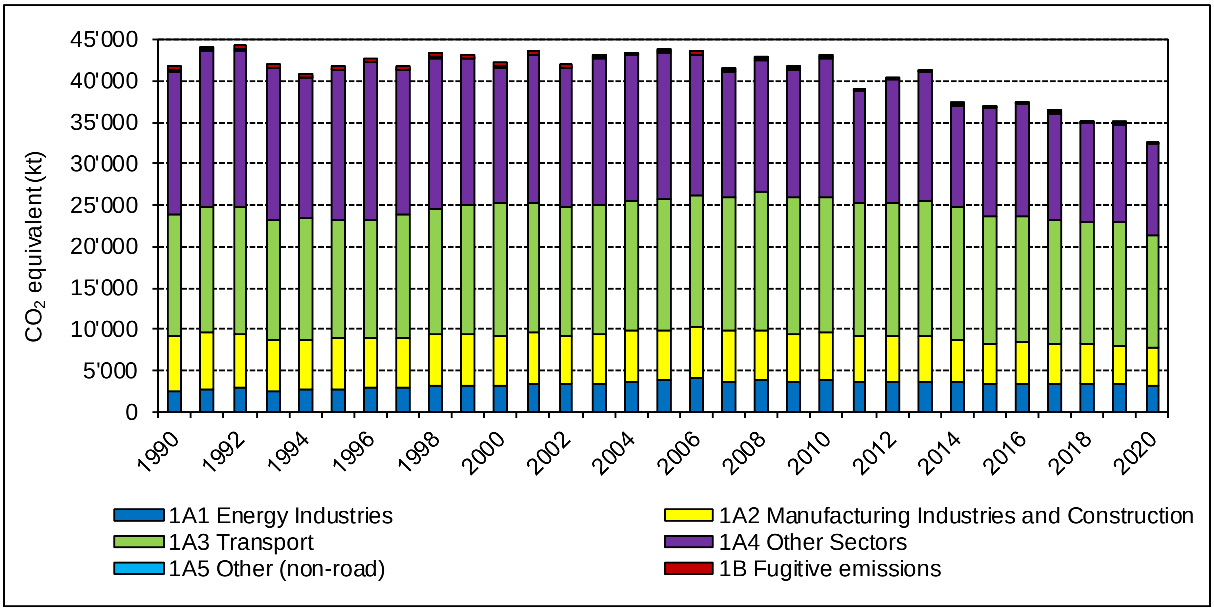


Figure 3-1 Switzerland's GHG emissions of sector 1 Energy in $CO_2$ equivalent (kt).

Considering total emissions of sector 1 Energy, fluctuations with no trend are observed in the period 1990–2005. From 2006 onwards, a decreasing trend can be identified, again superposed by fluctuations. The year 2020 shows the lowest value of the entire period 1990–2020. The following source categories contribute to the total emissions (see also Figure 2-6 and explanations in chp. 2.3.2):

- 1A3 Transport and 1A4 Other sectors are the main sources of the sector 1 Energy with 1A3 Transport being to most important category over the last years. Emissions in 1A3 Transport increased after 1990, reaching a maximum in 2008 and decreasing again to the 1990 level thereafter. Emissions from 1A4 Other sectors are strongly influenced by meteorological conditions in winter. A systematic decrease of emissions from 1A4 is observed since 2005.
- 1A1 Energy industries and 1A2 Manufacturing industries and construction contribute to total emissions as well, but are less important. Emissions in 1A1 Energy industries increased until 2006 with no clear trend since then except for a stepwise reduction in 2015, when one of two refineries closed. Emissions from 1A2 Manufacturing industries are gradually decreasing since 1990.
- 1A5 Other (Military) and 1B Fugitive emissions from fuels play only a minor role. Both categories show a decrease since 1990.

The trends of the individual gases are given in Table 3-1 and Figure 3-2:

- By far the most important gas emitted from sector 1 Energy is $CO_2$. Fluctuations reflect inter alia the climatic variability in Switzerland (see Figure 2-7 and related comments). A decreasing trend is observed since approximately 2005, predominantly due to the decrease in 1A4 Other sectors, but also due to decreasing fuel tourism and the closure of one refinery in 2015. The strong reduction of $CO_2$ emissions in 2020 compared to previous years is a result of the measures to contain the COVID-19 pandemic leading to reduced $CO_2$ emissions from source category 1A3b Road transportation and mild winter temperatures leading to reduced emissions from source category 1A4 Other sectors.

- The decreasing trend of $CH_4$ emissions in the energy sector since 1990 is the result of improved gas transmission and distribution networks, resulting in substantially lower fugitive emissions, and reduced emissions from gasoline passenger cars due to catalytic converters. Furthermore, improved combustion technologies in 1A4 Other sectors – stationary sources also contribute to the decreasing trend.
- The changes in $N_2O$ emissions can mainly be explained by changes in the emission of road transportation due to changes in emission factors for diesel oil and gasoline combustion. The first generation of catalytic converters generated $N_2O$ as an unintended by-product in the exhaust gases, leading to an increase in $N_2O$ emissions until 1997. With new converter materials being used, the emission factors are decreasing since 2001 with strongest reduction in the course of the introduction of the Euro 3 standard during 2003 and 2004 (see Figure 3-2). The massive effective reduction of the maximum sulphur content of the fuels from 2003 to 2004 led to a higher efficiency of the catalytic converters, which additionally strengthened the effect (see Table A – 13). Since 2007, the $N_2O$ emissions are slightly increasing in line with increasing mileages (see Table 3-76). For further details, see chp. 3.2.9.2.2.

Table 3-1 GHG emissions of source category 1 Energy by gas in $CO_2$ equivalent (kt)

| Gas | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | |
| $CO_2$ | 40'907 | 40'924 | 41'346 | 43'340 | 42'610 |
| $CH_4$ | 618 | 612 | 500 | 413 | 365 |
| $N_2O$ | 317 | 363 | 372 | 229 | 237 |
| Sum | 41'842 | 41'899 | 42'219 | 43'981 | 43'212 |

| Gas | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2019 vs. 2020 | 1990 vs. 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CO2 equivalent (kt) | | | | | | | | | | % | |
| $CO_2$ | 38'595 | 39'987 | 40'920 | 36'911 | 36'578 | 36'965 | 35'982 | 34'692 | 34'569 | 32'150 | -7% | -21% |
| $CH_4$ | 336 | 323 | 310 | 284 | 283 | 285 | 279 | 273 | 269 | 262 | -3% | -58% |
| $N_2O$ | 224 | 236 | 243 | 228 | 229 | 239 | 242 | 244 | 249 | 239 | -4% | -25% |
| Sum | 39'155 | 40'546 | 41'472 | 37'423 | 37'090 | 37'489 | 36'503 | 35'210 | 35'087 | 32'651 | -7% | -22% |

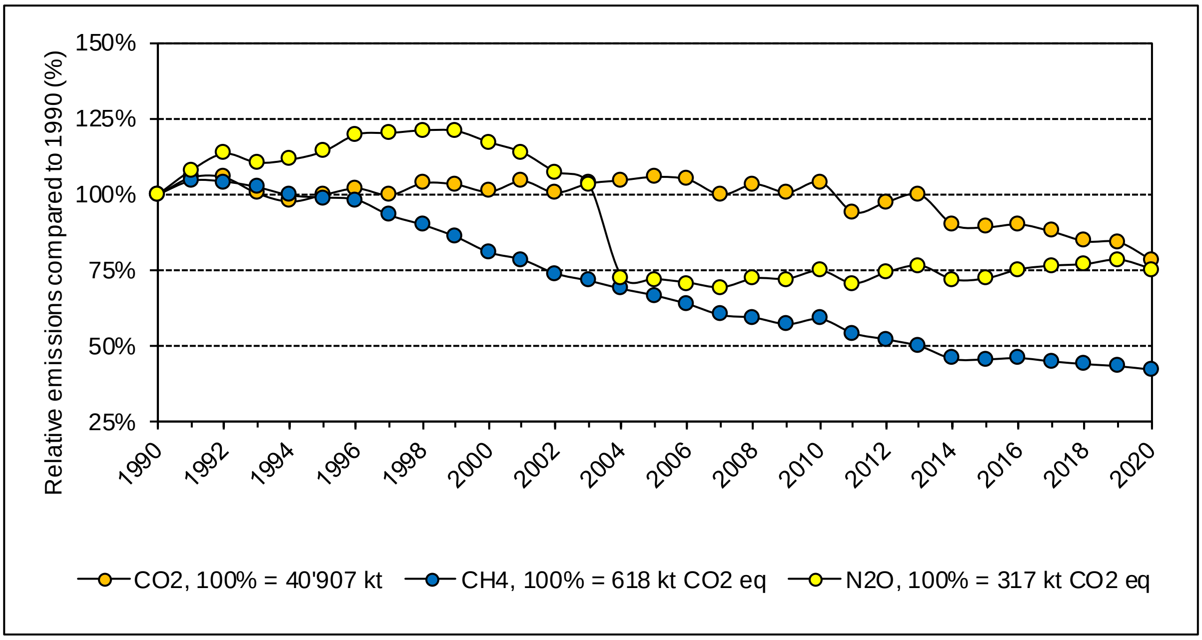


Figure 3-2 Relative trends of the greenhouse gas emissions of sector 1 Energy. The base year 1990 represents 100%.

The following table summarises the emissions of sector 1 Energy in 2020. The table also includes in two additional lines emissions from international bunkers (aviation and marine) as well as $CO_2$ emissions from biomass burning, which both are not accounted for under the Kyoto Protocol but are included in the reporting tables.

Table 3-2 Summary of sector 1 Energy, emissions in 2020 in kt $CO_2$ equivalent (Total: rounded values). For full biomass $CO_2$ emissions see Table 3-21.

| **Sector Energy** | **$CO_2$** | **$CH_4$** | **$N_2O$** | ***Total*** |
|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | |
| 1 Energy | 32'150 | 262 | 239 | *32'651* |
| 1A Fuel combustion | 32'124 | 76 | 239 | *32'439* |
| 1A1 Energy industries | 3'252 | 0.50 | 23 | *3'276* |
| 1A2 Manufacturing industries and construction | 4'458 | 4.8 | 36 | *4'499* |
| 1A3 Transport | 13'435 | 19 | 123 | *13'577* |
| 1A4 Other sectors | 10'860 | 52 | 56 | *10'968* |
| 1A5b Other (mobile) | 118 | 0.036 | 1.0 | *119* |
| 1B Fugitive emissions from fuels | 26 | 185 | 0.00023 | *212* |
| International bunkers | 2'065 | 0.17 | 17 | *2'082* |
| $CO_2$ emissions from biomass | 7'787 | - | - | *7'787* |

In 2020, a total of 46 key source categories are identified in the Swiss greenhouse gas inventory (Table 1-9). Amongst these, 19 belong to sector 1 Energy. The key categories for approaches 1 and 2 (according to level and trend) from sector 1 Energy are shown in Figure 3-3. While 19 categories are identified as key according to approach 1, only 3 categories are (also) identified as key according to approach 2. Indeed, Sector 1 Energy is the major sector in term of emissions, while sector 3 Agriculture and 4 LULUCF dominate the uncertainty contribution (see also Figure 5-3 to compare with sector 3 Agriculture).

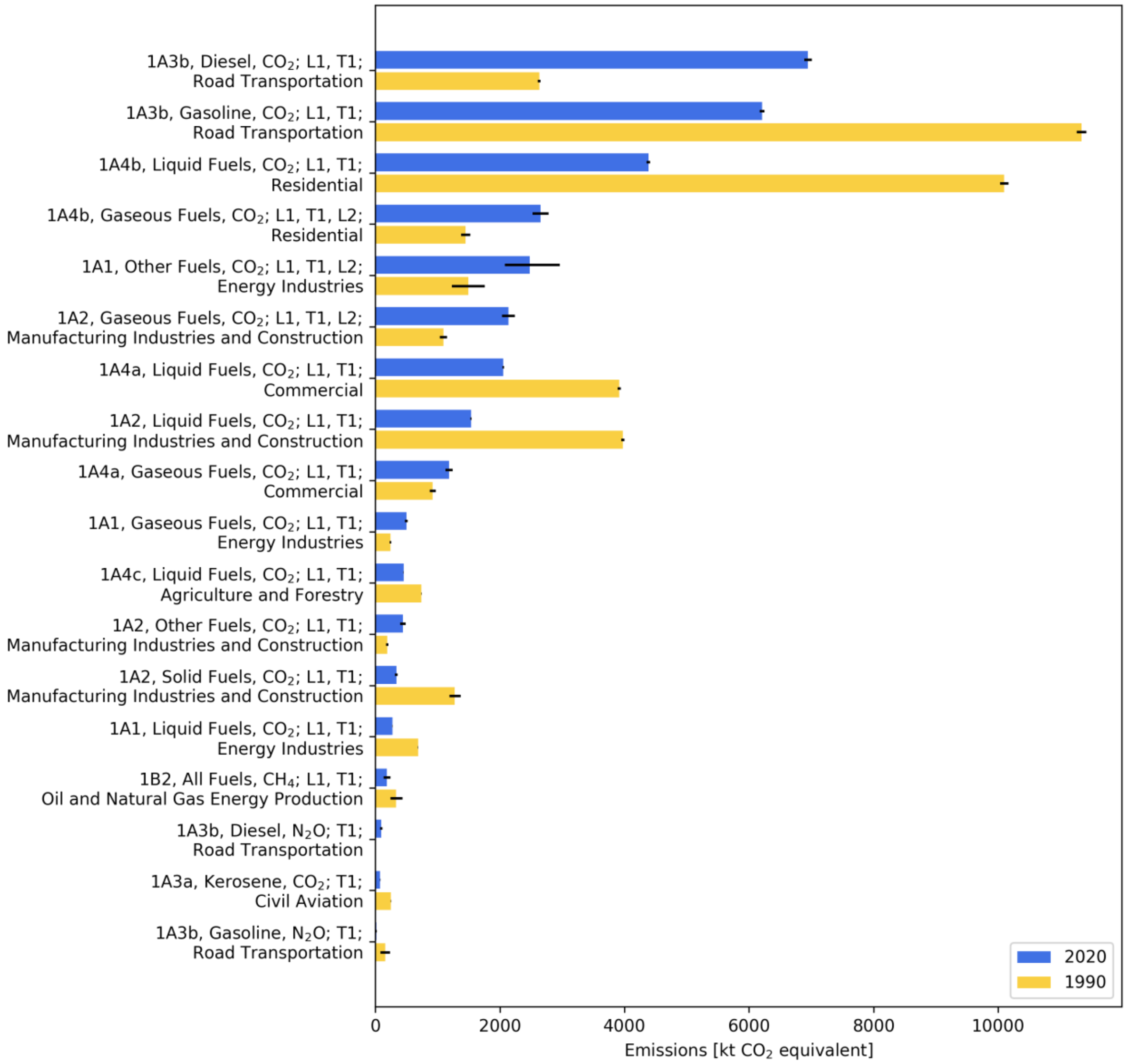


Figure 3-3 Key categories in the Swiss GHG inventory from sector 1 Energy determined by the key category analyses, approaches 1 and 2. Categories are set out in order of decreasing emissions in 2020. L1: key category according to approach 1 level in 2020; L2: same for approach 2; T1: key category according to approach 1 trend 1990–2020; T2: same for approach 2. Black uncertainty bars represent the narrowest 95% confidence interval obtained by Monte Carlo simulations (see chp. 1.6 for details).

# 3.2. Source category 1A – Fuel combustion activities

## 3.2.1. Comparison of the Sectoral Approach with the Reference Approach

Two methods are applied for modelling $CO_2$ emissions from the sector 1 Energy, the Sectoral Approach and the Reference Approach. For the inventory under the Framework Convention on Climate Change and the Kyoto Protocol the Sectoral Approach is used. The Reference Approach is only used for verification purposes (quality control activity).

Figure 3-4 shows the input data used and the disaggregation of fuel types for each of the two approaches.

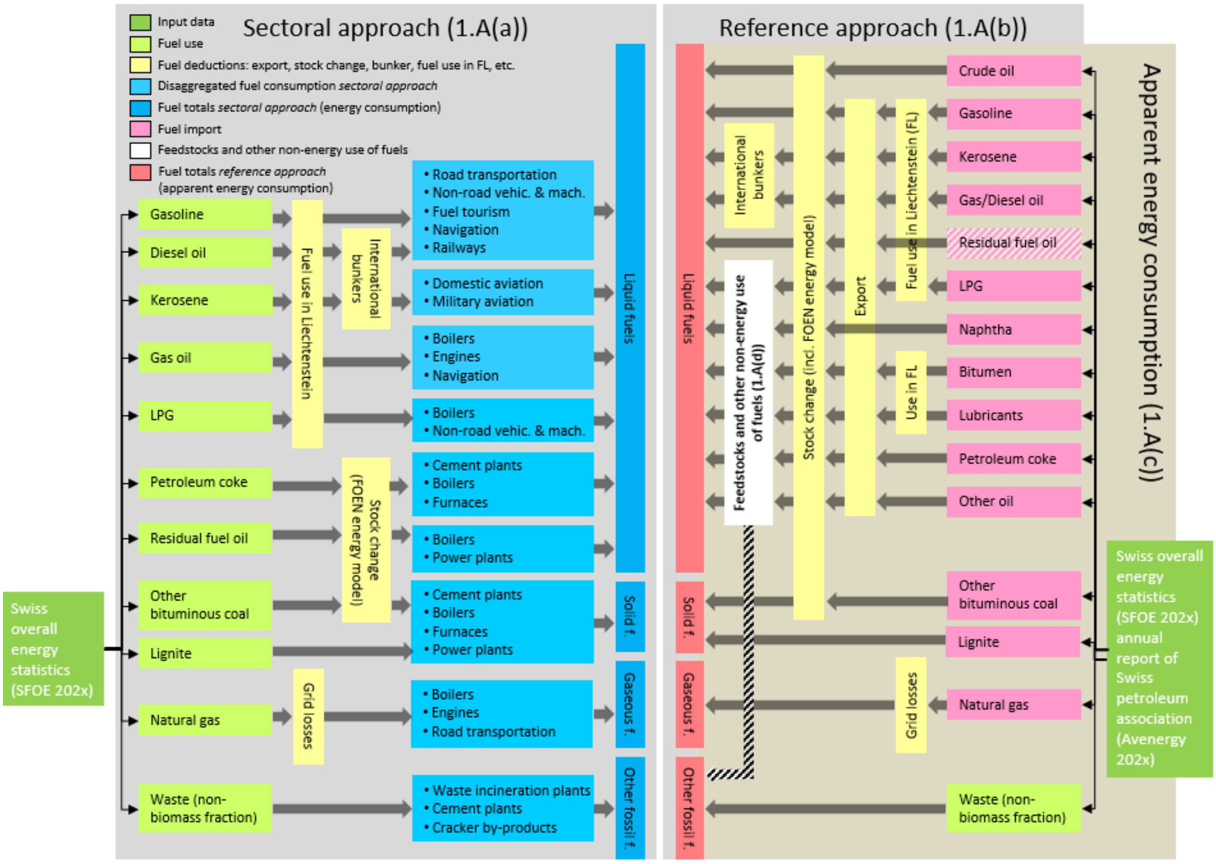


Figure 3-4 Calculation of Reference and Sectoral Approach. The input data for both approaches stem from the Swiss overall energy statistics (SFOE 2021). For the Reference Approach, additional information from Avenergy Suisse (formerly Swiss Petroleum Association) (Avenergy 2021) is used. While the Reference Approach considers the net import/export balance, the Sectoral Approach considers the fuel consumption. The dark grey arrows represent fuel deductions where occurring. The dashed arrow from the Feedstock use to Other fossil fuels stands for the $CO_2$ emissions from cracker by-products (originating from feedstock use of liquefied petroleum gas and naphtha) which are accounted for under Other fossil fuels. The graphic box of the import of Residual fuel oil is dashed since there is no more import of residual fuel oil. Coke oven coke and anthracite are included under other bituminous coal.

The Sectoral Approach is based on sectoral energy consumption data from the Swiss overall energy statistics (SFOE 2021) and additional source-specific information. In the Sectoral

Approach, fossil fuel consumption statistics are combined with bottom-up data and modelling of fuel consumption. A detailed description of the Sectoral Approach is provided in chp. 3.2.4.

The Reference Approach on the other hand corresponds to a top-down approach based on net quantities of fuel imported into Switzerland as listed in the energy supply statistics of the Swiss overall energy statistics (SFOE 2021). Apparent consumption (in tonnes) is derived from imports and exports of primary fuels (crude oil, natural gas, coal), secondary fuels (gasoline, diesel oil etc.) and stock changes. For crude oil, a constant value for carbon content and net calorific value is applied for the entire time period, although these properties may vary depending on origin. For solid, gaseous, secondary liquid and other fuels, the same carbon content values and net calorific values are applied as in the Sectoral Approach (see Table 3-10 and Table 3-11, Table 3-13 and Table 3-14 in chp. 3.2.4.2 and 3.2.4.4). After the deduction of feedstocks and non-energy use of fuels (see chp. 3.2.3), the net carbon emissions and effective $CO_2$ emissions are calculated for the Reference Approach as shown in the reporting tables 1.A(b)–1.A(d). The oxidation factor is set to one (see chp. 3.2.4.4.1). The Reference Approach covers the $CO_2$ emissions of all net imported primary fuels and emissions of imported secondary fuels. In 2014, 44% of all liquid fossil fuels sold in Switzerland (without kerosene) were produced in Swiss refineries. In 2015 after closing of one refinery, the share dropped down to 30% (EV 2016) and has since declined further (Avenergy 2021). In addition, the reporting tables 1.A(b) provide information of the Reference Approach of total biomass use as well as consumption of so-called other non-fossil fuels (biogenic waste) in Switzerland.

All necessary data for calculating the Reference Approach are implemented in the EMIS database and all the data on import, export, bunkers, stock changes, apparent consumption, carbon emission factors, carbon stored and actual emissions are calculated in the EMIS database under the following conditions:

- For the Reference Approach, gas oil and diesel oil are reported together, since the reporting table template structure requires this aggregation. Accordingly, a weighted average NCV is calculated based on values given in Table 3-10. In contrast, marine bunkers consist of diesel oil only and are reported using the country-specific NCV as of Table 3-10.
- Liechtenstein's liquid fossil fuel consumption is subtracted from the input figures in SFOE (2021), as the Swiss overall energy statistics includes Liechtenstein's liquid fuel consumption as well (customs union with Switzerland) (see also chp. 3.2.4). The same holds for the non-energy use of bitumen and lubricants.

The differences in energy consumption and $CO_2$ emissions between Reference and Sectoral Approach are calculated within the EMIS database. For the entire period, they are below 1% for energy consumption and in the range of about 1% for $CO_2$ emissions, as shown in Table 3-3 and in Figure 3-5. Various effects influence the difference between Reference and Sectoral Approach. On the one hand, energy and carbon contents of crude oil may vary over time. However, no data are available to quantify this effect. On the other hand, the efficiency of refineries and the market share of secondary fuel imports potentially influence the difference between the Reference and Sectoral Approach. Apparent differences between the Reference Approach and the IEA energy statistics (IEA 2012) are discussed in Annex A4.2.

Table 3-3 Differences in energy consumption and $CO_2$ emissions between the Reference and the Sectoral Approach. The difference is calculated according to [(RA-SA)/SA] * 100% with RA = Reference Approach, SA = Sectoral Approach.

| | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | % | | | | |
| Energy consumption | 0.6 | 0.8 | 0.4 | 0.5 | 0.5 |
| $CO_2$ emissions | 0.8 | 0.9 | 0.7 | 0.8 | 1.0 |

| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| | % | | | | | | | | | |
| Energy consumption | 0.5 | 0.4 | 0.4 | 0.4 | 0.2 | 0.5 | 0.2 | 0.2 | 0.5 | 0.1 |
| $CO_2$ emissions | 1.0 | 0.8 | 0.9 | 1.0 | 0.6 | 1.1 | 0.8 | 0.9 | 1.0 | 0.4 |

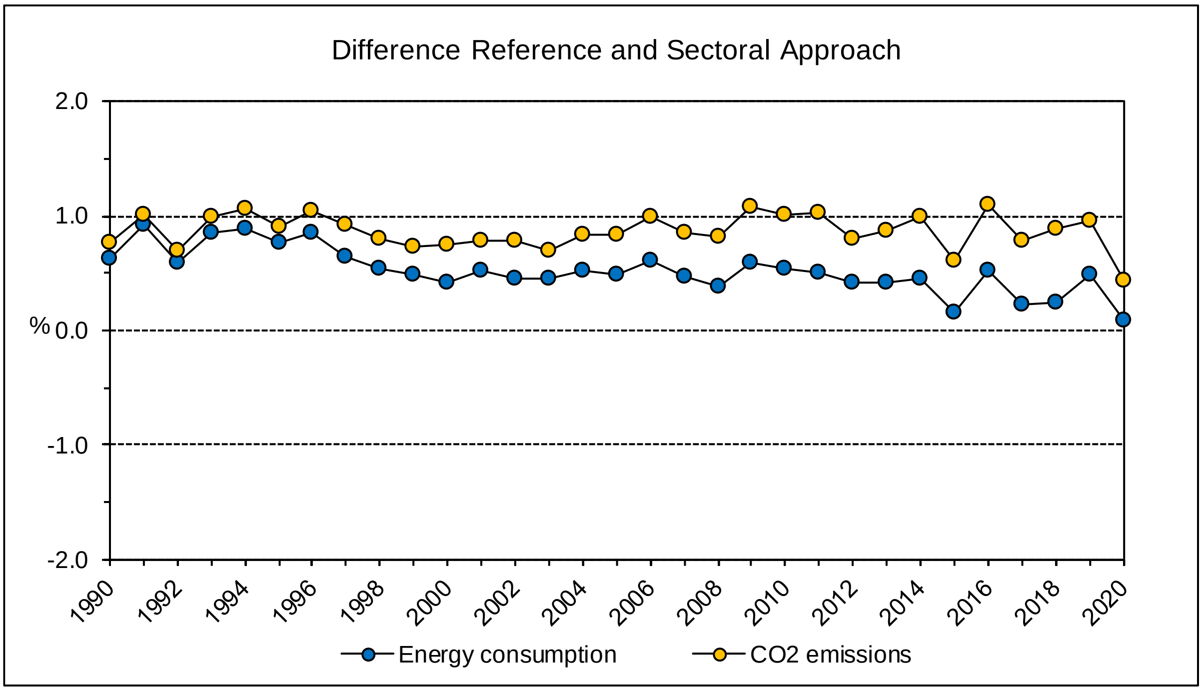


Figure 3-5 Time series for the differences between Reference and Sectoral Approach. Numbers are taken from Table 3-3. See caption there for further information.

### 3.2.1.1. Category-specific recalculations for the Reference Approach

The following recalculations were implemented in submission 2021. Recalculations are also described in the relevant chapters of the sectoral approach or the chapter on feedstock and non-energy use of fuels if they have an impact.

- 1AD/1AB: The feedstock use of lubricants and paraffin changed in 2019 due to revised domestic sales figures in the annual report of the Swiss petroleum association (Avenergy 2021). This also led to changes in the feedstock use of other oil.
- 1AB: The import of crude oil, gasoline, jet kerosene, gas/diesel oil, liquefied petroleum gas, naphtha, lubricants and petroleum coke changed in 2019, in addition for lubricants also in 2018 due to revised data in the Swiss overall energy statistics (SFOE 2021) and the annual report of the Swiss petroleum association (Avenergy 2021). This also led to changes in the import of other oil for 2018–2019.

- 1AB: The import of natural gas changed in 2019 due to revised data in the Swiss overall energy statistics (SFOE 2021).
- 1AB: The export of liquefied petroleum gas, bitumen and lubricants changed in 2019, 2018 and 2018–2019, respectively, due to revised data in the Swiss overall energy statistics (SFOE 2021) and the annual report of the Swiss petroleum association (Avenergy 2021). This also led to changes in the export of other oil for 2018–2019.
- 1AB: The stock change of gasoline and residual fuel oil changed in 2019 due to revised data in the Swiss overall energy statistics (SFOE 2021).

## 3.2.2. International bunker fuels (1D)

### 3.2.2.1. Source category description for 1D

With Switzerland being a landlocked country, international aviation dominates emissions from bunker fuels by far. International navigation is limited to activities on the river Rhine (Basel – Rotterdam) and navigation on Lake Geneva (bordering France) and Lake Constance (bordering Germany and Austria).

Table 3-4 Source category description of International bunkers.

| 1D | Source category | Specification |
|---|---|---|
| 1D1 | International aviation (aviation bunkers) | Bunker fuels include fuel used for international aviation only. |
| 1D2 | International navigation (marine bunkers) | Marine bunkers of the Rhine river and navigation on the Lake Geneva and the Lake Constance. |

### 3.2.2.2. Methodological issues for 1D

#### *3.2.2.2.1. International aviation / aviation bunkers (1D1)*

Following the decision tree of the 2006 IPCC Guidelines (IPCC 2006, Volume 2 Energy, chp. 3 Mobile Combustion, Figure 3.6.1), the emissions from aviation bunkers are calculated with a Tier 3A method because of availability of data on the origin and destination of flights and also on air traffic movements delivered by the Federal Office of Civil Aviation (FOCA).

The Tier 3A method follows standard modelling procedures at the level of single aircraft movements based on detailed movement statistics. For international aviation (aviation bunkers), the flights departing from Switzerland to a destination abroad are selected. The emission factors are country-specific based on measurement and analyses of fuel samples. The activity data of the international aviation bunker are summarised in Table 3-6 (see also Table 3-73). Given that detailed information about activity data is available, the resulting fuel consumption is considered complete. In spite of this, there remain small differences between the fuel consumption modelled bottom-up and the total fuel sold (SFOE 2021, FOCA 2021). In 1990, the modelled consumption adds up to 1.01 million tonnes, whereas 1.05 million tonnes of fuel was sold. Such difference of 4% is considered acceptable, because discrepancies up to 10% can easily result from fuelling strategies of airlines (FOCA 2006a). Investigation showed, that airlines are calculating whether it is economically beneficial to refuel at a place with lower fuel price. In order to match the bottom-up calculation with the fuel quantity sold, any occurring difference is attributed to international bunker emissions. The factor between calculated international fuel consumption and adjusted international fuel consumption is used to scale the bunker emissions linearly. For instance in 2020, the bunker fuel consumption and the emissions had to be expanded by the factor 1.12, the correction factor was 0.880 (FOCA 2021). For the year 2020, the overestimation of emissions from international aviation was very high compared to previous years because the modelling of aircraft fuel consumption is based on practically fully loaded aircraft (high load). Due to exceptional measures to contain the COVID-19 pandemic during the year 2020, many flights were very lightly loaded which in terms of aircraft led to slightly lower fuel consumption per route. More direct flight paths (low traffic volume) may be another reason. These effects relate almost exclusively to international flights. For the more recent years, the modelled and actual total fuel sales are listed in Table 3-5.

Table 3-5 Comparison between modelled and actual fuel sales in bunker fuel consumption (FC) for aviation.

| Modelled and actual fuel sales | Unit | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|
| Modelled fuel sales domestic | FC in t | 43'968 | 37'627 | 39'626 | 39'252 |
| Modelled fuel sales international | FC in t | 1'287'062 | 1'391'656 | 1'345'919 | 1'395'428 |
| Actual fuel sales SFOE minus modelled fuel sales domestic | FC in t | 1'289'152 | 1'382'835 | 1'324'224 | 1'390'824 |
| Correction factor for emission international | | 0.967 | 0.967 | 0.954 | 0.969 |
| Overestimation emission international (modelled) | % | 3.3% | 3.3% | 4.6% | 3.1% |

| Modelled and actual fuel sales | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Modelled fuel sales domestic | FC in t | 42'047 | 43'414 | 42'064 | 44'462 | 43'680 | 44'716 | 37'985 | 36'561 | 36'357 | 25'006 |
| Modelled fuel sales international | FC in t | 1'511'279 | 1'527'522 | 1'528'863 | 1'561'678 | 1'590'013 | 1'711'227 | 1'741'752 | 1'818'355 | 1'836'385 | 741'174 |
| Actual fuel sales SFOE minus modelled fuel sales domestic | FC in t | 1'488'805 | 1'523'116 | 1'539'963 | 1'549'228 | 1'602'319 | 1'679'034 | 1'723'717 | 1'823'917 | 1'846'453 | 677'093 |
| Correction factor for emission international | | 0.957 | 0.969 | 0.980 | 0.964 | 0.980 | 0.955 | 0.968 | 0.983 | 0.986 | 0.880 |
| Overestimation emission international (modelled) | % | 4.3% | 3.1% | 2.0% | 3.6% | 2.0% | 4.5% | 3.2% | 1.7% | 1.4% | 12.0% |

Table 3-6 International bunker fuels (1D1): aviation bunkers. Consumption of kerosene in TJ (Liechtenstein's kerosene consumption is subtracted, see chp. 3.2.4).

| 1D1 International aviation | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | Fuel consumption in TJ | | | | |
| 1D1 International aviation | 41'884 | 49'918 | 63'726 | 47'775 | 58'334 |
| 1990 = 100% | 100% | 119% | 152% | 114% | 139% |

| 1D1 International aviation | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Fuel consumption in TJ | | | | | | | | | |
| 1D1 International aviation | 62'461 | 63'903 | 64'709 | 65'006 | 67'333 | 70'603 | 72'824 | 77'214 | 78'196 | 28'170 |
| 1990 = 100% | 149% | 153% | 154% | 155% | 161% | 169% | 174% | 184% | 187% | 67% |

#### *3.2.2.2.2. International navigation / navigation bunkers (1D2)*

According to the decision tree concerning navigation bunkers (IPCC 2006, Volume 2 Energy, chp. 3 Mobile Combustion, Figure 3.5.1), emissions from international navigation are calculated with a Tier 2 approach for $CO_2$ (with country-specific carbon contents) and with a Tier 1 approach for $CH_4$ and $N_2O$ using IPCC default emission factors. On the river Rhine and on Lake Geneva and Lake Constance, some of the boats cross the border and go abroad (Germany, France). Fuels bought in Switzerland will therefore become bunker fuel. Accordingly, the amount of bunker diesel oil is reported as a memo item "International bunker / navigation".

- Only diesel oil is relevant for navigation on the river Rhine. Since there is an exemption from fuel taxation, activity data on marine river bunkers on the Rhine are well documented by the customs administration for the years 1997–2020 (SFOE 2021f).
- For navigation on two border lakes (Lake Constance, Lake Geneva), bunker fuel consumption was reported in INFRAS (2011a) after having performed surveys among the shipping companies involved. Activity data of these bunkers is summarised in Table 3-7. Data from 1995–2012 have been provided by the three navigation companies concerned as documented in INFRAS (2011a), data from 2013 onwards are constant on the 2012 level. For the years 1990 to 1994, proxies such as passenger data on a national basis had to be consulted. As marine lake bunkers provided only a minor share of the total international navigation in the early 1990s (about 7%) this approach is justified. The emission factor for $CO_2$ is country-specific and in accordance with Table 3-13.

Table 3-7 International bunker fuels (1D2): Navigation. Consumption of diesel oil in TJ.

| 1D2 International navigation | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | Fuel consumption in TJ | | | | |
| 1D2 International navigation | 821 | 739 | 531 | 579 | 514 |
| 1990 = 100% | 100% | 90% | 65% | 70% | 63% |

| 1D2 International navigation | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Fuel consumption in TJ | | | | | | | | | |
| 1D2 International navigation | 428 | 428 | 342 | 299 | 342 | 299 | 256 | 200 | 197 | 189 |
| 1990 = 100% | 52% | 52% | 42% | 36% | 42% | 36% | 31% | 24% | 24% | 23% |

### 3.2.2.3. Uncertainties and time-series consistency for 1D

International bunker fuels: see general remarks in chp. 3.2.4.7.

Consistency: Time series of 1D are all considered consistent.

### 3.2.2.4. Category-specific QA/QC and verification for 1D

The general QA/QC procedures are described in chp. 1.2.3. Furthermore QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

### 3.2.2.5. Category-specific recalculations for 1D

The following recalculation was implemented in submission 2022. Major recalculations, which contribute significantly to the total differences in GHG emissions of sector 1 Energy between the latest and the previous submissions are presented also in chp. 10.1.2.1.

- 1D2: The time series for marine bunkers has been harmonised with the data of the Swiss overall energy statistics, which led to a recalculation of diesel oil use in international navigation for all the years 1990 to 2019.

#### 3.2.2.6. Category-specific planned improvements for 1D

No category-specific improvements are planned.

### 3.2.3. Feedstocks and non-energy use of fuels

The Swiss overall energy statistics (SFOE 2021) reports feedstocks and non-energy fuel use on an aggregated level only. Some disaggregation is provided by the petroleum balance of the annual report of Avenergy Suisse (formerly Swiss petroleum association, EV) (Avenergy 2021). To complement this source, bottom-up data from annual monitoring reports of the Swiss emissions trading scheme (ETS) and from surveys of individual companies are used to provide a detailed breakdown into specific petroleum products and coal types. For submission 2015, a more differentiated breakdown of feedstocks and non-energy use of fuels was developed, which is described in an internal documentation (FOEN 2015g).

Feedstocks and non-energy use of fuels is reported in reporting tables 1.A(d) and differentiated in the following fuel types:

- Liquefied petroleum gas and naphtha are exclusively used in one single Swiss plant as feedstocks in the thermal cracking process for the production of ammonia and ethylene (see source categories 2B1 and 2B8b under chp. 4.3.2.1 and 4.3.2.4, respectively). Accordingly, activity data for liquefied petroleum gas and naphtha are confidential and included in fuel type Other oil in reporting table 1.A(d).
- Bitumen is the most important petroleum product which is used as a feedstock in Switzerland. It is mainly used for road paving with asphalt and to a lower extent in asphalt roofing (see source category 2D3 under 4.5.2.2).
- Lubricants are used in a variety of processes, including the blending with gasoline for 2-stroke engines. Two different ways of lubricant use are considered: lubricants used in 2-stroke engines are assumed to be 100% oxidised, whereas the use of all other lubricants are partly emissive. According to the 2006 IPCC Guidelines (IPCC 2006), 20% of those lubricants are oxidized during use (ODU). All $CO_2$ emissions from use of lubricants are reported under source category 2D1, see chp. 4.5.2.1.
- Petroleum coke is used as a feedstock by two consumers only, i.e. for the production of silicium carbide and graphite as well as of anodes in primary aluminium production (up to 2006) in source categories 2B5 and 2C3, respectively (see chp. 4.3.2.3 and 4.4.2.2). Apart from bottom-up information from these two consumers, top-down information is provided by Avenergy Suisse (Avenergy 2021). Activity data are confidential and included in fuel type Other oil in reporting table 1.A(d).
- Paraffin waxes for non-energy use are reported under Other oil, since there is no separate category for paraffin waxes in reporting table 1.A(d). The information used stems from the statistics of Avenergy Suisse (Avenergy 2021). Use of paraffin waxes is considered partly emissive (see source category 2D2 under chp. 4.5.2.1). According to the 2006 IPCC Guidelines (IPCC 2006), 20% of paraffin waxes are oxidized during use (ODU).
- Other oil comprises all other unspecified petroleum products for non-energy use. The net consumption of non-energy use of fuels reported in the Swiss overall energy statistics includes also sulphur produced by the refineries. This amount of sulphur is subtracted, resulting in lower fuel quantities for non-energy use of other oil for the entire time series compared to the Swiss overall energy statistics.

- Anthracite is also used as feedstock in the Swiss production plant for silicium carbide and graphite in source category 2B5 (chp. 4.3.2.3). Accordingly, activity data for anthracite are confidential and thus denoted as "C" in reporting tables 1.A(d). Based on personal communication with the relevant experts for the Swiss overall energy statistics, the feedstock use of anthracite is included in the stock changes of other bituminous coal.

Table 3-8 This table is only available in the confidential version of this chapter. It provides a complete time series of the fuel quantity, carbon excluded and the reported $CO_2$ emissions from feedstocks and non-energy use of fuels.

#### 3.2.3.1. Category-specific recalculations

There were no category-specific recalculations in 1AD.

### 3.2.4. Country-specific issues of 1A Fuel combustion

#### 3.2.4.1. System boundaries: Differences between UNFCCC and CLRTAP reporting

Switzerland uses the same data base for the Swiss greenhouse gas inventory as for the Swiss air pollution inventory and reports its greenhouse gas emissions according to the requirements of the UNFCCC as well as air pollutants according to the requirements of the CLRTAP. The nomenclature for both reportings is (almost) the same (NFR), but there are differences concerning the system boundaries. Under the UNFCCC, the national total for assessing compliance is based on fuel sold within the national territory, whereas under the CLRTAP, the national total for assessing compliance is based on fuel used within the territory.

One difference occurs for 1A3b Road transportation as can be seen from Table 3-9, columns CLRTAP / NFR Template "national total" and UNFCCC/CRF-Tables "national total" compared to CLRTAP / NFR Template "national total for compliance". The CLRTAP / NFR tables "national total for compliance" does not contain the amount of fuel sold in Switzerland but consumed abroad, which is called "fuel tourism and statistical difference", and which is accounted for in Switzerland's GHG inventory, but not in the reporting under the CLRTAP (see chp. 3.2.9.2.2). The difference between the two approaches amounts to several percent, with considerable variation from year to year due to fluctuating fuel price differences between Switzerland and its neighbouring countries.

Also, emissions from civil aviation are reported differently under the UNFCCC and the CLRTAP: Only emissions from domestic flights are accounted for under the UNFCCC, while emissions from international flights are reported as aviation bunker in 1D1. For the reporting of air pollutants under the CLRTAP, landing and take-off (LTO) cycle emissions of domestic and international flights are accounted for, while cruise emissions of international and domestic flights are reported as memo items (Table 3-9).

Table 3-9 Accounting rules for emissions from 1A3a Domestic aviation and 1A3b Road transportation under the CLRTAP and the UNFCCC.

<table>
<tr><th colspan="3" rowspan="3">Differences between reporting under CLRTAP and UNFCCC concerning the accounting to the national total</th><th colspan="3">CLRTAP / NFR tables</th><th colspan="2">UNFCCC / CRF tables</th></tr>
<tr><th colspan="5">accounted to</th></tr>
<tr><th>National total</th><th>National total for compliance</th><th>Separated information / Memo items</th><th>National total</th><th>Bunker (1D)</th></tr>
<tr><td rowspan="2">Road transportation (1A3b)</td><td rowspan="2">Fuels sold (1A3b)</td><td>Fuel used (1A3bi-v)</td><td>Yes</td><td>Yes</td><td>Yes</td><td>Yes</td><td>No</td></tr>
<tr><td>Fuel tourism and statistical differences</td><td>Yes</td><td>No</td><td>No</td><td>Yes</td><td>No</td></tr>
<tr><td rowspan="4">Aviation (1A3a)</td><td rowspan="2">Civil and domestic aviation</td><td>Landing and Take-Off (LTO)</td><td>Yes</td><td>Yes</td><td>No</td><td>Yes</td><td>No</td></tr>
<tr><td>Cruise</td><td>No</td><td>No</td><td>Yes</td><td>Yes</td><td>No</td></tr>
<tr><td rowspan="2">International aviation</td><td>Landing and Take-Off (LTO)</td><td>Yes</td><td>Yes</td><td>No</td><td>No</td><td>Yes</td></tr>
<tr><td>Cruise</td><td>No</td><td>No</td><td>Yes</td><td>No</td><td>Yes</td></tr>
</table>

### 3.2.4.2. Net calorific values (NCVs)

Table 3-10 summarizes the net calorific values (NCVs) which are used in order to convert from energy amounts in tonnes into energy quantities in gigajoules (GJ). More detailed explanations including information about the origin of the NCVs of the different fuels are given below.

Table 3-10 Net calorific values (NCVs) of various fuels. Where values for two years are indicated, the NCV is interpolated between these two years and constant NCVs are used before the first and after the second year (corresponding to the two indicated values). For the NCV of wood, a range covering all facility categories and years is provided. For the NCVs of natural gas and biogas see Table 3-11.

| **Fuel** | **Data sources** | **NCV [GJ/t]** |
|---|---|---|
| Gasoline | EMPA (1999), SFOE/FOEN (2014) | 42.5 (1998), 42.6 (2013) |
| Jet kerosene | EMPA (1999), SFOE/FOEN (2014) | 43.0 (1998), 43.2 (2013) |
| Diesel oil | EMPA (1999), SFOE/FOEN (2014) | 42.8 (1998), 43.0 (2013) |
| Gas oil | EMPA (1999), SFOE/FOEN (2014) | 42.6 (1998), 42.9 (2013) |
| Residual fuel oil | EMPA (1999) | 41.2 |
| Liquefied petroleum gas | SFOE (2021) | 46.0 |
| Petroleum coke | SFOE (2021), Cemsuisse (2010a) | 35.0 (1998), 31.8 (2010) |
| Other bituminous coal | SFOE (2021), Cemsuisse (2010a) | 28.052 (1998), 25.5 (2010) |
| Lignite | SFOE (2021), Cemsuisse (2010a) | 20.097 (1998), 23.6 (2010) |
| Natural gas | SGWA | *see caption* |
| **Biofuel** | **Data sources** | |
| Biodiesel | SFOE (2021) | 38.0 |
| Bioethanol | SFOE (2021) | 26.5 |
| Biogas | *assumed equal to natural gas* | *see caption* |
| Wood | SFOE (2021b) | 8.6-14.6 |

**Gasoline, jet kerosene, diesel oil and gas oil**

For gasoline, jet kerosene, diesel oil and gas oil, the NCV for 1998 and 2013 are based on national measurement campaigns and are the same as used by the Swiss Federal Office of Energy (SFOE 2021). A first campaign was conducted by the Swiss Federal Laboratories for Materials Science and Technology (EMPA) in 1998 (EMPA 1999). Since previous data are not available, the values for 1990–1998 are assumed to be constant at the 1998 levels. A second campaign, commissioned by the Swiss Federal Office of Energy (SFOE) and the

Swiss Federal Office for the Environment (FOEN), was conducted in 2013 (SFOE/FOEN 2014). This study was based on representative samples covering summer and winter fuel qualities from the main import streams. The sampling started in July 2013 and lasted six months. Samples were taken fortnightly from nine different sites (large-scale storage facilities and the two Swiss refineries) and analysed for carbon contents and NCVs amongst other. These updated values are used from 2013 onwards, while the NCVs for 1999–2012 are linearly interpolated between the measured values of 1998 and 2013.

**Residual fuel oil**

Residual fuel oil plays only a minor role in the Swiss energy supply. Therefore, this fuel was not analysed in the most recent measurement campaign in 2013 (SFOE/FOEN 2014). Thus, the respective NCV refers to the measurement campaign in 1998 (EMPA 1999). The NCV for residual fuel oil, which is the same as used by the Swiss Federal Office of Energy (SFOE 2021), is assumed to be constant over the entire reporting period. The same approach is applied for the $CO_2$ emission factor (see Table 3-13).

**Liquefied petroleum gas**

The NCV of liquefied petroleum gas is the same as used by the Swiss Federal Office of Energy (SFOE 2021) and is – as in the Swiss overall energy statistics – constant over the entire reporting period. It is assumed that liquefied petroleum gas consists of equal parts propane and butane.

**Petroleum coke, other bituminous coal, lignite**

For the entire reporting period, the NCVs of petroleum coke, other bituminous coal and lignite are the same as used by the Swiss Federal Office of Energy (SFOE 2021). For these fuels, the Swiss overall energy statistics contains NCVs for the years 1998 and 2010. Values in between are interpolated, before the first and after the last year of available data values are held constant. The NCVs for 2010 are based on measured samples taken from Switzerland's cement plants as they are the largest consumers of these fuels in Switzerland. Samples from the individual plants were taken from January to September 2010 and analysed for NCVs by an independent analytical laboratory (Cemsuisse 2010a). For each fuel, the measurements from the individual plants were weighted according to the relative consumption of each plant.

**Natural gas, biogas**

The NCV of natural gas (and also the $CO_2$ emission factor of natural gas, see Table 3-14 ) is calculated based on measurements of gas properties and corresponding import shares of individual gas import stations. Measurements of gas properties are available from the Swiss Gas and Water Industry Association (SGWA) on an annual basis since 2009 and for selected years before. The latest report is SGWA (2021). Import shares are available for 1991, 1995, 2000, 2005, 2007 and from 2009 onwards on an annual basis. Estimated import shares for the years 1991, 1995 and 2000 are taken from Quantis (2014). Values for the years in between are interpolated. The calculation procedure is documented in FOEN (2021i). The

NCV of biogas is assumed to be equal to the NCV of natural gas since the raw biogas is treated to become the same quality level including its energetic properties as natural gas.

Table 3-11 Net calorific values (NCVs) of natural gas and biogas for years with available data. Values for the years in between are linearly interpolated. Data source: Annual reports of the Swiss Gas and Water Industry Association (SGWA), the latest report is SGWA (2021). Spreadsheet to determine national averages: FOEN (2021i).

| Year | NCV of natural gas and biogas [GJ/t] |
|---|---|
| 1990 | 46.5 |
| 1991 | 46.5 |
| 1995 | 47.5 |
| 2000 | 47.2 |
| 2005 | 46.6 |
| 2007 | 46.3 |
| 2009 | 46.4 |
| 2010 | 46.3 |
| 2011 | 46.1 |
| 2012 | 45.8 |
| 2013 | 45.7 |
| 2014 | 45.7 |
| 2015 | 46.6 |
| 2016 | 47.1 |
| 2017 | 47.4 |
| 2018 | 47.6 |
| 2019 | 47.5 |
| 2020 | 47.6 |

**Wood**

The NCV of wood depends on the type of wood fuel (e.g. log wood, wood chips, pellets) and is based on the Swiss wood energy statistics (SFOE 2021b). Table 3-10 illustrates the range of the NCVs of all wood fuel types.

**Bioethanol and biodiesel**

The NCVs of bioethanol and biodiesel are the same as used by the Swiss Federal Office of Energy (SFOE 2021) and are – as in the Swiss overall energy statistics – constant over the entire reporting period.

### 3.2.4.3. Swiss energy model and final energy consumption

#### *3.2.4.3.1. Swiss overall energy statistics*

The fundamental data on final energy consumption is provided by the Swiss overall energy statistics (SFOE 2021). However, since Switzerland and Liechtenstein form a customs and monetary union governed by a customs treaty, data regarding liquid fuels in the Swiss overall energy statistics also cover liquid fuel consumption in Liechtenstein. In order to calculate the correct Swiss fuel consumption, Liechtenstein's liquid fossil fuel consumption, given by

Liechtenstein's energy statistics (OS 2021), is subtracted from the numbers provided by the Swiss overall energy statistics. In all years of the reporting period, the sum of liquid fossil fuels used in Liechtenstein was less than half a percent of the Swiss consumption.

The energy-related activity data in the energy model and thus in the GHG inventory correspond to the energy balance provided in the Swiss overall energy statistics (SFOE 2021). The energy statistics are updated annually and contain all relevant information about primary and final energy consumption. This includes annual aggregated consumption data for various fuels and main consumers such as households, transport, energy industries, industry, and services (see energy balance in Annex 4).

The main data sources of the Swiss overall energy statistics are:

- The Swiss organization for the compulsory stockpiling of oil products (Carbura) and Avenergy Suisse (formerly Swiss petroleum association, EV) for data on import, export, sales, stocks of oil products and for processing of crude oil in refineries.
- Annual import data for natural gas from the Swiss Gas Industry Association (VSG).
- Annual import data for petroleum products and coal from the Federal Office for Customs and Border Security (FOCBS).
- Data provided by industry associations (GVS, SGWA, Cemsuisse, VSG, VSTB, etc.).
- Swiss electricity statistics (SFOE 2021g).
- Swiss renewable energy statistics (SFOE 2021a).
- Swiss wood energy statistics (SFOE 2021b).
- Swiss statistics on combined heat and power generation (SFOE 2021c).

As can be seen in Figure 3-6, fossil fuels amount to slightly less than half of primary energy consumption (i.e. of the total energy demand including losses during transformation and distribution; the losses during transformation and distribution are larger for nuclear fuel and hydro power than for fossil fuels). The main end-users of fossil fuels are the transport and the housing sector, as electricity generation is predominantly based on hydro and nuclear power stations. The most recent energy balance is given in Annex 4.

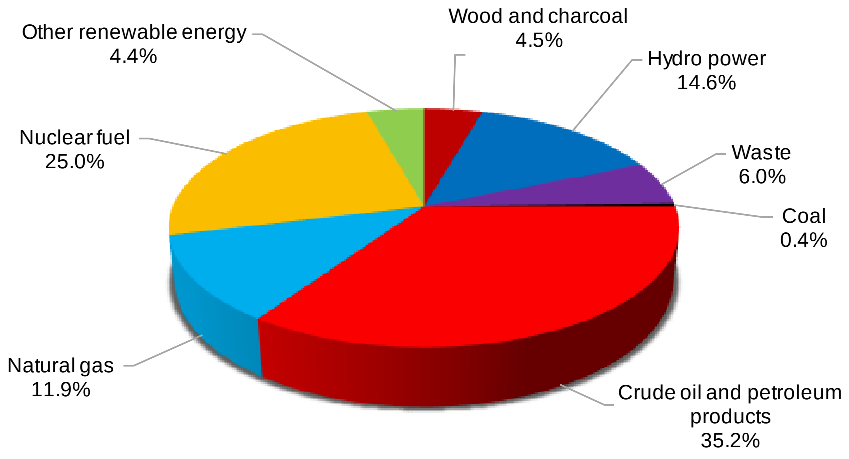


Figure 3-6 Switzerland's primary energy consumption in 2020 by fuels (see corresponding data in SFOE 2021).

Table 3-12 shows primary energy consumption excluding nuclear fuel and hydro power. On the one hand, the combined effect of decreasing consumption of gasoline and increasing consumption of kerosene and diesel oil led to an increasing trend until about 2010 and a stabilization thereafter in the transport sector. On the other hand, consumption of liquid fuels in the residential and services sectors (mainly gas oil) as well as in the industry sector (mainly gas oil and residual fuel oil) substantially decreased. Natural gas consumption increased since 1990, compensating to some extent the decreasing use of gas oil and residual fuel oil in the various sectors.

Table 3-12 Switzerland's energy consumption by fuel type. Only those fuels are shown that are implemented in the EMIS database (no hydro and nuclear power). The numbers are based on the fuels sold principle; thus, they include gasoline, diesel oil and biofuels consumption from fuel tourism, as well as all kerosene sold for domestic and international aviation. Natural gas and gasoline losses due to fugitive emissions (reported in sector 1B) are not included.

| Year | Gasoline | Kerosene domestic aviation | Kerosene international aviation (bunker) | Diesel | Diesel international navigation (bunker) | Gas oil | Residual fuel oil | Refinery gas & LPG | Petroleum coke | Solid fuels | Natural gas excl. natural gas losses | Other fuels | Bio fuels | Total as reported in CRF reporting tables | Total incl. bunker |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TJ | TJ | TJ | TJ | TJ | TJ | TJ | TJ | TJ | TJ | TJ | TJ | TJ | TJ | TJ |
| 1990 | 155'892 | 6'183 | 41'884 | 46'736 | 821 | 218'510 | 23'342 | 8'890 | 1'400 | 14'901 | 67'861 | 19'161 | 46'738 | 609'612 | 652'318 |
| 1991 | 162'228 | 5'690 | 40'872 | 47'417 | 737 | 238'602 | 23'590 | 12'437 | 980 | 12'162 | 76'114 | 18'596 | 48'731 | 646'548 | 688'157 |
| 1992 | 168'218 | 5'600 | 43'499 | 45'926 | 780 | 236'809 | 24'170 | 11'492 | 315 | 8'758 | 79'984 | 19'009 | 47'693 | 647'974 | 692'253 |
| 1993 | 156'063 | 5'434 | 45'342 | 44'197 | 781 | 225'920 | 17'165 | 12'388 | 1'120 | 7'442 | 83'911 | 19'158 | 47'997 | 620'793 | 666'917 |
| 1994 | 156'096 | 5'269 | 46'840 | 46'924 | 824 | 207'141 | 17'860 | 13'455 | 1'470 | 7'632 | 82'737 | 19'155 | 45'973 | 603'711 | 651'376 |
| 1995 | 151'383 | 5'029 | 49'918 | 47'865 | 739 | 217'523 | 17'278 | 12'756 | 1'260 | 7'962 | 91'275 | 19'688 | 48'038 | 620'057 | 670'714 |
| 1996 | 155'303 | 4'778 | 51'975 | 44'946 | 651 | 226'289 | 15'097 | 13'939 | 1'015 | 5'456 | 98'876 | 20'584 | 51'538 | 637'821 | 690'447 |
| 1997 | 161'284 | 4'791 | 53'983 | 46'770 | 614 | 212'223 | 12'581 | 14'236 | 280 | 4'590 | 95'453 | 21'655 | 48'401 | 622'264 | 676'862 |
| 1998 | 162'548 | 4'669 | 56'599 | 48'681 | 528 | 222'407 | 15'882 | 15'259 | 455 | 3'960 | 98'301 | 23'802 | 49'947 | 645'911 | 703'038 |
| 1999 | 168'026 | 4'419 | 60'824 | 51'626 | 558 | 212'349 | 11'058 | 15'805 | 521 | 4'105 | 101'863 | 24'403 | 50'711 | 644'887 | 706'270 |
| 2000 | 168'191 | 4'334 | 63'726 | 55'146 | 531 | 196'137 | 7'923 | 13'649 | 551 | 6'120 | 101'282 | 26'536 | 50'361 | 630'231 | 694'488 |
| 2001 | 163'588 | 4'055 | 60'153 | 56'134 | 576 | 213'089 | 9'942 | 14'069 | 410 | 6'233 | 105'478 | 27'068 | 53'563 | 653'629 | 714'357 |
| 2002 | 160'401 | 3'870 | 55'536 | 58'346 | 375 | 196'655 | 6'446 | 15'584 | 679 | 5'565 | 103'548 | 27'876 | 53'151 | 632'121 | 688'033 |
| 2003 | 159'639 | 3'598 | 49'840 | 61'765 | 486 | 208'040 | 7'061 | 13'642 | 202 | 5'663 | 109'522 | 27'642 | 55'735 | 652'509 | 702'835 |
| 2004 | 156'844 | 3'458 | 46'983 | 66'447 | 446 | 203'370 | 7'561 | 16'429 | 1'819 | 5'420 | 113'047 | 28'845 | 56'630 | 659'869 | 707'299 |
| 2005 | 152'099 | 3'326 | 47'775 | 72'486 | 579 | 205'729 | 5'805 | 16'432 | 2'906 | 5'940 | 116'100 | 29'236 | 58'746 | 668'806 | 717'159 |
| 2006 | 147'474 | 3'338 | 50'233 | 78'606 | 457 | 195'926 | 6'419 | 18'578 | 3'324 | 6'467 | 112'887 | 31'233 | 61'870 | 666'122 | 716'812 |
| 2007 | 146'053 | 3'473 | 53'692 | 84'420 | 465 | 171'313 | 5'179 | 15'587 | 2'730 | 7'196 | 109'874 | 30'015 | 60'922 | 636'762 | 690'919 |
| 2008 | 142'840 | 3'128 | 58'023 | 92'627 | 516 | 178'833 | 4'606 | 16'288 | 3'616 | 6'562 | 117'083 | 30'854 | 65'027 | 661'462 | 720'002 |
| 2009 | 139'006 | 3'239 | 55'426 | 94'143 | 425 | 173'219 | 3'575 | 16'301 | 3'254 | 6'193 | 112'313 | 29'811 | 65'152 | 646'206 | 702'058 |
| 2010 | 134'072 | 3'286 | 58'334 | 97'733 | 514 | 182'295 | 2'987 | 15'463 | 3'498 | 6'208 | 125'494 | 31'185 | 69'966 | 672'187 | 731'035 |
| 2011 | 128'885 | 3'235 | 62'461 | 100'449 | 428 | 143'760 | 2'292 | 14'856 | 2'957 | 5'792 | 111'269 | 30'882 | 65'593 | 609'970 | 672'859 |
| 2012 | 124'332 | 3'402 | 63'903 | 106'568 | 428 | 154'448 | 2'780 | 12'247 | 3'148 | 5'269 | 122'051 | 31'145 | 71'547 | 636'938 | 701'269 |
| 2013 | 118'664 | 3'359 | 64'709 | 111'482 | 342 | 162'532 | 1'959 | 15'053 | 2'735 | 5'567 | 128'592 | 30'925 | 75'161 | 656'027 | 721'078 |
| 2014 | 113'907 | 3'535 | 65'006 | 114'385 | 299 | 122'694 | 1'581 | 14'473 | 3'148 | 5'704 | 111'346 | 31'320 | 69'546 | 591'639 | 656'944 |
| 2015 | 105'618 | 3'454 | 67'333 | 112'808 | 342 | 129'349 | 862 | 9'822 | 1'145 | 5'205 | 118'996 | 32'084 | 72'963 | 592'306 | 659'981 |
| 2016 | 102'322 | 3'559 | 70'603 | 114'079 | 299 | 132'325 | 378 | 9'136 | 890 | 4'795 | 125'030 | 33'583 | 79'164 | 605'261 | 676'163 |
| 2017 | 99'178 | 3'110 | 72'824 | 113'750 | 256 | 123'726 | 350 | 8'770 | 763 | 4'609 | 125'289 | 33'342 | 82'405 | 595'293 | 668'372 |
| 2018 | 97'608 | 3'036 | 77'214 | 115'283 | 200 | 111'225 | 87 | 8'890 | 781 | 4'285 | 118'611 | 34'510 | 82'191 | 576'508 | 653'922 |
| 2019 | 96'807 | 2'874 | 78'196 | 115'347 | 197 | 108'625 | 111 | 8'108 | 777 | 3'812 | 121'618 | 34'964 | 84'621 | 577'662 | 656'055 |
| 2020 | 85'731 | 2'445 | 28'170 | 109'312 | 189 | 97'246 | 41 | 7'627 | 700 | 3'664 | 118'458 | 34'723 | 83'138 | 543'084 | 571'443 |

#### *3.2.4.3.2. Energy model – Conceptual overview*

For the elaboration of the greenhouse gas and air pollutants inventories, information about energy consumption is needed at a much more detailed level than provided by the Swiss overall energy statistics (SFOE 2021). Activity data in sector 1 Energy are therefore calculated and disaggregated by the Swiss energy model, which is an integral part of the emission database EMIS. The model is developed and updated annually by the Swiss Federal Office for the Environment (FOEN). It relies on the Swiss overall energy statistics and is complemented with further data sources, e.g. Liechtenstein's liquid fuel sales (OS 2021), the Swiss renewable energy statistics (SFOE 2021a), the Swiss wood energy statistics (SFOE 2021b), the energy consumption statistics in the industry and services sectors (SFOE 2021d), as well as additional information from the industry.

The Swiss overall energy statistics are not only the main data input into the energy model, but also serve as calibration and quality control instrument. The total energy consumption given by the Swiss overall energy statistics has to be equal to the sum of the disaggregated activity data of all source categories within the energy sector (including memo items/bunker). Differences are explicitly taken into account as "statistical differences" (see chp. 3.2.4.1).

As shown in Figure 3-7, the energy model consists of several sub-models, such as the industry model, the civil aviation model, the road transportation model, the non-road transportation model, and the energy model for wood combustion. A brief overview of each of these models is given below. However, depending on the scope of these sub-models, they are either described in the chapter dedicated to the corresponding source category or in an overarching chapter preceding the detailed description of the individual source categories. In chp. 3.2.4.3.3, the resulting sectoral disaggregation is shown separately for each fuel type.

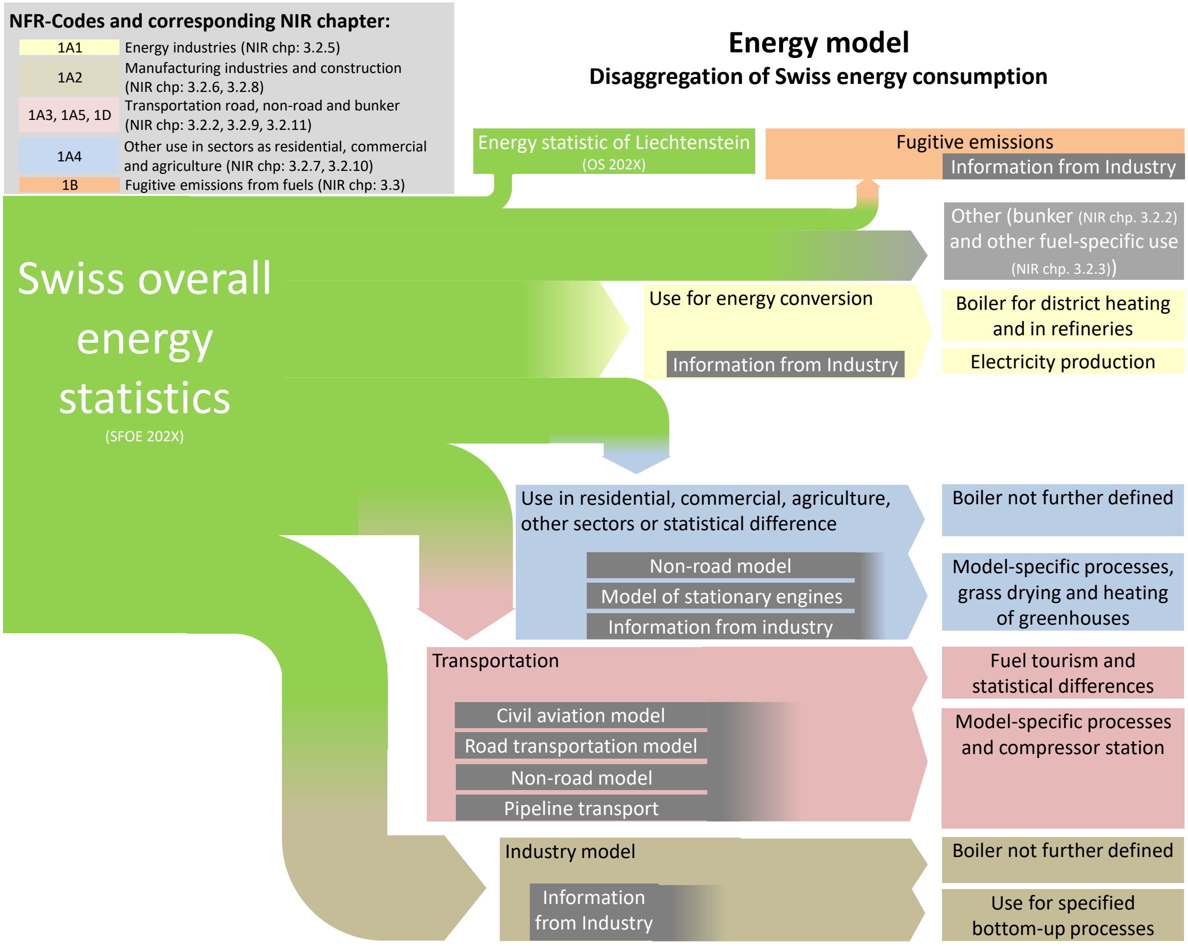


Figure 3-7 Overview of Switzerland's energy model. In the abbreviations SFOE 202X and OS 202X the "X" refers to the latest edition of the respective statistics.

**Industry model** (Details are given in chp. 3.2.6.2.1)
The industry model is based on two pillars: (1) the energy consumption statistics in the industry and services sectors (SFOE 2021d), which is a comprehensive annual survey of fuel consumptions for all years since 1999 or 2002 (depending on the fuel type), and (2) a bottom-up industry model (Prognos 2013) which extends fuel consumptions back to 1990. The resulting industry model provides a consistent split of energy consumption by source category and fuel type for the full reporting period. Further disaggregation is then achieved by using plant-level industry data for specific processes, as far as available.

**Civil aviation model** (Details are given in chp. 3.2.2.2.1 and 3.2.9.2.1)
The civil aviation model is developed and updated by the Federal Office for Civil Aviation (FOCA). It aggregates single aircraft movements according to detailed movement statistics of the Swiss airports. Differentiation of domestic and international aviation is based on the information on departure and destination of each flight in the movement database.

**Road transportation model** (Details are given in chp. 3.2.9.2.2)
The road transportation model is a territorial model, accounting for traffic on Swiss territory only. The model is based on detailed vehicle stock data from the vehicle registration database of the Federal Roads Office (FEDRO), mileage per vehicle category differentiated into different driving patterns, and specific consumption and emission factors. The difference between fuel sales and the territorial model (road and non-road transportation models combined) is reported as fuel tourism and statistical differences. Emissions are included in the most appropriate categories (see 3.2.9.2.2).

**Non-road transportation model** (Details are given in chp. 3.2.4.5.1)
The non-road transportation model covers all remaining mobile sources, i.e. industrial vehicles, construction machinery, agricultural and forestry machinery, gardening machinery as well as railways, navigation and military vehicles, except for military aviation, which is considered separately (see chp. 3.2.11.2.1). The model combines vehicle or machinery numbers, their operation hours, engine power, and load factors to derive specific fuel consumption, emission factors and resulting emissions. Data stem from surveys among producers, various user associations, and the national database of non-road vehicles run by FEDRO.

**Model for wood energy combustion** (Details are given in chp. 3.2.4.5.2)
Based on the Swiss wood energy statistics (SFOE 2021b), total wood consumption is disaggregated into source categories (public electricity and heat production, industry, commercial/institutional, residential, agriculture/forestry/fisheries) and into 24 different combustion installations (ranging from open fireplaces to large-scale automatic boiler or heat and power plants). Where available, industry data on wood combustion is taken into account to allocate parts of the wood consumption as given by the Swiss wood energy statistics to a specific source category.

#### *3.2.4.3.3. Disaggregation of the energy consumption by source category and fuel types*
The energy model as outlined above disaggregates total energy consumption as provided by the Swiss overall energy statistics (SFOE 2021) into the relevant source categories 1A1-1A5. Figure 3-9 to Figure 3-18 visualize for each fuel type separately the disaggregation process of the energy model (as shown schematically in Figure 3-7), the interaction between the different sub-models as well as additional data sources.

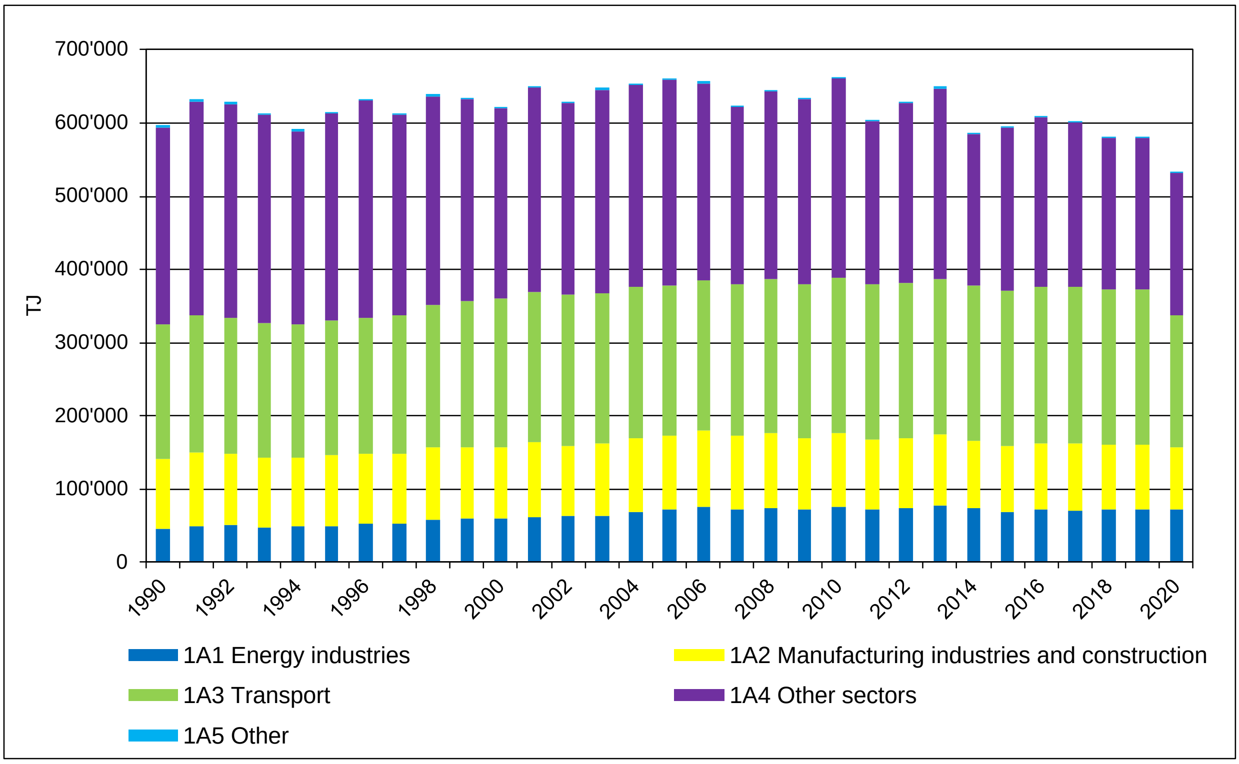


Figure 3-8 Switzerland's energy consumption by source categories 1A1-1A5 according to the Swiss energy model. Since 1990 population increased by about 29%, industrial production by about 73% and the motor vehicle fleet by about 65% (SFOE 2021, table 43a).

Starting from the total energy consumption from the Swiss overall energy statistics for each fuel type, the energy is assigned to the relevant source categories based on the various sub-models of the energy model (mentioned in chp. 3.2.4.3.2 above). In addition, the following assignments are considered as well.

Within the source categories 1A4a and 1A4b, the amount of gas oil and natural gas used for co-generation in turbines and engines is derived from a model of stationary engines developed by Eicher + Pauli (Kaufmann 2015) for the statistics on combined heat and power generation (SFOE 2021c). The residual energy is then assigned to boilers which are not further specified.

For source category 1A4ci Other sectors – Agriculture/forestry/fishing, specific bottom-up industry information is available for grass drying and heating of greenhouses. The fuel consumption for grass drying is provided by the Swiss association of grass drying plants (VSTB). Further, based on annual energy consumption data from the Energy Agency of the Swiss Private Sector (EnAW) regarding agricultural greenhouses exempt from the $CO_2$ levy, total energy consumption of all greenhouses within Switzerland is extrapolated. The fuel consumption for grass drying and greenhouses is subtracted from the total fuel consumption of residential, commercial, agriculture and statistical differences (see Figure 3-7).

In order to report all energy consumption, the statistical differences as reported in the Swiss overall energy statistics are allocated to source category 1A4ai Other sectors – Commercial/institutional (stationary combustion) and 1A3bviii Fuel tourism and statistical differences. In the greenhouse gas inventory, emissions from 1A3bviii Fuel tourism and statistical differences are reported in the source categories 1A3bi, 1A3bii, and 1A3biii (see chp. 3.2.9.2.2 for a more detailed description).

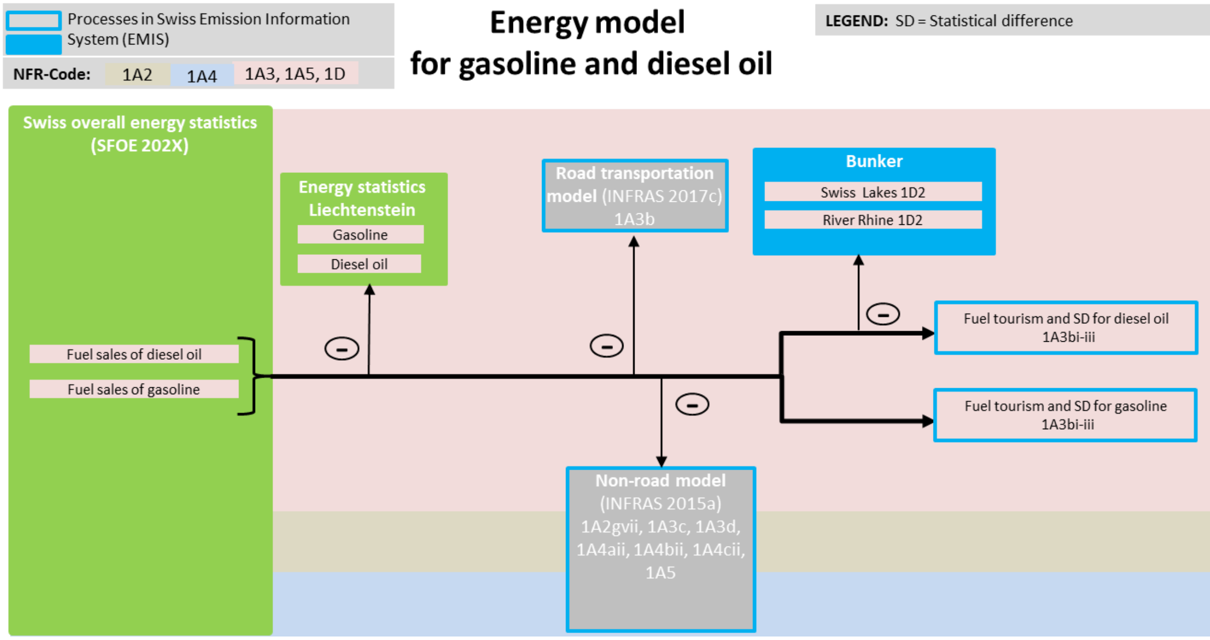


Figure 3-9 Schematic disaggregation of fuel consumption for gasoline and diesel oil. Marine bunker fuel consumption is based on the national customs statistics (see chp. 3.2.2.2.2). In the greenhouse gas inventory, emissions from 1A3bviii Fuel tourism and statistical differences are reported in the source categories 1A3bi, 1A3bii, and 1A3biii (see chp. 3.2.9.2.2 for a more detailed description).

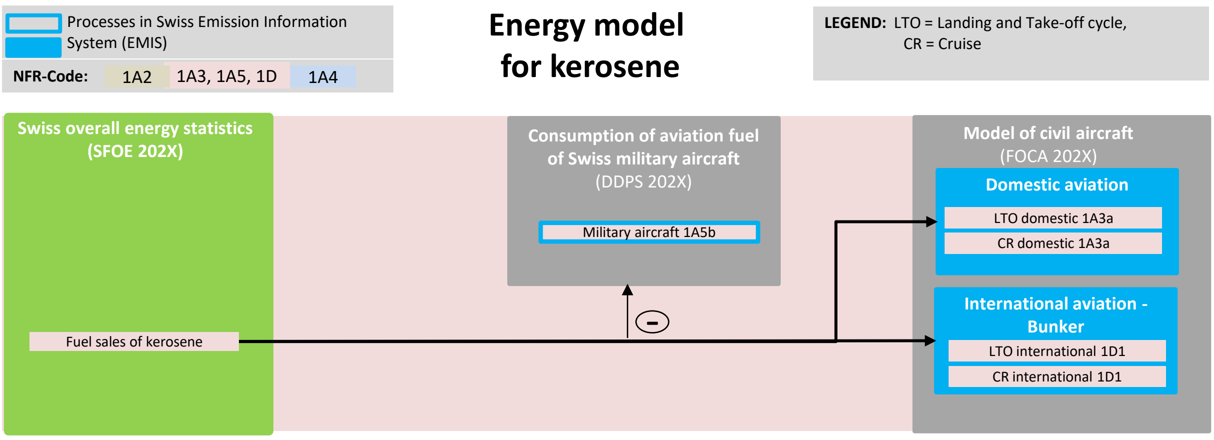


Figure 3-10 Schematic disaggregation of fuel consumption for kerosene. Fuel consumption for military aircraft is provided by the Federal Department of Defence, Civil Protection and Sport. The differentiation between domestic and international aviation as well as between CR and LTO is provided by the civil aviation model (see chp. 3.2.2.2.1).

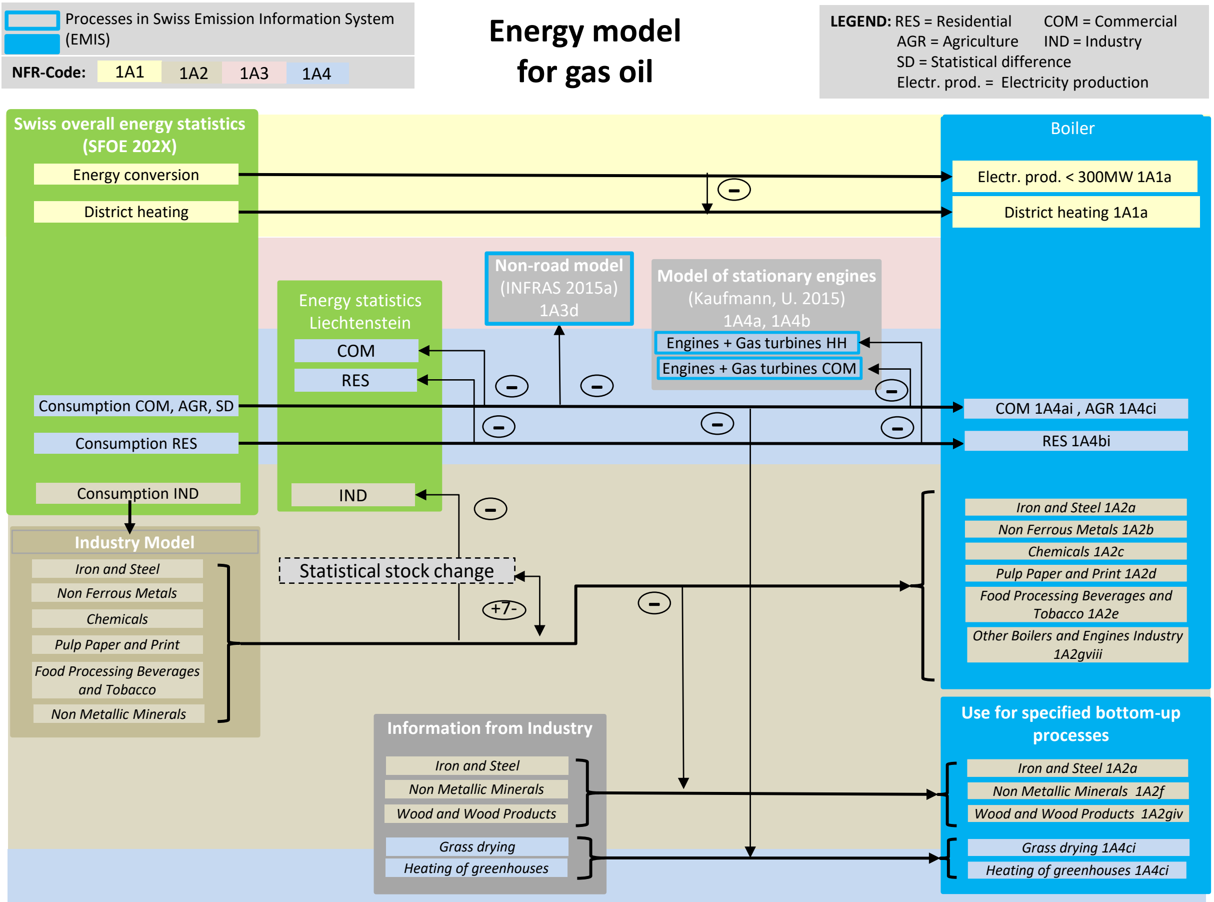


Figure 3-11 Schematic disaggregation of fuel consumption for gas oil. The Swiss overall energy statistics provides gas oil use for energy conversion and the amount thereof being used for district heating. Based on this information, gas oil use is split into the source categories 1A1ai Electricity generation and 1A1aiii Heat plants. According to the non-road model, a small amount of gas oil is consumed in source category 1A3d navigation (steam-powered vessels).

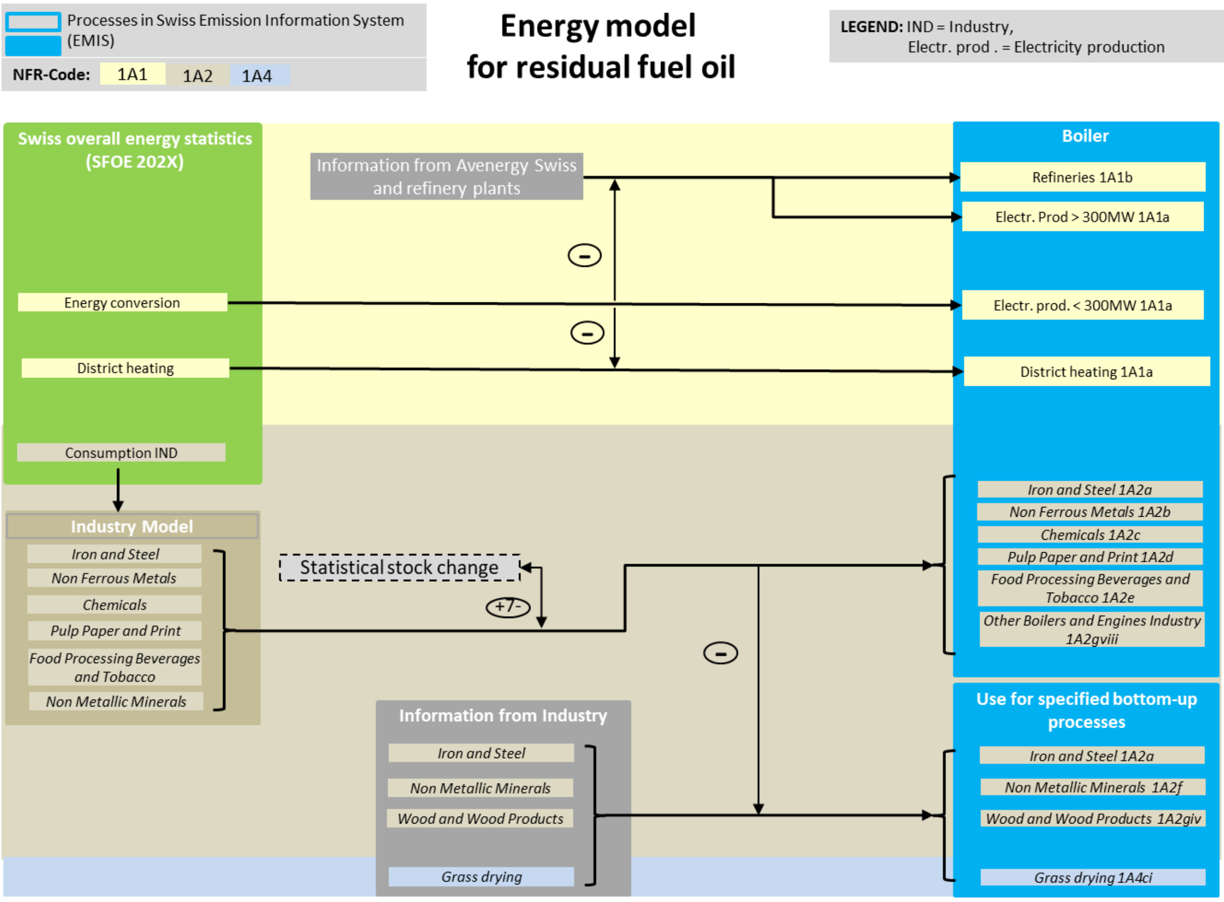


Figure 3-12 Schematic disaggregation of fuel consumption for residual fuel oil. The Swiss overall energy statistics reports residual fuel oil use in energy conversion and the amount thereof consumed in electricity production (one single fossil fuel power station, operational from 1985 to 1994), district heating, and in petroleum refineries. Based on this information, residual fuel oil use in Energy industries is split into the source categories 1A1ai Electricity generation, 1A1aiii Heat plants and 1A1b Petroleum refining.

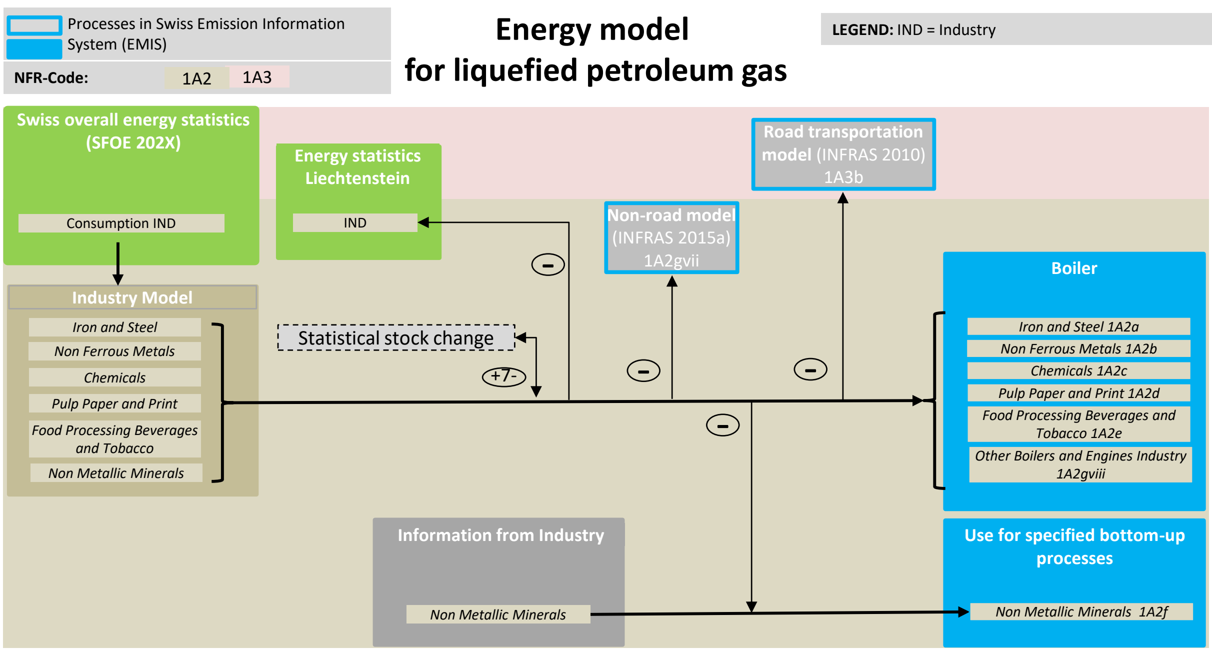


Figure 3-13 Schematic disaggregation of fuel consumption for liquefied petroleum gas.

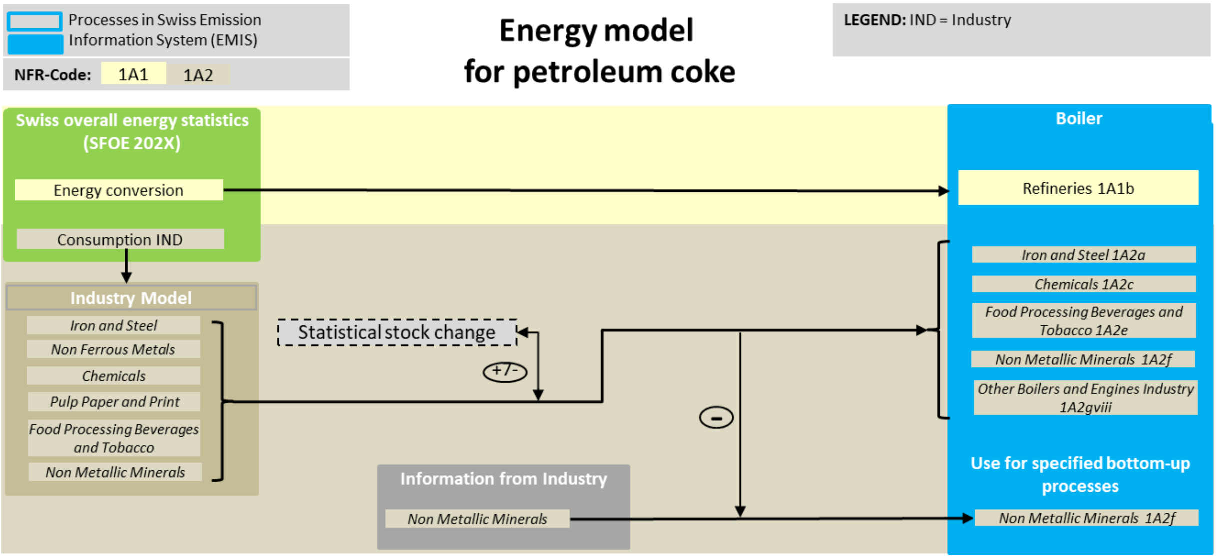


Figure 3-14 Schematic disaggregation of fuel consumption for petroleum coke.

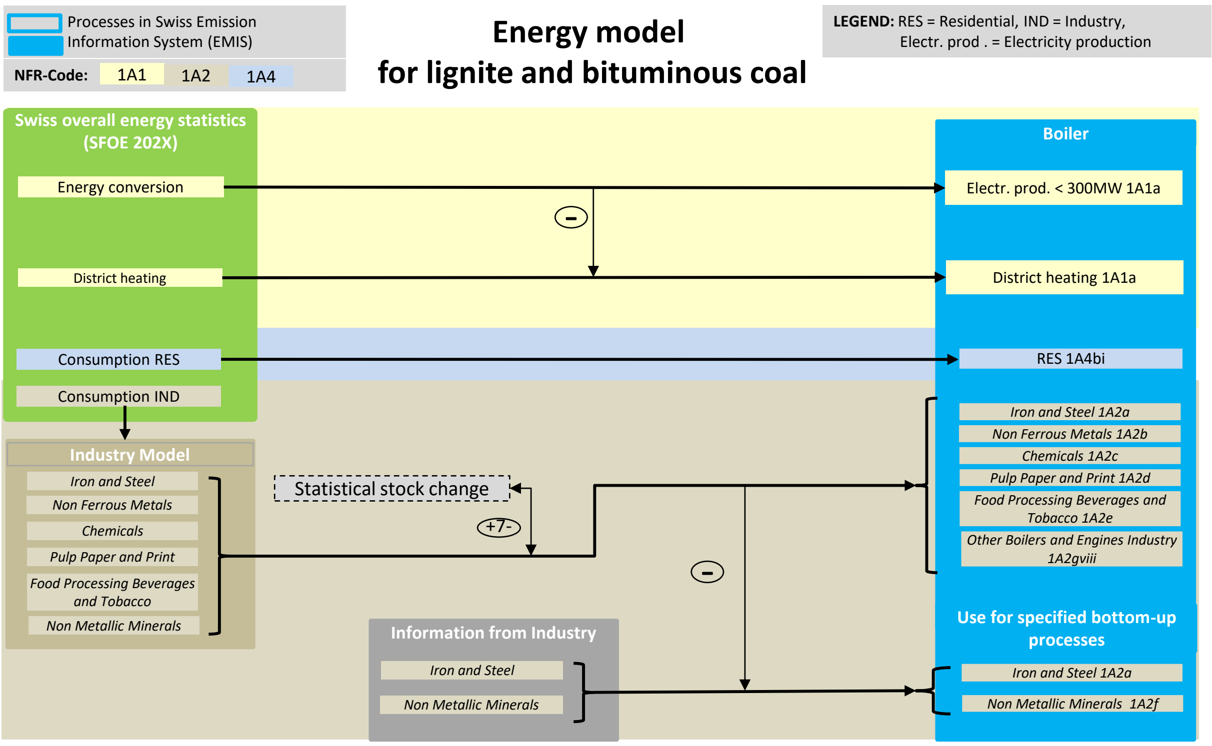


Figure 3-15 Schematic disaggregation of fuel consumption for lignite and bituminous coal. The Swiss overall energy statistics provides bituminous coal use for energy conversion and the amount thereof being used for district heating. Based on this information, use of bituminous coal in Energy industries is split into the source categories 1A1ai Electricity generation and 1A1aiii Heat plants up to 1995. Coal consumption for Public electricity and heat production ceased thereafter.

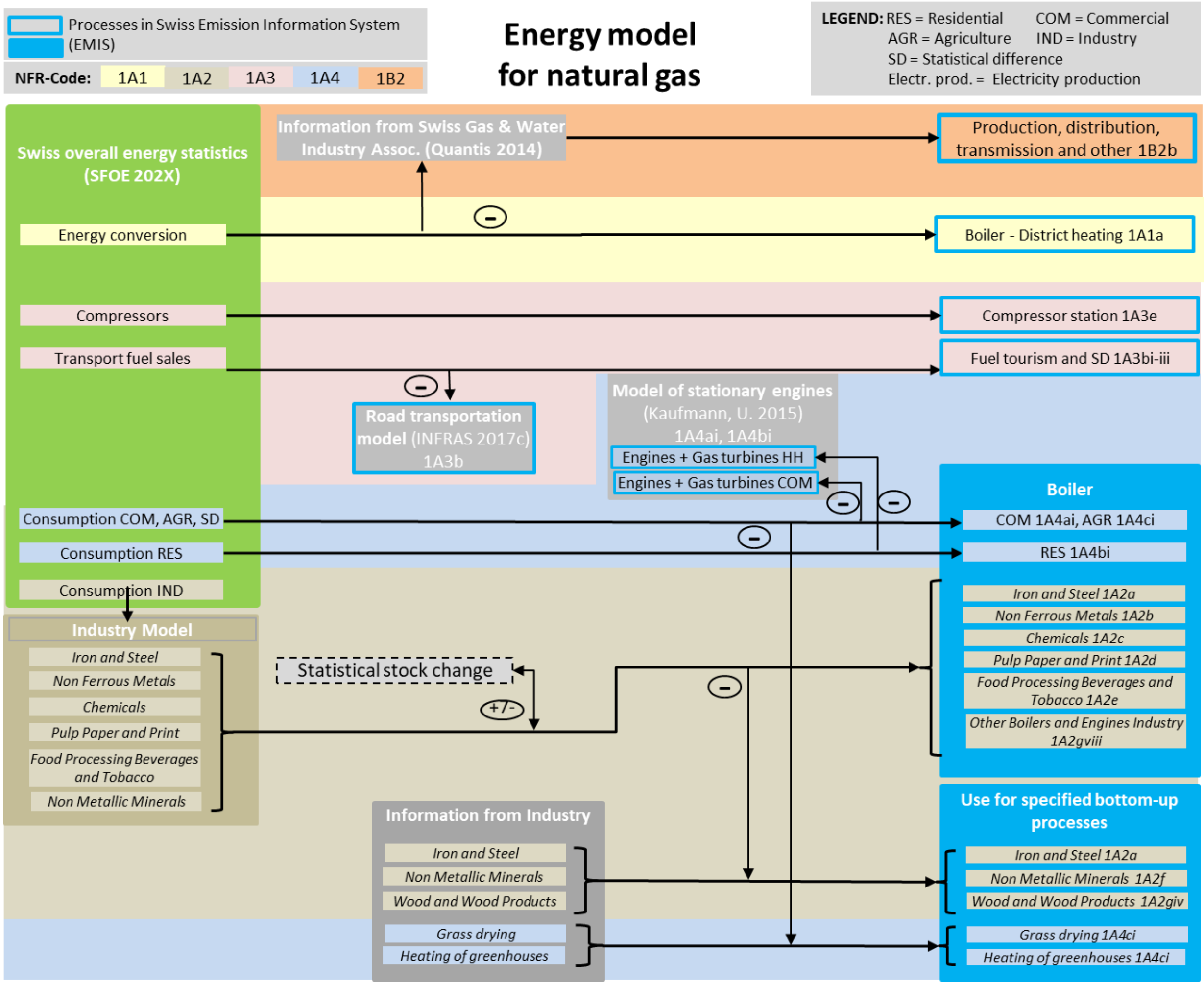


Figure 3-16 Schematic disaggregation of fuel consumption for natural gas. The Swiss overall energy statistics provides gas use in the transformation sector (energy conversion and distribution losses). Distribution losses as estimated by the Swiss Gas and Water Industry Association (SGWA) are subtracted and reported under source category 1B2 Fugitive emissions from fuels. The remaining fuel consumption for natural gas is reported under source category 1A1a Public electricity and heat production. In the greenhouse gas inventory, emissions from 1A3bviii Fuel tourism and statistical differences are reported in the source categories 1A3bi, 1A3bii, and 1A3biii (see chp. 3.2.9.2.2 for a more detailed description).

A corresponding Figure 3-16b is available in the confidential version of this chapter, providing more details.

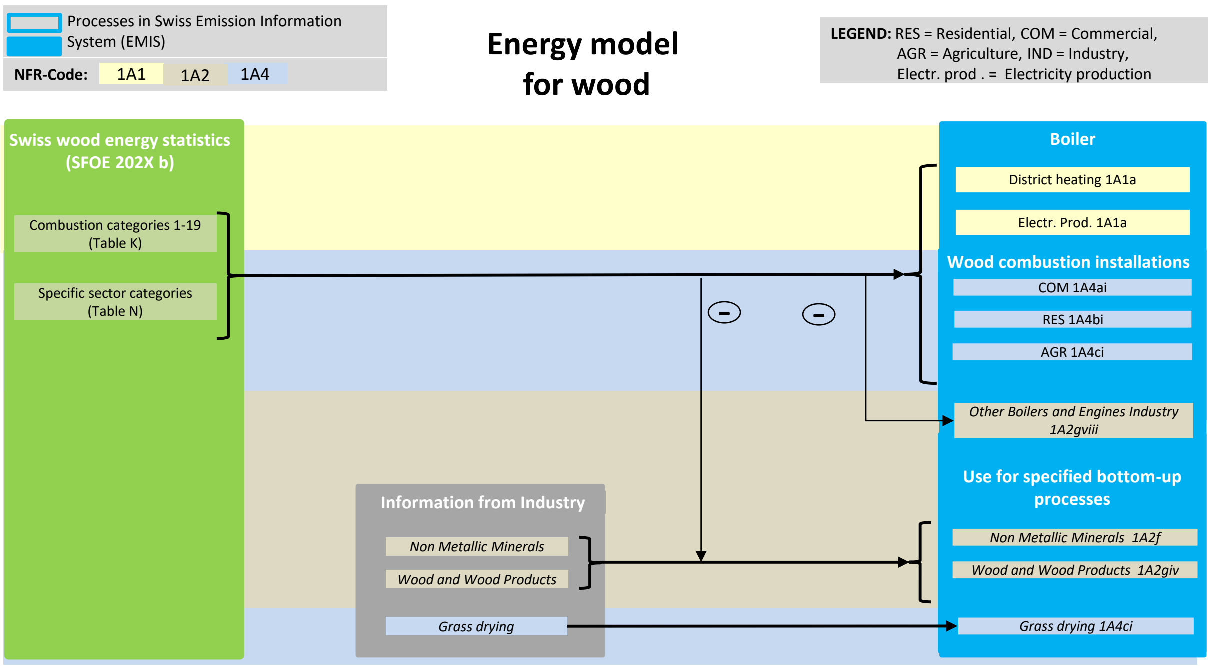


Figure 3-17 Schematic disaggregation of fuel consumption for wood (see chp. 3.2.4.5.2.)

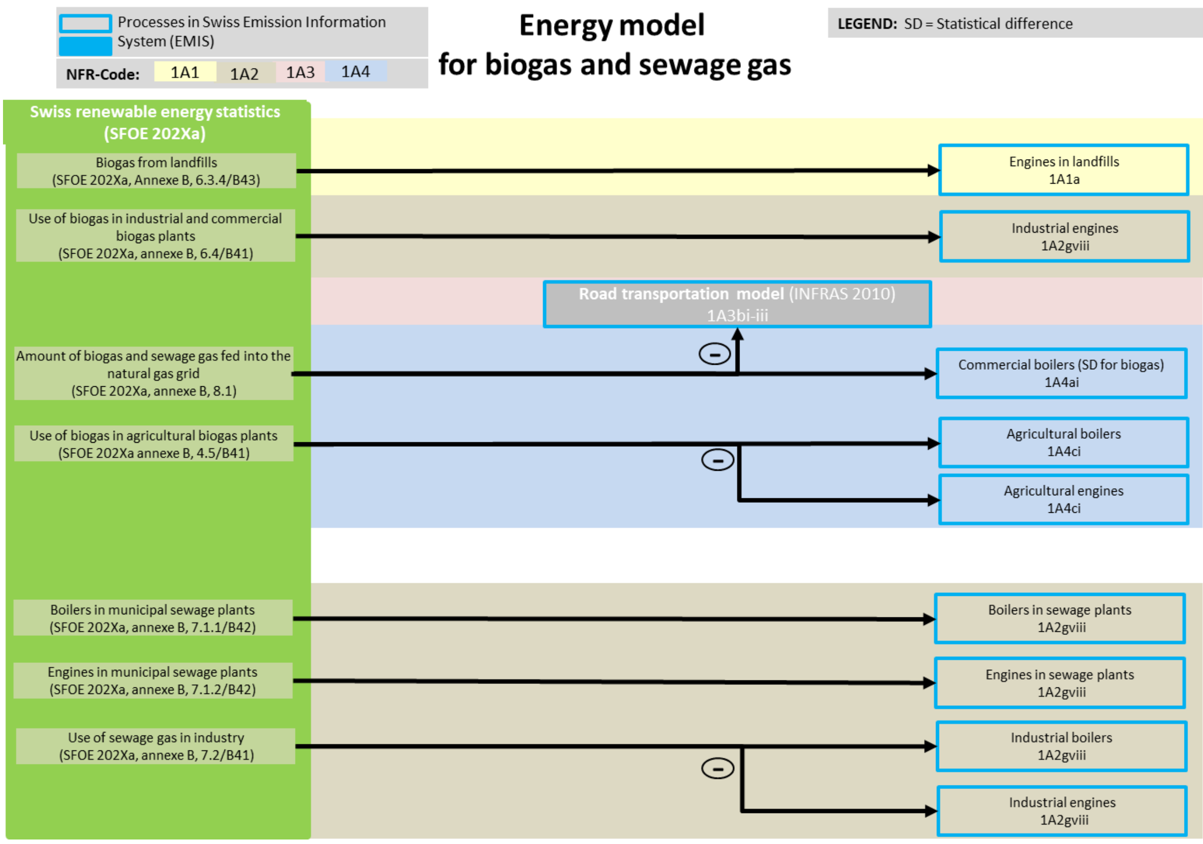


Figure 3-18 Schematic disaggregation of fuel consumption for biogas and sewage gas.

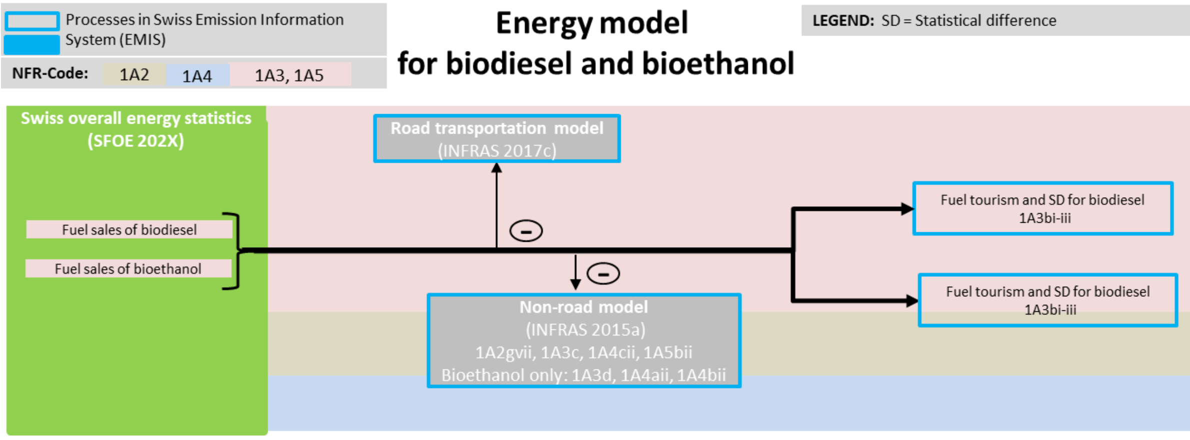


Figure 3-19 Schematic disaggregation of fuel consumption for biodiesel and bioethanol.

### 3.2.4.4. Emission factors of 1A Fuel combustion

#### *3.2.4.4.1. Oxidation factor for 1A Fuel combustion*

For the emission calculation, an oxidation factor of 100% is assumed for all fossil fuel combustion processes, since the technical standards for combustion installations in Switzerland are high and the small fraction of originally non-oxidised carbon retained in ash, particulates or soot is likely to be oxidized later. This is consistent with the 2006 IPCC Guidelines (IPCC 2006) and the EU and Swiss guidelines for the Emissions Trading Scheme (ETS), where also a default oxidation factor of 100% was applied.

Because an oxidation factor of 100% is assumed, indirect $CO_2$ emissions from $CH_4$, CO and NMVOC are implicitly reported as direct $CO_2$ emissions in source category 1A Energy. Therefore, from this source category no indirect $CO_2$ emissions are included in CRF Table6 as documented in chp. 9.

#### *3.2.4.4.2. $CO_2$ emission factors for 1A Fuel combustion*

**General $CO_2$ emission factors**

The $CO_2$ emission factors applied for the time series 1990–2020 are given in Table 3-13. Detailed information regarding the underlying data and assumptions are provided in chp. 3.2.4.2 Net calorific values (NCV), since in most cases, NCVs and carbon content were determined jointly.

Table 3-13 $CO_2$ emission factors 1990–1998 and years from 2013 onwards. For years between 1998 and 2013, the factors are linearly interpolated. Data source SGWA stands for annually updated reports of the Swiss Gas and Water Industry Association (SGWA).

| **$CO_2$ emission factors** | | | **1990-1998** | **2013-2020** |
|---|---|---|---|---|
| **Fossil fuel** | **CS/D** | **Data sources** | t $CO_2$ / TJ | t $CO_2$ / TJ |
| Gasoline | CS | EMPA (1999), SFOE/FOEN (2014) | 73.9 | 73.8 |
| Jet kerosene | CS | EMPA (1999), SFOE/FOEN (2014) | 73.2 | 72.8 |
| Diesel oil | CS | EMPA (1999), SFOE/FOEN (2014) | 73.6 | 73.3 |
| Gas oil | CS | EMPA (1999), SFOE/FOEN (2014) | 73.7 | 73.7 |
| Residual fuel oil | CS | EMPA (1999) | 77.0 | 77.0 |
| Liquefied petroleum gas | CS | FOEN (2019k) | 65.5 | 65.5 |
| Petroleum coke | CS | Cemsuisse (2010a) | 91.4 | 91.4 |
| Other bituminous coal | CS | Cemsuisse (2010a) | 92.7 | 92.7 |
| Lignite | CS | Cemsuisse (2010a) | 96.1 | 96.1 |
| Natural gas | CS | SGWA | *see table below* | |
| **Biofuel** | **CS/D** | **Data sources** | | |
| Biodiesel | CS | assumed equal to diesel oil | 73.6 | 73.3 |
| Bioethanol | CS | assumed equal to gasoline | 73.9 | 73.8 |
| Biogas | CS | assumed equal to natural gas | *see table below* | |
| Wood | CS | Cemsuisse (2010a) | 99.9 | 99.9 |

### $CO_2$ emission factors for natural gas and biogas

Table 3-14 Time series of $CO_2$ emission factors of natural gas and biogas. SGWA refers to annual updates of properties of natural gas that are provided by the Swiss Gas and Water Industry Association (SGWA).

| **$CO_2$ emission factors** | | | **1990** | **1995** | **2000** | **2005** | **2010** |
|---|---|---|---|---|---|---|---|
| **Fuel** | **CS/D** | **Data sources** | t $CO_2$ / TJ | | | | |
| Natural gas/Biogas | CS | SGWA | 56.1 | 55.7 | 56.2 | 56.4 | 56.5 |

| **$CO_2$ emission factors** | | | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fuel** | **CS/D** | **Data sources** | t $CO_2$ / TJ | | | | | | | | | |
| Natural gas/Biogas | CS | SGWA | 56.6 | 56.5 | 56.4 | 56.5 | 56.4 | 56.4 | 56.3 | 56.2 | 56.4 | 56.2 |

### $CO_2$ emission factors for wood

The $CO_2$ emission factor for wood combustion activities is taken from Cemsuisse (2010a).

## *3.2.4.4.3. $CH_4$ emission factors for 1A Fuel combustion*

### General $CH_4$ emission factors

An overview of the general $CH_4$ emission factors is given in Table 3-15. These emission factors are used for most stationary combustion processes (exceptions are discussed in the detailed sectoral chapters where they occur). For stationary combustion, mainly IPCC default emission factors are used for the entire time period (IPCC 2006). For wood combustion, country-specific factors are used. Details are given below in Table 3-16. $CH_4$ emission factors related to transport activities (aviation, road and non-road transportation) are category-specific and given in the corresponding chapters.

Table 3-15 $CH_4$ emission factors for stationary combustion for the whole time period.

| $CH_4$ emission factors | | | 1990-2020 |
|---|---|---|---|
| **Fuel** | **CS/D** | **Data sources** | g $CH_4$ / GJ |
| Gas oil | D | IPCC (2006) | 3 |
| Residual fuel oil | D | IPCC (2006) | 3 |
| Liquefied petroleum gas | D | IPCC (2006) | 1 |
| Petroleum coke | D | IPCC (2006) | 3 |
| Other bituminous coal | D | IPCC (2006) | 10 |
| Lignite | D | IPCC (2006) | 10 |
| Natural gas | D | IPCC (2006) | 1 |
| **Biofuel** | **CS/D** | **Data Sources** | |
| Biogas | D | IPCC (2006) | 1 |
| Wood | CS | Zotter et al. (2022) | 0.2 - 200 |

### $CH_4$ emission factors for wood

There are many different combustion installations in use which have very different $CH_4$ emission factors. A detailed overview of all applied wood related $CH_4$ emission factors for the entire time series is given in Table 3-16.

The $CH_4$ emission factors are based on a country-specific emission factor model for wood energy that was completely revised for the submission 2021 (Zotter et al. 2022). The model is based on a large number of air pollution control measurements, laboratory and field measurements, literature data (e.g. beReal, EFs in the Nordic countries) and the EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA 2019) and covers the entire time series. The $CH_4$ emission factors are modelled based on VOC emissions of each combustion installation type and a mean $CH_4$ to VOC ratio of 0.3.

The EF for the different combustion installations varies depending on the year, rated thermal input and technology used. The EF of a single category represents the emission characteristics of a large number of combustion installations with a range of technology types, maintenance and operating conditions at a given time. According to their lifespan, existing combustion installations are gradually replaced by installations of new technology with better combustion, resulting in gradually decreasing emission factors.

Table 3-16 $CH_4$ emission factors for wood combustion installations.

| 1A Wood combustion | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | g $CH_4$/GJ | | | | |
| Open fireplaces | 130 | 127 | 124 | 122 | 113 |
| Closed fireplaces, log wood stoves | 130 | 124 | 119 | 113 | 107 |
| Pellet stoves | NO | NO | 16 | 13 | 10 |
| Log wood hearths | 200 | 192 | 183 | 175 | 157 |
| Log wood boilers | 70 | 62 | 53 | 45 | 37 |
| Log wood dual chamber boilers | 200 | 192 | 183 | 175 | 157 |
| Automatic chip boilers < 50 kW | 60 | 52 | 43 | 35 | 27 |
| Automatic pellet boilers < 50 kW | NO | NO | 14 | 12 | 10 |
| Automatic chip boilers 50-300 kW w/o wood proc. companies | 30 | 27 | 24 | 22 | 17 |
| Automatic pellet boilers 50-300 kW | NO | NO | 7.8 | 6.7 | 5.0 |
| Automatic chip boilers 50-300 kW within wood proc. companies | 30 | 27 | 24 | 22 | 17 |
| Automatic chip boilers 300-500 kW w/o wood proc. companies | 30 | 27 | 24 | 22 | 17 |
| Automatic pellet boilers 300-500 kW | NO | NO | NO | 6.7 | 5.0 |
| Automatic chip boilers 300-500 kW within wood proc. companies | 30 | 27 | 24 | 22 | 17 |
| Automatic chip boilers > 500 kW w/o wood proc. companies | 10 | 8.9 | 7.8 | 6.7 | 5.0 |
| Automatic pellet boilers > 500 kW | NO | NO | NO | 3.0 | 2.3 |
| Automatic chip boilers > 500 kW within wood proc. companies | 12 | 11 | 10 | 9.5 | 7.0 |
| Combined chip heat and power plants | NO | 0.89 | 0.78 | 0.67 | 0.47 |
| Plants for renewable waste from wood products | 4.0 | 3.7 | 3.4 | 3.2 | 2.3 |

| 1A Wood combustion | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| | g $CH_4$/GJ | | | | | | | | | |
| Open fireplaces | 110 | 107 | 103 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Closed fireplaces, log wood stoves | 105 | 103 | 102 | 100 | 98 | 97 | 95 | 93 | 92 | 90 |
| Pellet stoves | 9.0 | 8.0 | 7.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| Log wood hearths | 150 | 143 | 137 | 130 | 130 | 130 | 130 | 130 | 130 | 130 |
| Log wood boilers | 35 | 33 | 32 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Log wood dual chamber boilers | 150 | 143 | 137 | 130 | 130 | 130 | 130 | 130 | 130 | 130 |
| Automatic chip boilers < 50 kW | 25 | 23 | 22 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Automatic pellet boilers < 50 kW | 10 | 10 | 10 | 10 | 9.3 | 8.7 | 8.0 | 7.3 | 6.7 | 6.0 |
| Automatic chip boilers 50-300 kW w/o wood proc. companies | 15 | 13 | 12 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Automatic pellet boilers 50-300 kW | 4.5 | 4.0 | 3.5 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Automatic chip boilers 50-300 kW within wood proc. companies | 15 | 13 | 12 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Automatic chip boilers 300-500 kW w/o wood proc. companies | 15 | 13 | 12 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Automatic pellet boilers 300-500 kW | 4.5 | 4.0 | 3.5 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Automatic chip boilers 300-500 kW within wood proc. companies | 15 | 13 | 12 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Automatic chip boilers > 500 kW w/o wood proc. companies | 4.5 | 4.0 | 3.5 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Automatic pellet boilers > 500 kW | 2.0 | 1.7 | 1.3 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Automatic chip boilers > 500 kW within wood proc. companies | 6.0 | 5.0 | 4.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Combined chip heat and power plants | 0.40 | 0.33 | 0.27 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Plants for renewable waste from wood products | 2.0 | 1.7 | 1.3 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

### *3.2.4.4.4. $N_2O$ emission factors for 1A Fuel combustion*

Table 3-17 shows the general $N_2O$ emission factors in source category 1A which are based on default values from the 2006 IPCC Guidelines (IPCC 2006) and kept constant over the whole period. $N_2O$ emission factors related to transport activities (aviation, road and non-road transportation) are category-specific and given in the corresponding chapters.

Table 3-17 $N_2O$ emission factors. Default emission factors are used for all fuels for the whole time period.

| **$N_2O$ emission factors** | | | **1990-2020** |
|---|---|---|---|
| **Fuel** | **CS/D** | **Data sources** | g $N_2O$ / GJ |
| Jet Kerosene | D | IPCC (2006) | 2 |
| Gas oil | D | IPCC (2006) | 0.6 |
| Residual fuel oil | D | IPCC (2006) | 0.6 |
| Liquefied petroleum gas | D | IPCC (2006) | 0.1 |
| Petroleum coke | D | IPCC (2006) | 0.6 |
| Other bituminous coal | D | IPCC (2006) | 1.5 |
| Lignite | D | IPCC (2006) | 1.5 |
| Natural gas | D | IPCC (2006) | 0.1 |
| **Biofuel** | **CS/D** | **Data sources** | |
| Biogas | D | IPCC (2006) | 0.1 |
| Wood | D | IPCC (2006) | 4 |

### 3.2.4.5. Models overlapping more than one source category

#### *3.2.4.5.1. Non-road transportation model (excl. aviation)*

**Choice of method**

- The GHG emissions are calculated by a Tier 3 method based on the decision tree in Fig. 3.3.1 in chp. 3. Mobile Combustion in IPCC (2006), complemented with
- Tier 2 for railways $CO_2$, Fig. 3.4.1 in IPCC (2006)
- Tier 3 for railways $CH_4$, $N_2O$ and precursors, Fig. 3.4.2 in IPCC (2006)
- Tier 2 for navigation, Fig. 3.5.1 (Box 1) in IPCC (2006)

**Methodology**

The emissions of the non-road sector underwent an extended revision in 2014/2015, resulting in an update of GHG emissions including precursors. Results are documented in FOEN (2015j). The non-road categories considered are listed in Table 3-18. All of them include several technologies, fuels (diesel oil, 2- or 4-stroke gasoline, liquefied petroleum gas, gas oil), and emission standards according to the classification shown in Figure 3-20.

Table 3-18 Non-road categories as specified in FOEN (2015j) and the corresponding code in the reporting tables (CRF).

| **Non-road categories (by Corinair)** | **Nomenclature CRF** |
|---|---|
| Construction machinery | 1.A.2.g.vii Off-road vehicles and other machinery |
| Industrial machinery | 1.A.2.g.vii Off-road vehicles and other machinery |
| Railway machinery | 1.A.3.c Railways |
| Navigation machinery | 1.A.3.d Domestic Navigation |
| Garden-care/professional appliances | 1.A.4.a.ii Commercial/institutional, Off-road vehicles and other machinery |
| Garden-care/hobby appliances | 1.A.4.b.ii Residental, Off-road vehicles and other machinery |
| Agricultural machinery | 1.A.4.c.ii Agriculture/forestry/fishing, Off-road vehicles and other machinery |
| Forestry machinery | 1.A.4.c.ii Agriculture/forestry/fishing, Off-road vehicles and other machinery |
| Military machinery (excl. aviation) | 1.A.5.b Other, mobile, Military |

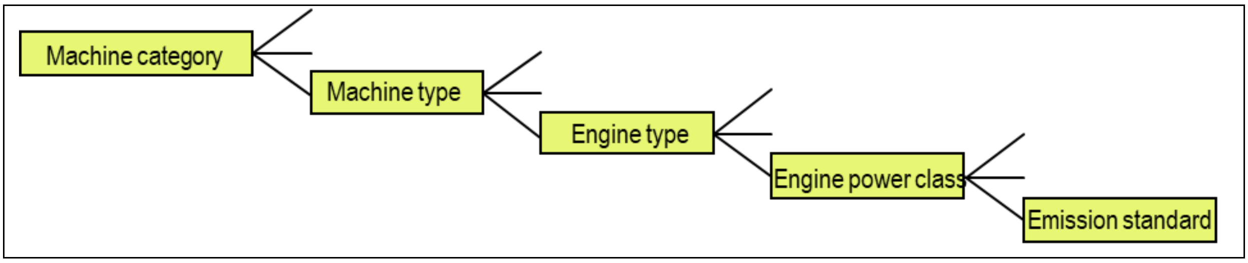


Figure 3-20 Each non-road vehicle is classified by its machine category, machine type, engine type and engine-power class and emission standard (FOEN 2015j, INFRAS 2015a).

The emission modelling is based on activity data and emission factors by means of the following equation, which holds on the most disaggregated level of engine power class (Figure 3-20):

$$Em = N \cdot H \cdot P \cdot \lambda \cdot \varepsilon \cdot CF_1 \cdot CF_2 \cdot CF_3$$

with

| | | |
|---|---|---|
| $Em$ | = | emission per engine type (in g/a) |
| $N$ | = | number of vehicles (--) |
| $H$ | = | number of operation hours per year (h/a) |
| $P$ | = | engine power output (kW) |
| $\lambda$ | = | effective load factor (--) |
| $\varepsilon$ | = | emission factor (g/kWh) |
| $CF_1$ | = | correction factor for the effective load (--) |
| $CF_2$ | = | correction factor for dynamical engine use (--) |
| $CF_3$ | = | degradation factor due to aging (--) |

With this equation, the emissions of the following gases and also the fuel consumption are calculated:

- GHG: $CH_4$, $N_2O$
- precursor gases: $NO_x$, CO
- air pollutant: VOC
- fuel consumption: in this case, $\varepsilon$ represents the consumption instead of emission factor (in g/kWh)

For other gases, the following method is applied:

- $CO_2$ is calculated as product of fuel consumption and $CO_2$ emission factors (according to Table 3-13)

- $SO_2$ is calculated as product of fuel consumption and $SO_2$ emission factors (according to Table A – 13)
- NMVOC is calculated as the difference between VOC and $CH_4$
- $CO_2$ emissions from the use of lubricants as an additive in gasoline for 2-stroke engines are modelled separately and the corresponding $CO_2$ emissions from the lubricants are reported under 2D1 Lubricant use (chp. 4.5.2.1). Non-$CO_2$ emissions from the combustion of lubricants in 2-stroke engines however are reported in the energy sector (1A2gvii, 1A3b, 1A3d, 1A4aii, 1A4bii, 1A4cii, 1A5bii).

The total emission and consumption per non-road category is calculated by taking the sum over all engine-power classes, engine types, machine types and emission standards.

Emissions are only calculated in steps of 5 years from 1980 to 2050. Emissions for years in-between are interpolated linearly. A more detailed description of the analytical details is given in the Annex of FOEN (2015j).

**Emission factors**

Emission factors are taken from various sources based on measurement, modelling and literature.

- $CO_2$ and $SO_2$ emission factors are country-specific, see Table 3-13 and Table A – 13.
- For other gases, the main data sources are USEPA (2010), IFEU (2010), EMEP/EEA (2016), EMEP/EEA (2019) and Integer (2013).

For a detailed description of emission factors and their origin, see tables in the annex of FOEN (2015j) and online in the database belonging to INFRAS (2015a).

**Activity data**

Activity data were collected by surveys among producers and several user associations in Switzerland (FOEN 2015j), and by evaluating information from the national information system for traffic admission (IVZ, formerly MOFIS) run by the Federal Roads Office (FEDRO 2014). In addition, several publications serve as further data sources:

- SBV (2013) for agricultural machinery
- SFSO (2013a) for agricultural machinery
- Jardin Suisse (2012) for garden care /hobby and professional appliances
- KWF (2012) for forestry machinery
- The national statistics on imports/exports of non-road vehicles was assessed by FCA (2015c)
- Off-Highway Research (2005, 2008, 2012) provided information on the number of non-road vehicles.

- Federal Department of Defence, Civil Protection and Sport: List of military machinery with vehicle stock, engine-power classes and operating hours (DDPS 2014a).

From these data sources, all necessary information like size distributions, modelling of the fleets, annual operating hours (age-dependent), load factors, year of placing on the market and age distribution was derived. Details are documented in FOEN (2015j). All activity data (vehicle stocks, operating hours, consumption factors) can be downloaded by query from the public part of the non-road database INFRAS (2015a), which is the data pool of FOEN (2015j). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels.

##### *3.2.4.5.2. Model for wood energy combustion*

**Choice of method**

The emissions from wood combustion in 1A Fuel combustion are calculated by a Tier 2 method based on the decision tree for stationary fuel combustion (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1 on page 2.15).

**Methodology**

The Swiss wood energy statistics (SFOE 2021b) provide both the annual wood consumption for specified categories of combustion installations (table K, categories 1–19, see Table 3-19), and the allocations of the combustion categories to the sectoral consumer categories (table N, household, agriculture/forestry, industry, services, electricity and district heating). This allows for assigning the annual wood consumption at the level of combustion installation categories directly to the source categories 1A1a Public electricity and heat production, 1A2gviii Other, 1A4ai Commercial/institutional, 1A4bi Residential and 1A4ci Agriculture/forestry/fishing (EMIS 2022/1A Holzfeuerungen).

Table 3-19 Categories of wood combustion installations based on the Swiss wood energy statistics (SFOE 2021b).

| **1A Wood combustion, categories** |
| --- |
| Open fireplaces |
| Closed fireplaces, log wood stoves |
| Pellet stoves |
| Log wood hearths |
| Log wood boilers |
| Log wood dual chamber boilers |
| Automatic chip boilers < 50 kW |
| Automatic pellet boilers < 50 kW |
| Automatic chip boilers 50-300 kW w/o wood processing companies |
| Automatic pellet boilers 50-300 kW |
| Automatic chip boilers 50-300 kW within wood processing companies |
| Automatic chip boilers 300-500 kW w/o wood processing companies |
| Automatic pellet boilers 300-500 kW |
| Automatic chip boilers 300-500 kW within wood processing companies |
| Automatic chip boilers > 500 kW w/o wood processing companies |
| Automatic pellet boilers > 500 kW |
| Automatic chip boilers > 500 kW within wood processing companies |
| Combined chip heat and power plants |
| Plants for renewable waste from wood products |

### Emission factors

Emission factors are described in chp. 3.2.4.4.2 for $CO_2$, 3.2.4.4.3 for $CH_4$, and 3.2.4.4.4 for $N_2O$.

### Activity data

Total activity data are based on the Swiss wood energy statistics (SFOE 2021b). As additional data source, specific bottom-up information from the industry is used in order to allocate wood combustion emissions directly to a particular source category. Thus, activity data of wood combustion within 1A2f, 1A2giv and 1A4ci are allocated on the basis of industry information (see Figure 3-17 and EMIS 2022/1A Holzfeuerungen):

- Wood energy consumption in the source categories 1A2f Brick and tile production (2000–2012), 1A2f Cement production and 1A2giv Fibreboard are subtracted from the activity data of 1A2gviii Automatic chip boiler >500 kW without wood processing companies and 1A2gviii Plants for renewable waste from wood products, respectively.
- Since 2013, also the wood energy consumption in 1A4ci Grass drying is available and has been subtracted from the activity data in 1A4ci Automatic chip boiler >500 kW without wood processing companies.

Table 3-20 Wood energy consumption in 1A Fuel combustion.

| **1A Wood combustion** | **1990** | **1995** | **2000** | **2005** | **2010** |
|---|---|---|---|---|---|
| | TJ | | | | |
| Total | 28'219 | 29'700 | 27'425 | 31'395 | 40'084 |
| Open fireplaces | 226 | 270 | 195 | 181 | 124 |
| Closed fireplaces, log wood stoves | 7'272 | 7'167 | 6'486 | 7'036 | 8'520 |
| Pellet stoves | NO | NO | 6.6 | 48 | 151 |
| Log wood hearths | 8'520 | 7'018 | 4'737 | 4'020 | 2'348 |
| Log wood boilers | 5'306 | 5'564 | 5'105 | 5'357 | 4'909 |
| Log wood dual chamber boilers | 1'964 | 1'777 | 977 | 480 | 273 |
| Automatic chip boilers < 50 kW | 239 | 433 | 550 | 753 | 1'008 |
| Automatic pellet boilers < 50 kW | NO | NO | 56 | 804 | 2'106 |
| Automatic chip boilers 50-300 kW w/o wood proc. companies | 461 | 854 | 1'158 | 1'859 | 2'723 |
| Automatic pellet boilers 50-300 kW | NO | NO | 3.5 | 113 | 596 |
| Automatic chip boilers 50-300 kW within wood proc. companies | 897 | 1'188 | 1'217 | 1'366 | 1'533 |
| Automatic chip boilers 300-500 kW w/o wood proc. companies | 237 | 521 | 713 | 998 | 1'496 |
| Automatic pellet boilers 300-500 kW | NO | NO | NO | 19 | 195 |
| Automatic chip boilers 300-500 kW within wood proc. companies | 411 | 568 | 585 | 628 | 669 |
| Automatic chip boilers > 500 kW w/o wood proc. companies | 314 | 1'084 | 1'706 | 2'359 | 4'427 |
| Automatic pellet boilers > 500 kW | NO | NO | NO | 9.5 | 186 |
| Automatic chip boilers > 500 kW within wood proc. companies | 1'393 | 2'193 | 2'398 | 2'801 | 2'993 |
| Combined chip heat and power plants | NO | 3.5 | 186 | 127 | 2'756 |
| Plants for renewable waste from wood products | 979 | 1'060 | 1'345 | 2'438 | 3'071 |

| **1A Wood combustion** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
|---|---|---|---|---|---|---|---|---|---|---|
| | TJ | | | | | | | | | |
| Total | 35'301 | 40'015 | 44'168 | 37'303 | 38'869 | 42'518 | 43'479 | 41'069 | 43'156 | 41'931 |
| Open fireplaces | 87 | 84 | 84 | 62 | 64 | 68 | 67 | 62 | 62 | 58 |
| Closed fireplaces, log wood stoves | 6'960 | 7'787 | 8'604 | 6'825 | 7'446 | 7'862 | 7'540 | 6'926 | 6'943 | 6'376 |
| Pellet stoves | 135 | 163 | 190 | 159 | 181 | 199 | 196 | 186 | 187 | 175 |
| Log wood hearths | 1'621 | 1'566 | 1'454 | 978 | 1'006 | 993 | 900 | 792 | 764 | 675 |
| Log wood boilers | 3'682 | 3'822 | 3'900 | 2'819 | 2'970 | 3'033 | 2'852 | 2'597 | 2'597 | 2'320 |
| Log wood dual chamber boilers | 194 | 190 | 182 | 125 | 119 | 112 | 88 | 67 | 57 | 42 |
| Automatic chip boilers < 50 kW | 799 | 867 | 946 | 739 | 786 | 798 | 742 | 667 | 644 | 559 |
| Automatic pellet boilers < 50 kW | 1'809 | 2'151 | 2'511 | 2'099 | 2'376 | 2'610 | 2'619 | 2'538 | 2'676 | 2'489 |
| Automatic chip boilers 50-300 kW w/o wood proc. companies | 2'344 | 2'762 | 3'164 | 2'628 | 3'009 | 3'324 | 3'347 | 3'222 | 3'336 | 3'169 |
| Automatic pellet boilers 50-300 kW | 578 | 733 | 905 | 843 | 1'068 | 1'284 | 1'425 | 1'459 | 1'565 | 1'550 |
| Automatic chip boilers 50-300 kW within wood proc. companies | 1'314 | 1'428 | 1'539 | 1'281 | 1'400 | 1'487 | 1'484 | 1'421 | 1'418 | 1'362 |
| Automatic chip boilers 300-500 kW w/o wood proc. companies | 1'318 | 1'548 | 1'744 | 1'427 | 1'632 | 1'804 | 1'809 | 1'726 | 1'788 | 1'706 |
| Automatic pellet boilers 300-500 kW | 194 | 246 | 269 | 239 | 277 | 332 | 347 | 343 | 355 | 341 |
| Automatic chip boilers 300-500 kW within wood proc. companies | 593 | 632 | 679 | 565 | 597 | 629 | 620 | 613 | 613 | 594 |
| Automatic chip boilers > 500 kW w/o wood proc. companies | 4'098 | 4'977 | 5'832 | 4'955 | 5'801 | 6'538 | 6'708 | 6'456 | 6'838 | 6'702 |
| Automatic pellet boilers > 500 kW | 223 | 258 | 297 | 281 | 317 | 364 | 362 | 346 | 366 | 346 |
| Automatic chip boilers > 500 kW within wood proc. companies | 2'577 | 2'786 | 2'979 | 2'502 | 2'660 | 2'741 | 2'632 | 2'490 | 2'515 | 2'417 |
| Combined chip heat and power plants | 3'900 | 5'010 | 5'421 | 5'325 | 3'792 | 3'935 | 4'856 | 4'696 | 5'920 | 6'144 |
| Plants for renewable waste from wood products | 2'877 | 3'005 | 3'467 | 3'450 | 3'367 | 4'405 | 4'886 | 4'464 | 4'513 | 4'905 |

### 3.2.4.6. Emissions from biomass (memo item)

$CO_2$ emissions from biomass do not count for the national total emissions and therefore are a memo item only. The $CO_2$ emissions from biomass as reported in the reporting tables are incomplete as the following $CO_2$ emissions from biomass are not foreseen for reporting in the reporting tables: 2G4 Use of tobacco, 2H2 Food and beverages, 5A Solid waste disposal, 5B Biological treatment of solid waste, 5D Wastewater treatment and discharge as well as 6 Other. In contrast, $CO_2$ emissions from biomass from source category 5C Incineration and open burning of waste are included in CRF Table5.C, but not accounted for the total $CO_2$ emissions from biomass as shown in CRF Summary1.As3, CRF Summary2, CRF Table10s1 and CRF Table10s2 (these tables include $CO_2$ emissions from biomass from sector 1 Energy only).

Table 3-21 provides an overview of latest effective $CO_2$ emissions from biomass and their reporting in the reporting tables (without land use, land-use change and forestry). For further information on the $CO_2$ emissions from biomass refer to the chapters of the respective source categories.

Table 3-21 Effective $CO_2$ emissions from biomass in the latest inventory year and their representation in the reporting tables.

| **$CO_2$ emissions from biomass** | **2020** kt | **Note** |
|---|---|---|
| 1A1 Energy industries (without MSW incineration) | 434 | Included in reporting tables |
| 1A1 Energy generation from MSW Incineration | 2'327 | Included in reporting tables |
| 1A2 Manufacturing industries and construction | 1'547 | Included in reporting tables |
| thereof use of waste derived fuels in cement production | 73 | |
| thereof use of biofuels (1A2gvii) | 24 | |
| 1A3 Transport | 500 | Included in reporting tables |
| 1A4 Other sectors (Commercial/institutional, residential) | 2'979 | Included in reporting tables |
| 1A5 Other | 0.72 | Included in reporting tables |
| 2H2 Food and beverages industry | 15 | Not included in reporting tables |
| 2G Other product use (Consumption of tabacco) | 10 | Not included in reporting tables |
| 5A Solid waste disposal | 36 | Not included in reporting tables |
| 5B Biological treatment of solid waste (composting and anaerobic digestion) | 169 | Not included in reporting tables |
| 5C Incineration and open burning of waste (without MSW incineration) | 115 | Included in CRF Table5.C, but not accounted for in the summary reporting tables |
| 5D Wastewater treatment and discharge | 4.3 | Not included in reporting tables |
| 6 Other | 2.5 | Not included in reporting tables |
| Total $CO_2$ emissions from biomass in Switzerland in 2020 | 8'140 | |
| Total $CO_2$ emissions from biomass included in the following summary reporting tables (energy-related $CO_2$ emissions from biomass combustion included in sector 1 Energy): CRF Summary1.As3, CRF Summary2, CRF Table10s1 and CRF Table10s2 | 7'787 | |

### 3.2.4.7. Uncertainty and time series consistency for source category 1A

In the following, basic uncertainties of AD and EF $CO_2$ by fuel type are presented for source category 1A Fuel combustion.

Table 3-22 Uncertainties of activity data, $CO_2$ emission factors and $CO_2$ emissions for 1A Fuel combustion.

| **Fuel type** | **Uncertainties** | | |
|---|---|---|---|
| | **Activity data** | **$CO_2$ emission factors** | **$CO_2$ emissions** |
| | **%** | | |
| kerosene | 0.96 | 0.16 | 0.97 |
| gasoline | 0.69 | 0.13 | 0.70 |
| diesel oil | 0.88 | 0.068 | 0.88 |
| liquid fuels | 0.69 | 0.081 | 0.69 |
| solid fuels | 5 | 5.1 | 7.1 |
| gaseous fuels | 5 | 0.88 | 5.1 |
| other fuels | 5 | 9.2 | 10 |
| biomass | 10 | -- | -- |

#### Liquid fuels

***Uncertainty of the $CO_2$ emission factors:*** In 2013, a large measurement campaign was carried out to determine the $CO_2$ emission factors of the dominant liquid fuels (SFOE/FOEN 2014). From the standard deviation presented in this study, the 95% uncertainties are derived and shown in Table 3-23 as lower and upper values as well as relative uncertainties.

For mobile combustion, the 2006 IPCC Guidelines provide default uncertainties for the $CO_2$ emission factors of 2% for kerosene, 4% for gasoline and 1% for diesel oil (IPCC 2006, vol. 2, TABLE 3.2.1). Switzerland's measurements indicate much lower uncertainties. For stationary combustion, the 2006 IPCC Guidelines give no default values but show instead a summary of an uncertainty assessment of $CO_2$ emission factors for selected countries (IPCC 2006, vol. 2, TABLE 2.13). The values lie in the range between 0.5% and 3% and are again higher than the values derived from the Swiss measurements.

Table 3-23 Uncertainties of aggregated results of measurements of the $CO_2$ emission factors of selected liquid fuels (SFOE/FOEN 2014).

| **Fuel type** | **$CO_2$ emission factors (measurements)** | | | **95% uncertainties EF ($CO_2$)** | | **no. samples** |
|---|---|---|---|---|---|---|
| | mean | lower | upper | absolute | relative | |
| | t/TJ | t/TJ | t/TJ | t/TJ | % | |
| Kerosene | 72.81 | 72.70 | 72.93 | 0.12 | 0.16% | 24 |
| Gasoline | 73.80 | 73.71 | 73.90 | 0.10 | 0.13% | 138 |
| Diesel oil | 73.30 | 73.25 | 73.35 | 0.05 | 0.07% | 75 |
| Gas oil | 73.67 | 73.61 | 73.73 | 0.06 | 0.08% | 138 |

***Uncertainties of activity data:*** The values shown in Table 3-24 are based on a written message of SFOE to FOEN (SFOE 2012a). It lists two kinds of relevant sources of uncertainties: measurement uncertainties and uncertainties of the conversion from mass to energy units. For diesel oil, the transformation to other products represents a third source of uncertainty. Since the used equations are multiplications, the relative uncertainties have to be summed up.

Table 3-24 Sources of uncertainties contributing to the total uncertainty of the activity data of selected liquid fuels (SFOE 2012a).

| **Source of uncertainty** | **kerosene** | **gasoline** | **diesel oil** | **gasoil** |
|---|---|---|---|---|
| | activity data uncertainty in % | | | |
| Measurement | 0.39% | 0.39% | 0.39% | 0.39% |
| Conversion mass to energy | 0.57% | 0.29% | 0.29% | 0.29% |
| Product transformation | - | - | 0.20% | - |
| Total Uncertainty | 0.96% | 0.69% | 0.88% | 0.69% |

### Gaseous fuels

***Uncertainty of the $CO_2$ emission factor:*** The composition of the imported gas is analysed in detail at the import stations. From this information, the FOEN annually calculates the $CO_2$ emission factor for each import station and the weighted mean. To estimate the uncertainty of the emission factor, the weighted standard deviation is calculated and is multiplied by a factor of 1.96 to represent a 95% uncertainty interval. This calculation has been carried out for all years with available data (selected years between 1990 and 2009 and all years thereafter). The uncertainties fluctuate from year to year. For the uncertainty analysis, the following values for the uncertainty of the $CO_2$ emission factor for gaseous fuels are used: 1.48% for 1990 and of 0.39% for 2020.

***Uncertainty of activity data:*** There is no country-specific estimate of the uncertainty for the consumption of natural gas. It is taken from the 2006 IPCC Guidelines (IPCC 2006, vol. 2, Table 2.15), which give a range of 2%–5% for industrial combustion and 3%–5% for commercial, institutional and residential combustion. For Switzerland, an overall value of 5% is used.

**Solid fuels**

***Uncertainty of the $CO_2$ emission factor:*** There is no country-specific uncertainty available. The 2006 IPCC Guidelines suggest a range from 0.5% to 10% (IPCC 2006, vol. 2, Table 2.13). For Switzerland, an uncertainty of 5% is chosen (mean of suggested range).

***Uncertainty of activity data:*** There is no country-specific estimate of the uncertainty for the consumption of coal. It is taken from the 2006 IPCC Guidelines (IPCC 2006, vol. 2, Table 2.15), which give a range of 2%–5% for industrial combustion and 3%–5% for commercial, institutional and residential combustion. For Switzerland, an overall value of 5% is used (as for natural gas).

**Other fuels (waste-to-energy)**

***Uncertainty of the $CO_2$ emission factor:*** There are two factors influencing the uncertainty of $CO_2$ emissions from municipal solid waste incineration (1A1a), namely the carbon content of waste and the fossil carbon fraction of the carbon content.

- The carbon content is determined according to a study by Fellner et al. (2007). The relation between the calorific value of waste and the carbon content is derived therein, including upper and lower limits. The relation is verified by measurements. The relative difference between upper and lower limits (5.9%) is interpreted as 95% confidence interval for the carbon content.
- The fossil fraction of the carbon content was determined in a study by Mohn et al. (2011). The radio carbon ($^{14}C$) method was applied in the field to calculate the ratio of fossil versus biogenic $CO_2$ emissions from five waste-to-energy plants. Gas samples for $^{14}CO_2$ analysis were taken at the plants during miscellaneous seasons. Six field campaigns of three weeks were carried out for three plants and three field campaigns, again of three weeks, were carried out for two plants, leading to a total measurement time of 72 weeks. The field campaigns provided a median and (absolute) 95% confidence interval of the fossil fraction of (47.7±7.5)% (Table 3-25). The relative uncertainty was thus 15.8%. The results fit well to former field campaigns on three plants, which yielded a mean fossil fraction of 48.0% (Mohn et al. 2008). For the greenhouse gas inventory and its uncertainty analysis the latest results from Mohn et al. (2011) are used.
- The emission factor for fossil $CO_2$ results from the multiplication of the carbon content and the fossil fraction. The relative uncertainty of the $CO_2$ emission factor is thus computed using uncertainty propagation: $[(5.9\%)^2 + (15.8\%)^2]^{0.5} = 16.9\%$.

Table 3-25 Fossil fractions of municipal solid waste measured at five different incineration plants. The absolute uncertainty values (3rd col.) are expressed in the same unit as the shares, in %.

| Plant | Fossil shares | Uncertainty (95% confidence interval) | | Field campaigns |
|---|---|---|---|---|
| | | absolute | relative | (duration) |
| | % | % | % | weeks |
| Buchs | 47.7 | | | 6 * 3 = 18 |
| Winterthur | 43.4 | | | 6 * 3 = 18 |
| Linthgebiet | 50.6 | | | 6 * 3 = 18 |
| Linthgebiet | 54.5 | | | 3 * 3 = 9 |
| Zuchwil | 45.9 | | | 3 * 3 = 9 |
| Median / sum | 47.7 | 7.5 | 15.8 | 72 |

***Uncertainty of activity data:*** There is no country-specific estimate of the uncertainty for the combustion of waste. It is taken from the 2006 IPCC Guidelines (IPCC 2006, vol. 2, p. 2.40), which state: “Experts believe that the uncertainty resulting from the two errors (*systematic, random*) combined is probably in the range of ±5% for most developed countries.” In accordance with that statement, the value of 5% is used.

### Biomass

***Uncertainty of the $CO_2$ emission factor:*** For $CO_2$ emissions of biomass burning, no uncertainty is estimated (memo item).

***Uncertainty of activity data:*** No country-specific uncertainty of the activity data is available. The 2006 IPCC Guidelines suggest 2%–5% for industrial, institutional and residential combustion and 10%–30% for biomass burning in small sources (IPCC 2006, vol. 2, Table 2.15). An average uncertainty of 10% is applied for biomass burning in all source categories.

### Uncertainty of $CH_4$ and $N_2O$ emission factors

Since the $CO_2$ emissions vastly dominate the GHG emissions of source category 1A (almost 99%), the uncertainty evaluation of the non-$CO_2$ emissions is carried out on a semi-quantitative level (see Table 3-26).

Only for **1A3b Road transportation**, a quantitative analysis has been performed. Following a study for the road transportation in Germany (IFEU/INFRAS 2009), where the same handbook of emission factors is used as in Switzerland, the uncertainties for the $CH_4$ and $N_2O$ emission factors have been determined (see rows 1A3b gasoline and diesel oil in Table 3-26). The uncertainties of $CH_4$ and $N_2O$ emissions of CNG (1A3b), which were not investigated in IFEU/INFRAS (2009), have been estimated qualitatively as “medium” according to Table 1-10. For the source categories **1A1, 1A2, 1A3a, 1A3c, 1A3d, 1A3e, 1A4a, 1A4b, 1A4c, 1A5** the uncertainties of $CH_4$ and $N_2O$ emissions have similarly been estimated qualitatively (see Table 3-26).

### Summary

Table 3-26 provides a summary of the uncertainties of 1A Fuel combustion as derived in the preceding sections. The combined uncertainty assigned to the $CO_2$ emissions is computed by propagating the uncertainties of the activity data and the emission factors.

Table 3-26 Uncertainties of 1A Fuel combustion categories for activity data, emission factors and combined uncertainties for 2020. The latter are calculated by uncertainty propagation (approach 1). For 1A2/Other Fuels a mean uncertainty is assumed based on semi-quantitative estimations from Table 1-10. The emission factor uncertainty is calculated “backward” ($U(EF) = \sqrt{U(EM)^2 - U(AD)^2}$) from the combined and the activity data uncertainty. $CH_4$ and $N_2O$: semi-quantitative uncertainties are used (see Table 1-10). For 1990, uncertainties are generally the same as for 2020, except for the $CO_2$ emission factor for gas (1.48% for 1990).

| 1A Fuel Combustion Categories | Fuel type | Uncertainties | | | | |
|---|---|---|---|---|---|---|
| | | Activity data | $CO_2$ em. factors | $CO_2$ emissions | $CH_4$ emissions | $N_2O$ emissions |
| | | % | % | % | -- | -- |
| 1. Energy industries | liquid fuels | 0.69 | 0.081 | 0.69 | medium | medium |
| 1. Energy industries | solid fuels | 5.0 | 5.1 | 7.1 | medium | medium |
| 1. Energy industries | gaseous fuels | 5.0 | 0.39 | 5.0 | medium | medium |
| 1. Energy industries | other fuels | 5.0 | 9.2 | 10 | medium | medium |
| 2. Manufacturing industries and construction | liquid fuels | 0.69 | 0.081 | 0.69 | medium | medium |
| 2. Manufacturing industries and construction | solid fuels | 5.0 | 5.1 | 7.1 | medium | medium |
| 2. Manufacturing industries and construction | gaseous fuels | 5.0 | 0.39 | 5.0 | medium | medium |
| 2. Manufacturing industries and construction | other fuels | 5.0 | 9.2 | 10 | medium | medium |
| 3a. Transport; Domestic aviation | kerosene | 0.96 | 0.16 | 0.97 | high | high |
| 3b. Transport; Road transportation | gasoline | 0.69 | 0.13 | 0.70 | 37% | 50% |
| 3b. Transport; Road transportation | diesel oil | 0.88 | 0.068 | 0.88 | 20% | 22% |
| 3b. Transport; Road transportation | gaseous fuels | 5.0 | 0.39 | 5.0 | medium | medium |
| 3c. Transport; Railways | diesel oil | 0.88 | 0.068 | 0.88 | medium | high |
| 3d. Transport; Domestic navigation | liquid fuels | 0.69 | 0.081 | 0.69 | medium | high |
| 3e. Transport; Other transportation | gaseous fuels | 5.0 | 0.39 | 5.0 | medium | medium |
| 4a. Other sectors; Commercial/institutional | liquid fuels | 0.69 | 0.081 | 0.69 | medium | medium |
| 4a. Other sectors; Commercial/institutional | gaseous fuels | 5.0 | 0.39 | 5.0 | medium | medium |
| 4b. Other sectors; Residential | liquid fuels | 0.69 | 0.081 | 0.69 | medium | medium |
| 4b. Other sectors; Residential | solid fuels | 5.0 | 5.1 | 7.1 | medium | medium |
| 4b. Other sectors; Residential | gaseous fuels | 5.0 | 0.39 | 5.0 | medium | medium |
| 4c. Other sectors; Agriculture/forestry/fishing | liquid fuels | 0.69 | 0.081 | 0.69 | medium | medium |
| 4c. Other sectors; Agriculture/forestry/fishing | gaseous fuels | 5.0 | 0.39 | 5.0 | medium | medium |
| 5. Other | liquid fuels | 0.69 | 0.081 | 0.69 | medium | high |
| 1A Stationary sources | biomass | 10 | -- | -- | medium | medium |
| 1A Mobile sources | biomass | 10 | -- | -- | high | high |

### Time series consistency 1A

Time series for 1A Fuel combustion are all considered consistent.

## 3.2.4.8. Category-specific QA/QC and verification for source category 1A

Various QA/QC activities are relevant for all source categories in 1A. Therefore, they are briefly described here and not repeated in the chapters dealing with the source categories 1A1 to 1A5.

### Comparison of emission estimates using different approaches

At the level of total energy-related $CO_2$ emissions, a quality control consists in the comparison of emissions modelled using the sectoral approach with emissions calculated based directly on fuel consumption according to the Swiss overall energy statistics (SFOE 2021). The differences in total $CO_2$ emissions for the entire time period are negligible, indicating the completeness of the inventory.

The cross-check of the Reference and Sectoral Approach is also used for an assessment of emissions related to the consumption of fuels in the energy sector. Again, a good agreement between the two approaches is found (see chp. 3.2.1).

### Activity data checks

The SFOE constructs a national commodity balance expressed in mass and in energy units including mass balances of fuel conversion industries.

The gross carbon supply in the Reference Approach has been adjusted for fossil fuel carbon destined for non-energy use. The numbers in the Swiss overall energy statistics (SFOE 2021) are consistent with those provided by international organisations, e.g. IEA.

### Emission factor check and review

Emission factors for the main fossil fuels have been reassessed for submission 2015. In 2013, the Swiss Federal Office of Energy (SFOE) and the Swiss Federal Office for the Environment (FOEN) launched an in-depth investigation into the NCVs and $CO_2$ emission factors of gas oil, diesel oil, gasoline, and kerosene (SFOE/FOEN 2014, see chp. 3.2.4.2). The most recent results differ only marginally from previously used values. The $CO_2$ emission factors compare well with the IPCC default values (see Table 3-27).

Table 3-27 Comparison of default $CO_2$ emission factors from IPCC (2006) with current country-specific values of Switzerland for selected fuels.

| **$CO_2$ emission factors** | **IPCC 2006** | | | **Switzerland** |
|---|---|---|---|---|
| | lower | upper | default | CS |
| | t $CO_2$ /TJ | | | t $CO_2$ /TJ |
| Gasoline | 67.5 | 73.0 | 69.3 | 73.8 |
| Jet kerosene | 69.7 | 74.4 | 71.5 | 72.8 |
| Diesel oil | 72.6 | 74.8 | 74.1 | 73.3 |
| Gas oil | 72.6 | 74.8 | 74.1 | 73.7 |

Switzerland's country-specific $CO_2$ emission factor for gasoline is higher than the upper limit of the IPCC range (Table 3-27). However, the value is based on more than 100 fuel samples taken from July to December 2013 (SFOE/FOEN 2014) and is in agreement with earlier measurements (EMPA 1999). Accordingly, the value is considered to correctly represent national circumstances.

For natural gas, the $CO_2$ emission factor is annually assessed. A country-specific $CO_2$ emission factor is calculated based on measurements of gas properties and corresponding import shares of individual gas import stations (see chp. 3.2.4.4). The resulting values are largely consistent with the $CO_2$ EF used by the countries from which gas is imported (i.e. Germany, the Netherlands, Norway, France, Italy and Denmark, with IEFs between 55.8 and 57.6 t $CO_2$/TJ, based on submissions in 2021).

For submission 2021, the $CH_4$ emission factors from combustion of wood were scrutinized and revised based on Zotter et al. (2022). The range of country-specific values is not entirely consistent with the lower IPCC default values (1A1, 1A2, Table 3-28). However, as the country-specific emission factors are based on an extensive measurement campaign, they are considered representative for Swiss circumstances.

Table 3-28 Comparison of default $CH_4$ emission factors from the 2006 IPCC Guidelines (IPCC 2006) with country-specific values for wood/wood waste.

| **$CH_4$ emission factors** | **IPCC 2006** | | | **Switzerland** |
|---|---|---|---|---|
| | lower | upper | default | CS |
| | kg $CH_4$ /TJ | | | kg $CH_4$ /TJ |
| Wood/wood waste | 10 (1A1, 1A2)<br>100 (1A4) | 100 (1A1, 1A2)<br>900 (1A4) | 30 (1A1, 1A2)<br>300 (1A4) | 0.2 - 200 |

**Expert review**

As described in chp. 1.2.3, data from source category 1A and the initial draft of the NIR were scrutinized in an external review involving national experts and stakeholders in the different fields related to emissions from stationary sources.

### 3.2.4.9. Planned improvements for source category 1A in general

No general improvements for 1A are planned.

## 3.2.5. Source category 1A1 – Energy industries (stationary)

### 3.2.5.1. Source category description for 1A1 (stationary)

Table 3-29 Key categories of 1A1 Energy industries. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| **Code** | **IPCC category** | **Gas** | **Identification criteria** |
|---|---|---|---|
| 1A1 | Energy Industries; Gaseous Fuels | CO2 | L1, T1 |
| 1A1 | Energy Industries; Liquid Fuels | CO2 | L1, T1 |
| 1A1 | Energy Industries; Other Fuels | CO2 | L1, T1, L2, T2 |

Source category 1A1 Energy industries comprises emissions from fuels combusted by the fuel extraction and energy-producing industries. The most important source category is 1A1a

Public electricity and heat production, followed by 1A1b Petroleum refining. Activities in source category 1A1c Manufacture of Solid Fuels and other energy industries are virtually not occurring in Switzerland (apart from a tiny charcoal production activity in historic trade).

Within source category 1A1a, heat and electricity production in waste incineration plants cause the largest emissions, as electricity production in Switzerland is dominated by hydroelectric power plants and nuclear power stations (SFOE 2021). Emissions from industries producing heat and/or electricity (CHP) for their own use are included in category 1A2 Manufacturing Industries and Construction.

Table 3-30 Specification of source category 1A1 Energy Industries.

| 1A1 | Source category | Specification |
|---|---|---|
| 1A1a | Public electricity and heat production | Main source are waste incineration plants with heat and power generation (Other fuels) and public district heating systems. The only fossil fuelled public electricity generation unit "Vouvry" (300 MWe; no public heat production) ceased operation in 1999. |
| 1A1b | Petroleum refining | Combustion activities supporting the refining of petroleum products, excluding evaporative emissions. |
| 1A1c | Manufacture of solid fuels and other energy industries | Charcoal production |

### 3.2.5.2. Methodological issues for 1A1 (stationary)

#### *3.2.5.2.1. Public electricity and heat production (1A1a)*

Public electricity and heat production in Switzerland encompasses different plant types where various fuels are used (Table 3-31). Energy recovery from municipal solid waste and special waste incineration is mandatory in Switzerland (Swiss Confederation 2015, Art. 27) and plants are equipped with energy recovery systems. The emissions from municipal solid waste and special waste incineration plants are therefore reported under category 1A1a. There was a single fossil fuel power station operating with residual fuel oil in Vouvry. However, the power station closed down in 1999.

Table 3-31 Plant type and fuels used in source category 1A1a.

| Plant type | Fuel type |
|---|---|
| Heat plants for renewable wastes | wood waste (biomass) |
| Heating boilers > 300 MW (Vouvry) | residual fuel oil |
| Heating boilers < 300 MW | gas oil, residual fuel oil, bituminous coal |
| Central heating boilers for district heating | natural gas, gas oil, residual fuel oil, bituminous coal |
| Wood combined heat and power generation | wood, wood waste (biomass) |
| Engines on landfill sites | landfill gas (biogas) |
| Municipal solid waste incineration plants | municipal solid waste (other, waste-to-energy) |
| Special waste incineration plants | special wastes (other, waste-to-energy) |

**Methodology (1A1a)**

For $CO_2$ emissions in source category 1A1a Public electricity and heat production, a country-specific approach is used combining Tier 2 and Tier 3 methods (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1). For $CH_4$ emissions, a Tier 2 method was applied using IPCC default emission factors (IPCC 2006), except for biomass, where country-specific emission factors are used. For $N_2O$ IPCC default values are used (Tier 1, IPCC 2006), except for municipal solid waste and special waste incineration plants, where country-specific emission factors were used (Tier 2).

**Emission factors (1A1a)**

Table 3-32 presents the emission factors used in 1A1a. Emission factors for gas oil, natural gas, biomass and biogas (highlighted green in Table 3-32) are further explained in chp. 3.2.4.4.

Table 3-32 Emission factors for 1A1a Public Electricity and Heat Production in 2020.

| 1A1a Public electricity and heat production | $CO_2$ | $CO_2$ biog. | $CH_4$ | $N_2O$ | $NO_x$ | NMVOC | $SO_2$ | CO |
|---|---|---|---|---|---|---|---|---|
| | t/TJ | | kg/TJ | | | | | |
| Gas oil | 73.7 | NA | 3.0 | 0.6 | 32 | 2 | 6.5 | 6 |
| Residual fuel oil | NO | NA | NO | NO | NO | NO | NO | NO |
| Petroleum coke | NO | NA | NO | NO | NO | NO | NO | NO |
| Natural gas | 56.2 | NA | 1.0 | 0.1 | 17 | 2 | 0.5 | 9 |
| Other (waste-to-energy), fossil | 88.8 | NA | NE | 1.1 | 32.1 | 2.8 | 4.1 | 6.5 |
| Other (waste-to-energy), biogenic | NA | 91.9 | NE | 1.1 | | | | |
| Biomass (wood, renewable waste) | NA | 99.9 | 0.3 | 4.0 | 55 | 0.41 | 4.1 | 18 |
| Biogas (co-generation from landfills) | NA | 56.2 | 20 | 0.1 | 119 | 1 | 0.5 | 198 |

*Emission factors for waste incineration and landfill gas use*

Specific emission factors within 1A1a Public electricity and heat production apply for municipal solid waste incineration, special waste incineration and for landfill gas use. The emission factors for $CO_2$, $NO_x$, CO, NMVOC and $SO_2$ are country-specific and based on measurements and expert estimates. Emission factors for $CH_4$ and $N_2O$ are IPCC default values (IPCC 2006), with the exception of waste and biomass as fuel, where country-specific emission factors are applied. Emission factors are documented in EMIS 2022/1A1a Kehrichtverbrennungsanlagen, EMIS 2022/1A1a Sondermüllverbrennungsanlagen and EMIS 2022/1A1a & 5A Kehrichtdeponien.

*Source-specific $CO_2$ emission factors for municipal solid waste incineration plants*

C-content of waste is calculated based on the net calorific value, which is deduced by a standard method and published on a yearly basis since 2009 by SFOE for each municipal solid waste incineration plant and as a Swiss average (FOEN/SFOE/VBSA 2021). In deviation from the general description of oxidation factors in chp. 3.2.4.4.1, an oxidation factor of 0.99 is assumed here. The assumption is based on measurements in two municipal solid waste incineration plants in Zurich (AWEL 2009) and on a study in Austria (Zeschmar-Lahl 2004), where the municipal solid waste incineration plants have the same standards as in Switzerland. The measurements in Zurich showed transfer coefficients into air of 0.96–0.99 and the ones in Austria stated a transfer coefficient into clean air of 0.989.

The fossil fraction of waste incinerated in municipal solid waste incineration plants is based on a study conducted in the year 2014 (Rytec 2014). The study uses data from three measurement campaigns during which the waste composition has been analysed (FOEN 2014o) and measurements of the radioactive isotope carbon-14 ($^{14}C$) in the flue gas for calibration have been made (Mohn et al. 2011). The $CO_2$ emission factor in municipal solid waste incineration plants fluctuates over the reporting period because of gradual changes in the net calorific values of the waste (Table 3-33).

Table 3-33 Emission factor $CO_2$ total, share of $CO_2$ fossil and net calorific value (NCV) in municipal solid waste incineration plants (MSWIP).

| 1A1a Public electricity and heat production, Other fossil fuels | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| $CO_2$ total (MSWIP) | t/TJ | 92.80 | 91.86 | 91.09 | 91.49 | 92.32 |
| Share of $CO_2$ fossil (MSWIP) | 1 | 0.497 | 0.505 | 0.513 | 0.505 | 0.486 |
| NCV of waste (MSWIP) | TJ/t | 0.0114 | 0.0119 | 0.0124 | 0.0121 | 0.0117 |

| 1A1a Public electricity and heat production, Other fossil fuels | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $CO_2$ total (MSWIP) | t/TJ | 92.25 | 92.62 | 92.76 | 92.43 | 92.28 | 92.01 | 91.92 | 91.90 | 91.85 | 91.86 |
| Share of $CO_2$ fossil (MSWIP) | 1 | 0.482 | 0.478 | 0.478 | 0.478 | 0.478 | 0.478 | 0.478 | 0.478 | 0.478 | 0.478 |
| NCV of waste (MSWIP) | TJ/t | 0.0117 | 0.0115 | 0.0114 | 0.0116 | 0.0117 | 0.0118 | 0.0119 | 0.0119 | 0.0119 | 0.0119 |

Sodium bicarbonate and calcium carbonate are used in some municipal solid waste incineration plants for flue gas treatment. Sodium bicarbonate is used since 2013 and calcium carbonate was used between 1990 and 2005. According to IPCC 2006, the corresponding emissions are reported in source category 2A4d.

*Source-specific $CO_2$ emission factors for special waste incineration plants*

Based on detailed information regarding waste composition and estimated emission factors in the years 1992–2004, a weighted average emission factor for special waste incineration was calculated. Special waste is assumed to be of entirely fossil origin. Overall, a specific emission factor of 1.45 t $CO_2$/t waste results for special waste. This value is considerably higher than the one reported in SAEFL (2000). As there is no newer data on the special waste composition, the emission factor deduced as described above is used for the whole period from 1990 until today. See documentation in EMIS 2022/1A1a Sondermüllver-brennungsanlagen.

*Source-specific $CH_4$ emission factors in municipal and special waste incineration plants*

Emissions of $CH_4$ are not occurring in waste incineration plants because of the high temperatures and the long dwell time in the combustion chamber as confirmed by Mohn (2013). In the year 2013, Empa assessed the $N_2O$ and $CH_4$ emission factors for municipal solid waste incineration plants (Mohn 2013). In this study, Empa evaluated measurements that were performed in 2011 in five Swiss municipal solid waste incineration plants with different Denox techniques (SCR, SNCR). For most of the measurements, $CH_4$ concentrations were below the detection limit of 0.3 ppm. The study concluded that "$CH_4$ emission concentrations were very low and below the background concentration of 1.8 ppm". These measurements, which showed that $CH_4$ concentration in the exhaust air was below the $CH_4$ concentration in ambient air, would point to $CH_4$ removal rather than emissions occurring. Therefore, $CH_4$ emissions from municipal waste incineration are reported as not estimated because they are considered insignificant. The same fact applies for special waste incineration.

*Source-specific $N_2O$ emission factors for municipal solid waste incineration*

In 2013, a study evaluated $N_2O$ measurements that have been performed in the years 2010–2011 in the flue gas of five Swiss municipal waste incineration plants (Mohn 2013) and derived plant-specific emission factors for Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR) equipped installations.

Average Swiss emission factors have been calculated according to the state of equipment of all Swiss waste incineration plants (with two types of Denox-equipment (SCR, SNCR) and without Denox-equipment). For installations without Denox-equipment, the emission factor comes from SAEFL (2000). According to the state of equipment of all Swiss waste incineration plants in the years 1990, 1994, 1998, 2004, 2008, 2012, 2016 and 2020, weighted average $N_2O$ emission factors have been calculated, based on the amounts of waste burnt in every plant. For the years in between, the $N_2O$ emission factors were linearly interpolated. Since 2020, the emission factor is assumed to be constant (however the emission factor related to energy changes by reason of the conversion with the net calorific value of waste). It is planned to calculate new weighted averages for the $N_2O$ emission factors periodically every four years, depending on data available; see documentation in EMIS 2022/1A1a Kehricht- und Sondermüllverbrennungsanlagen. The emission factor is therefore not constant over time.

*Source-specific $N_2O$ emission factors for special waste incineration*

The emission factor of special waste for the year 1990 is based on SAEFL (2000). It is assumed that this value (3.1 g/GJ) then increases until 2003 (6.1 g/GJ) due to the installation of Denox-equipment and thereafter declines as a result of optimized installations.

Table 3-34 $N_2O$ emission factors of municipal solid (MSWIP) and special waste incineration plants (SWIP) in 1A1a Public electricity and heat production.

| 1A1a Public electricity and heat production, Other fossil fuels | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| $N_2O$ (MSWIP) | kg/TJ | 5.26 | 2.96 | 2.06 | 1.44 | 1.40 |
| $N_2O$ (SWIP) | kg/TJ | 3.06 | 4.23 | 5.41 | 5.48 | 3.89 |

| 1A1a Public electricity and heat production, Other fossil fuels | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_2O$ (MSWIP) | kg/TJ | 1.40 | 1.43 | 1.37 | 1.29 | 1.21 | 1.13 | 1.13 | 1.13 | 1.12 | 1.12 |
| $N_2O$ (SWIP) | kg/TJ | 3.57 | 3.25 | 2.94 | 2.62 | 2.30 | 1.98 | 1.67 | 1.35 | 1.03 | 0.71 |

## Activity data (1A1a)

Activity data for liquid, gaseous, solid fuels and wood are based on the Swiss overall energy statistics (SFOE 2021) and additional data sources as described in chp. 3.2.4.3. Activity data for Other fuels are based on the amount of waste incinerated in MSWIPs and SWIPs (FOEN 2021h, see Table 3-36). Activity data for combined heat and power generation in landfills are taken from the Swiss renewable energy statistics (SFOE 2021a).

Please note that waste-to-energy activities in CRF Table1.A(a)s1 are allocated to fuel types ‘Other fossil fuels’ and ‘Biomass’. ‘Other fossil fuels’ encompasses emissions from the fossil shares of MSWIP and SWIP. Whereas ‘Biomass’ covers emissions from wood, waste wood, landfill gas use in co-generation and biogenic share from MSWIP.

Table 3-35 Activity data in 1A1a Public Electricity and Heat Production.

| 1A1a Public electricity and heat production | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Total fuel consumption | | 40'379 | 39'179 | 49'913 | 56'976 | 61'740 |
| Gas oil | TJ | 980 | 554 | 790 | 1'300 | 490 |
| Residual fuel oil | TJ | 3'214 | 1'813 | 340 | 290 | 40 |
| Petroleum coke | TJ | NO | NO | NO | NO | NO |
| Other bituminous coal | TJ | 530 | 46 | NO | NO | NO |
| Lignite | TJ | NO | NO | NO | NO | NO |
| Natural gas | TJ | 4'339 | 5'422 | 8'292 | 9'827 | 9'926 |
| Other (waste-to-energy), fossil | TJ | 16'605 | 16'870 | 22'482 | 24'711 | 26'002 |
| Biomass | TJ | 14'711 | 14'474 | 18'009 | 20'848 | 25'282 |
| Other (waste-to-energy), biogenic | TJ | 14'163 | 13'394 | 16'889 | 19'797 | 22'275 |
| Biomass (wood, renewable waste) | TJ | 301 | 466 | 547 | 844 | 2'958 |
| Biogas (co-generation from landfills) | TJ | 247 | 614 | 573 | 207 | 49 |

| 1A1a Public electricity and heat production | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total fuel consumption | | 59'796 | 63'402 | 63'334 | 59'366 | 61'381 | 65'016 | 64'743 | 65'334 | 66'495 | 65'476 |
| Gas oil | TJ | 400 | 800 | 670 | 770 | 660 | 430 | 490 | 380 | 450 | 340 |
| Residual fuel oil | TJ | 10 | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Petroleum coke | TJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Other bituminous coal | TJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Lignite | TJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Natural gas | TJ | 7'512 | 8'213 | 8'449 | 5'082 | 7'080 | 8'956 | 7'927 | 8'141 | 8'464 | 7'541 |
| Other (waste-to-energy), fossil | TJ | 25'575 | 26'262 | 25'738 | 26'049 | 26'832 | 27'657 | 27'430 | 27'997 | 28'285 | 27'918 |
| Biomass | TJ | 26'299 | 28'127 | 28'476 | 27'464 | 26'809 | 27'972 | 28'896 | 28'817 | 29'297 | 29'678 |
| Other (waste-to-energy), biogenic | TJ | 22'272 | 23'051 | 22'489 | 23'112 | 23'716 | 24'765 | 24'886 | 25'100 | 25'267 | 25'331 |
| Biomass (wood, renewable waste) | TJ | 3'982 | 5'032 | 5'949 | 4'321 | 3'071 | 3'195 | 4'003 | 3'711 | 4'021 | 4'343 |
| Biogas (co-generation from landfills) | TJ | 44 | 44 | 39 | 31 | 21 | 13 | 6.5 | 6.0 | 8.4 | 4.0 |

Since 1990 the use of waste-derived fuels increased considerably. This is due to the fact that since 1st of January 2000, disposal of combustible wastes in landfill sites is prohibited by law, see Swiss Confederation 2015 (VVEA, Art. 25), and Swiss Confederation 1990 (the preceding Ordinance TVA, Art. 32). The increase is also partly due to municipal solid waste imported from neighbouring countries to optimize the load factor of MSWIPs. During the reporting period, the consumption of natural gas increased, and the consumption of liquid fuels decreased. This is due to a fuel shift in combined heat and power generation and the closure of the only power station located in Vouvry that has been operated with residual fuel oil in the 1990s.

*Municipal solid waste incineration and special waste incineration*

Figure 7-5 in Sector 5 Waste gives an overview over the waste amounts, their treatment and their reporting in the Swiss greenhouse gas inventory. Municipal solid waste includes waste generated in households and waste of similar composition from other sources.

The amount of municipal solid waste in kt reported in Table 3-36 is the total amount of waste burnt (it includes fossil and biogenic shares). The fossil and biogenic share in TJ are given as well.

Special waste is composed of special wastes with high calorific value, wastewater and sludge with organic load, inorganic solids and dusts, inorganic sludge containing heavy metals, acids and alkalis, PCB-containing wastes, non-metallic shredder residues, contaminated soil, filter materials and chemicals residues and others.

Table 3-36 Activity data for 1A1aiv Other: Municipal solid waste and special waste incinerated with heat and/or power generation. The amount of municipal solid waste in kt is the total amount of waste burnt.

| **1A1aiv Public electricity and heat production, Other** | **Unit** | **1990** | **1995** | **2000** | **2005** | **2010** |
|---|---|---|---|---|---|---|
| Total fuels | TJ | 30'768 | 30'264 | 39'371 | 44'508 | 48'277 |
| Municipal solid waste fossil | TJ | 13'995 | 13'664 | 17'790 | 20'197 | 21'062 |
| Municipal solid waste biogenic | TJ | 14'163 | 13'394 | 16'889 | 19'797 | 22'275 |
| Special waste | TJ | 2'610 | 3'206 | 4'692 | 4'514 | 4'941 |
| Total waste | kt | 2'603 | 2'433 | 3'040 | 3'527 | 3'968 |
| Municipal solid waste (fossil and biogenic) | kt | 2'470 | 2'270 | 2'801 | 3'297 | 3'717 |
| Special waste | kt | 133 | 163 | 239 | 230 | 252 |

| **1A1aiv Public electricity and heat production, Other** | **Unit** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total fuels | TJ | 47'847 | 49'313 | 48'228 | 49'161 | 50'548 | 52'422 | 52'316 | 53'097 | 53'552 | 53'248 |
| Municipal solid waste fossil | TJ | 20'724 | 21'108 | 20'593 | 21'163 | 21'717 | 22'678 | 22'789 | 22'984 | 23'137 | 23'195 |
| Municipal solid waste biogenic | TJ | 22'272 | 23'051 | 22'489 | 23'112 | 23'716 | 24'765 | 24'886 | 25'100 | 25'267 | 25'331 |
| Special waste | TJ | 4'851 | 5'155 | 5'145 | 4'886 | 5'115 | 4'979 | 4'641 | 5'013 | 5'148 | 4'722 |
| Total waste | kt | 3'924 | 4'104 | 4'035 | 4'066 | 4'150 | 4'264 | 4'248 | 4'297 | 4'322 | 4'312 |
| Municipal solid waste (fossil and biogenic) | kt | 3'676 | 3'841 | 3'773 | 3'817 | 3'889 | 4'010 | 4'011 | 4'042 | 4'059 | 4'072 |
| Special waste | kt | 247 | 263 | 262 | 249 | 261 | 254 | 236 | 255 | 262 | 241 |

#### *3.2.5.2.2. Petroleum refining (1A1b)*

**Methodology (1A1b)**

Up to 2015, two refineries were in operation in Switzerland. Since one of the refineries ceased operation in 2015, the data are considered confidential since 2014. Data are available to reviewers on request. Based on the generalised decision tree Fig. 2.1 for stationary combustion (IPCC 2006, vol.2, chp. 2), Switzerland applies a Tier 3 approach with country-specific emission factors for $CO_2$ emissions. The calculations are based on measurements and data from the refining industry as documented in the EMIS database (EMIS 2022/1A1b Heizkessel Raffinerien).

**Emission factors (1A1b)**

$CO_2$ emission factors of residual fuel oil, petroleum coke and refinery gas are estimated based on measurements from the refineries for the years 2005–2011 and 2013–2020 provided in the framework of the Swiss emissions trading system. From 2005 onwards, the measured emission factors are applied. The emission factors for 2012 are interpolated between 2011 and 2013. In years before 2005, the emission factors of residual fuel oil and petroleum coke are based on the weighted mean of the available data (2005–2011 and 2013–2015). The $CO_2$ emission factor of refinery gas is based on an estimate provided by one of the two refining plants for the years 1990–2004, which is assumed to be constant. Since 2013 the annual emission factor is derived from annual monitoring reports and the allocation report (2005–2011), which provide plant-specific data.

The resulting $CO_2$ emission factor of refinery gas is higher than the IPCC default value (IPCC 2006).

Table 3-37 Emission factors for 1A1b Petroleum refining in 2020.

| 1A1b Petroleum refining | Unit | $CO_2$ | $CH_4$ | $N_2O$ | $NO_x$ | NMVOC | $SO_2$ | CO |
|---|---|---|---|---|---|---|---|---|
| Residual fuel oil | kg/TJ | NO | NO | NO | NO | NO | NO | NO |
| Refinery gas | kg/TJ | C | C | C | C | C | C | C |
| Petroleum coke | kg/TJ | NO | NO | NO | NO | NO | NO | NO |
| Natural gas | kg/TJ | C | C | C | C | C | C | C |

**Activity data (1A1b)**

Activity data on fuel combustion for 1A1b Petroleum refining is provided by the Swiss overall energy statistics (SFOE 2021) and by the industry (bottom-up data). The data from the industry is collected by Carbura and forwarded to the Swiss Federal Office of Energy for inclusion in the Swiss overall energy statistics (SFOE 2021). As one of the refineries ceased operation in 2015, the data are considered confidential since 2014. Data are available to reviewers on request.

Refinery gas is the most important fuel used in source category 1A1b. Energy consumption, in particular use of refinery gas, has increased substantially since 1990 because one of the two Swiss refineries operated at reduced capacity in 1990 and resumed full production in later years. In 2012, one of the refineries was closed over six month due to insolvency and the search for a new buyer (EV 2014). Between 2004 and 2015, one of the Swiss refineries was also using petroleum coke as a fuel and since 2015 natural gas is used additionally to residual fuel oil and refinery gas. From the year 2019 onwards only refinery gas and natural gas are used.

Net calorific values are provided by the annual monitoring reports of the refining industries for the years 2005–2011 and 2013–2020 that are required under the Swiss Federal Act and Ordinance on the Reduction of $CO_2$ Emissions (Swiss Confederation 2011, Swiss Confederation 2012). For years with missing data (1990–2004 and 2012), the weighted mean of the net calorific value is applied for residual fuel oil and petroleum coke. The net calorific value of refinery gas is based on an estimate provided by one of the two refining plants for the years 1990–2004, which is assumed to be constant. The use of a plant-specific net calorific value leads to a slight difference to the energy consumption data provided by the Swiss overall energy statistics (SFOE 2021).

Table 3-38 Activity data for 1A1b Petroleum refining.

| 1A1b Petroleum refining | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 5'629 | 9'836 | 9'636 | 14'548 | 14'176 |
| Residual fuel oil | TJ | 1'259 | 1'786 | 1'908 | 902 | 891 |
| Refinery gas | TJ | 4'370 | 8'050 | 7'728 | 11'833 | 11'282 |
| Petroleum coke | TJ | NO | NO | NO | 1'813 | 2'003 |
| Natural gas | TJ | NO | NO | NO | NO | NO |

| 1A1b Petroleum refining | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 13'169 | 11'242 | 13'834 | 14'173 | 7'232 | 6'355 | 6'298 | 6'627 | 5'911 | 5'987 |
| Residual fuel oil | TJ | 764 | 1'212 | 1'094 | 1'330 | C | C | C | C | NO | NO |
| Refinery gas | TJ | 10'720 | 8'249 | 11'055 | 10'935 | C | C | C | C | C | C |
| Petroleum coke | TJ | 1'685 | 1'781 | 1'685 | 1'908 | C | NO | NO | NO | NO | NO |
| Natural gas | TJ | NO | NO | NO | NO | NO | NO | C | C | C | C |

### *3.2.5.2.3. Manufacture of solid fuels and other energy industries (1A1c)*

#### Methodology (1A1c)

In source category 1A1c Manufacture of solid fuels and other energy industries, only the emissions from charcoal production are reported as no other activities occur in Switzerland.

Based on the generalised decision tree in Fig. 2.1 for stationary combustion (IPCC 2006, vol.2, chp. 2), emissions are estimated using a Tier 2 approach.

#### Emission factors (1A1c)

The $CO_2$ emission factor is based on literature (USEPA 1995). $CH_4$ as well as emission factors for precursors $NO_x$, NMVOC and CO are taken from the revised 1996 IPCC Guidelines (IPCC 1997c, EMIS 2022/1A1c).

Table 3-39 Emission factors for 1A1c Manufacture of solid fuels and other energy industries in 2020. The $CO_2$ emission factor refers to $CO_2$ of biogenic origin.

| 1A1c Charcoal | Unit | $CO_2$ biog. | $CH_4$ | $N_2O$ | $NO_x$ | NMVOC | $SO_2$ | CO |
|---|---|---|---|---|---|---|---|---|
| Charcoal production | kg/TJ | 16'900 | 1'000 | NA | 10 | 1'700 | NE | 7'000 |

#### Activity data (1A1c)

The annual amount of charcoal produced is based on detailed queries with the few remaining sites where charcoal is produced. The main producer is the Köhlerverein Romoos, small quantities are produced at individual traditional local trade shows (Karthause Ittingen, Freilichtmuseum Ballenberg), as documented in EMIS 2022/1A1c. The FAO database contained values that differ substantially from these detailed bottom-up data. FAO has been informed about the discrepancy and was provided with the data used in the greenhouse gas inventory.

The charcoal is not used in the industry anymore but mainly for barbecues. Production has increased between 1990 and 2016 due to two regular charcoal production sites starting operation in 2004, low wood prices and increased demand for local charcoal in Switzerland (Koehlerei 2014).

Table 3-40 Activity data for 1A1c Manufacture of Solid Fuels and other energy industries.

| 1A1c Charcoal | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Charcoal production | TJ | 1.3 | 1.4 | 2.2 | 3.4 | 3.6 |

| 1A1c Charcoal | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Charcoal production | TJ | 3.7 | 4.1 | 3.3 | 4.3 | 3.8 | 4.1 | 3.9 | 4.3 | 5.1 | 3.9 |

### 3.2.5.3. Uncertainties and time-series consistency for 1A1 (stationary)

The uncertainty of emission estimates for source category 1A1 (stationary) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7.

Time series for 1A1 Energy industries are all considered consistent.

### 3.2.5.4. Category-specific QA/QC and verification for 1A1 (stationary)

The general QA/QC procedures are described in chp. 1.2.3. Furthermore QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

Concerning activity data and emission factors in the refinery sector, emissions and fuel combustion statistics are collected at large combustion plants for pollution legislation purposes. This plant-level data is used to cross-check national energy statistics from this sector for representativeness.

### 3.2.5.5. Category-specific recalculations for 1A1 (stationary)

The following recalculations were implemented in submission 2022. Major recalculations, which contribute significantly to the total differences in GHG emissions of sector 1 Energy between the latest and the previous submissions are presented also in chp. 10.1.2.1.

- 1A1a: Activity data of incinerated municipal waste, construction waste and other & special waste have changed for 2019 due to updates in the underlying statistics by the FOEN. Municipal waste has decreased by 9820 t (-0.34%), construction waste and other & special waste have increased by 8665 t (+1.7%) and 1155 t (+0.56%), respectively.
- 1A1a: Activity data of plants for renewable waste from wood products have been revised for 2019 due to a small recalculation in the Swiss wood energy statistics (SFOE 2021b).
- 1A1a: There was a small reallocation of gas oil use from 1A1aiii to 1A1ai in the calculations to avoid (apparent) negative energy consumption for all years 1990–2019. This does not lead to any difference in total gas oil use in 1A1a.
- 1A1a: The emission factor for $N_2O$ for municipal waste incineration is calculated every 4 years as a weighted average taking into account the denox equipment of each plant (SCR or SNCR) and the amount of waste burnt. For 2020, a new emission factor has been calculated. The emission factor for 2016 has also changed due to a correction in the data of the denox equipment for 2 plants (two more SCR instead of SNCR). The emission factors for $N_2O$ have decreased for the years 2013–2019.
- 1A1c: Activity data of charcoal production has changed for 2019 due to updated production of one of the charcoal production plants for the year 2019.

#### 3.2.5.6. Category-specific planned improvements for 1A1 (stationary)

There are no category-specific planned improvements.

### 3.2.6. Source category 1A2 – Manufacturing industries and construction (stationary, without 1A2gvii)

#### 3.2.6.1. Source category description for 1A2 (stationary)

Table 3-41 Key categories of 1A2 Manufacturing industries and construction. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 1A2 | Manufacturing Industries and Construction; Gaseous Fuels | CO2 | L1, T1, L2 |
| 1A2 | Manufacturing Industries and Construction; Liquid Fuels | CO2 | L1, T1 |
| 1A2 | Manufacturing Industries and Construction; Other Fuels | CO2 | L1, T1 |
| 1A2 | Manufacturing Industries and Construction; Solid Fuels | CO2 | L1, T1 |

*[Source category 1A2 contains the sum of emissions of stationary and mobile sources – the statement on key categories holds for the aggregated emissions only. The $CO_2$ emissions of 1A2 from Liquid Fuels are dominated by the stationary sources, however, 41% (2020) of the $CO_2$ emissions stem from mobile sources 1A2gvii.]*

The source category 1A2 Manufacturing industries and construction comprises all emissions from the combustion of fuels in stationary boilers and cogeneration facilities within manufacturing industries and construction. This includes use of conventional fossil fuels as well as waste-derived fuels and biomass. Use of fossil fuels as feedstocks or other non-energy use of fuels as for example bitumen and lubricants are reported in CRF Table1.A(d) and described in chp. 3.2.3.

Table 3-42 Specification of source category 1A2 Manufacturing industries and construction.

| 1A2 | Source category | Specification |
|---|---|---|
| 1A2a | Iron and steel | Iron and steel industry: boilers, cupola furnaces in iron foundries and electric arc furnaces and heating furnaces in steel production |
| 1A2b | Non-ferrous metals | Non-ferrous metals industry: secondary aluminium production, copper alloys production |
| 1A2c | Chemicals | Chemical industry: production of chemicals such as. ammonia, niacin, nitric acid (ceased in 2018), ethylene, acetic acid and sulphuric acid as well as silicon carbide (amongst others) |
| 1A2d | Pulp, paper and print | Pulp, paper and print industry |
| 1A2e | Food processing, beverages and tobacco | Food processing, beverages and tobacco industry: meat production, milk products, convenience food, chocolate, sugar and baby food (amongst others). |
| 1A2f | Non-metallic minerals | Fine ceramics, container glass, glass, glass wool, lime, rock wool, mixed goods, cement, brick and tile |
| 1A2giv | Wood and wood products | Fibreboard production |
| 1A2gviii | Other | Industrial fossil fuel and biomass boilers and engines that do not provide heat or electricity to the public. |

## 3.2.6.2. Methodological issues for 1A2 (stationary)

### *3.2.6.2.1. Methodology (1A2) and industry model*

For $CO_2$ emissions from fuel combustion in source category 1A2 Manufacturing industries and construction, Tier 2 and 3 methods are applied (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1) using country-specific emission factors – except for other fossil fuels (gasolio, heating gas, and synthesis gas (from 2018 onwards)) in 1A2c Chemicals, where plant-specific emission factors are used.

For all fuel combustion in 1A2f Cement production, and for wood combustion in 1A2f Brick and tile production (2000–2012), 1A2giv and 1A2gviii, $CH_4$ emissions are calculated by a Tier 2 approach using country-specific emission factors. For $CH_4$ emissions from all other fuel combustion processes in source category 1A2 Manufacturing industries and construction, a Tier 1 method is applied (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1) using default emission factors from the 2006 IPCC Guidelines.

For $N_2O$ emissions from fuel combustion in source category 1A2 Manufacturing industries and construction, a Tier 1 method is applied (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1) using default emission factors from the 2006 IPCC Guidelines.

**Overview industry model**

The industry model is one sub-model of the Swiss energy model (see chp. 3.2.4.3). The industry model disaggregates the stationary fuel consumption into the source categories and processes under 1A2 Manufacturing industries and construction. The following figure visualizes the disaggregation process.

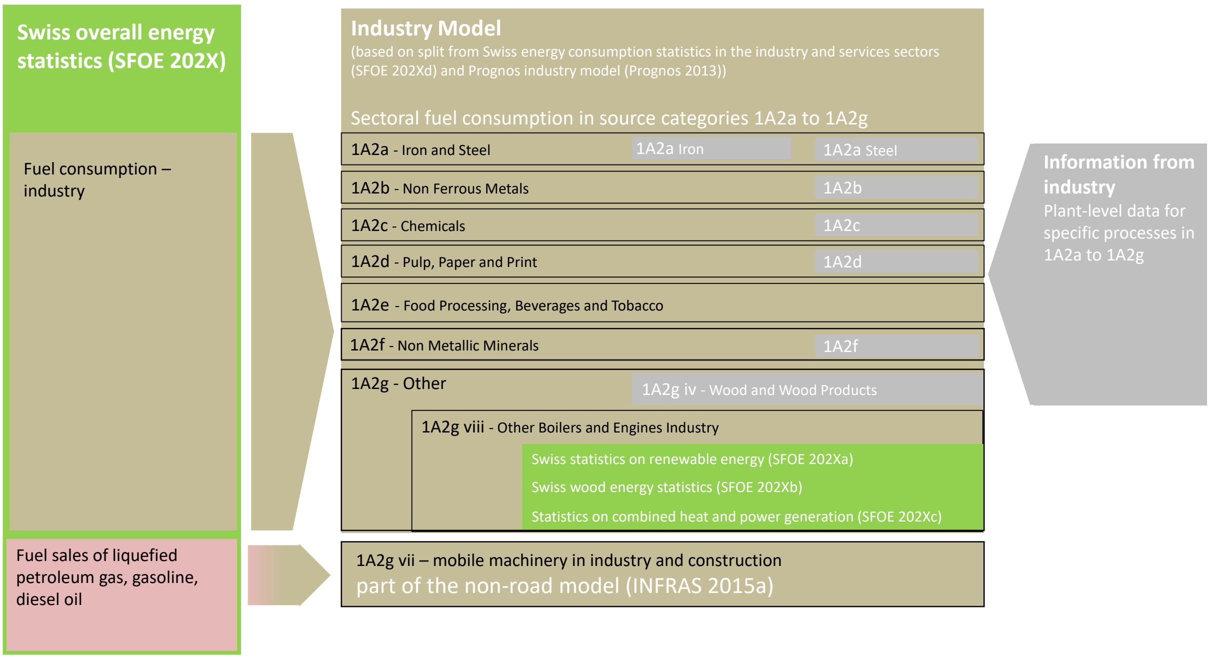


Figure 3-21 Schematic presentation of the data sources used for the industrial sectors 1A2a–1A2g. The references SFOE 202X, 202Xa, 202Xb and 202Xc refer to the 2021 edition of the corresponding energy statistics. For each fuel type, the Swiss overall energy statistics provide the total consumption for industry. The total consumption is then distributed to the different source categories based on information from industry surveys (SFOE 2021d) and the Prognos industry model (Prognos 2013). The grey boxes on the right show the specific bottom-up industry information.

The total fuel consumption regarding each fuel type in the industry sector is provided by the Swiss overall energy statistics (SFOE 2021, see also description in chp. 3.2.4.3). The energy disaggregation into the source categories 1A2a to 1A2g is carried out for each fuel type individually based on the energy consumption statistics in the industry and services sectors (SFOE 2021d). These statistics are available since 1999 for gas oil and natural gas. For all other fossil fuels (i.e. residual fuel oil, liquefied petroleum gas, petroleum coke, other bituminous coal and lignite) data are available since 2002. In order to generate a consistent time series since 1990, additional data from an industry model is applied (Prognos 2013) as described in the following paragraphs.

In addition, the share of fuel used for co-generation in turbines and engines within 1A2 is derived from a model of stationary engines developed by Eicher + Pauli (Kaufmann 2015) for the statistics on combined heat and power generation (SFOE 2021c).

*Energy consumption statistics in the industry and services sectors*

The energy consumption statistics in the industry and services sectors (SFOE 2021d) refer to representative surveys with about 13’000 workplaces in the industry and services sectors that are then grossed up or extrapolated to the entire industry branch. For certain sectors and fuel types (i.e. industrial waste, residual fuel oil, other bituminous coal and lignite) the surveys represent a census covering all fuel consumed. The surveys are available for all years since 1999 or 2002, depending on the fuel type.

In 2015, a change in the survey method of the energy consumption statistics in the industry and services sectors was implemented (SFOE 2015d). The business and enterprise register, which forms the basis for the samples of the surveys, was revised. While previously the business and enterprise register was based on direct surveys with work places, it is now based on annual investigations of registry data (e.g. from the old-age and survivors' insurance). In the course of this revision, a comparative assessment was conducted for the year 2013. This comparison showed that the energy consumption in the source categories of 1A2 stationary are modified by less than one percent, but also that the differences between the new and the old results for 2013 are not statistically significant (SFOE 2015d). As these statistics are only used for allocation of total energy consumption to different source categories, the impact on the different source categories solely consists of a reallocation of the energy consumption and does not affect the total of the sector. Moreover, only consumption of gas oil and natural gas is affected. For all these reasons, the time series consisting of data based on the previous (1990–2012) and latest (since 2013) survey method are considered consistent.

*Modelling of industry categories*

The energy consumption statistics in the industry and services sectors (SFOE 2021d) are complemented by a bottom-up industry model (Prognos 2013). The model is based on 164 individual industrial processes and further 64 processes related to infrastructure in industry. Fuel consumption of a specific process is calculated by multiplication of the process activity data with the process-specific fuel consumption factor.

The model provides data on the disaggregation of total fuel consumption according to different industries and services between 1990 and 2012. For the time period where the two disaggregation methods overlap, systematic differences between the two time series can be detected. These two data sets have been combined in order to obtain consistent time series of the shares of each source category 1A2a–1A2g for each fuel type. For this purpose, the approach to "generate consistent time series from overlapping time series" is used according to the 2006 IPCC Guidelines (IPCC 2006, Volume 1, chp. 5, consistent overlap). To illustrate the approach, an example for gas oil attributed to source category 1A2c is provided in Figure 3-22. A detailed description for all fuel types and source categories (1A2a–1A2g), including further assumptions, is provided in the underlying documentation of the EMIS database (EMIS 2022/1A2 Sektorgliederung Industrie).

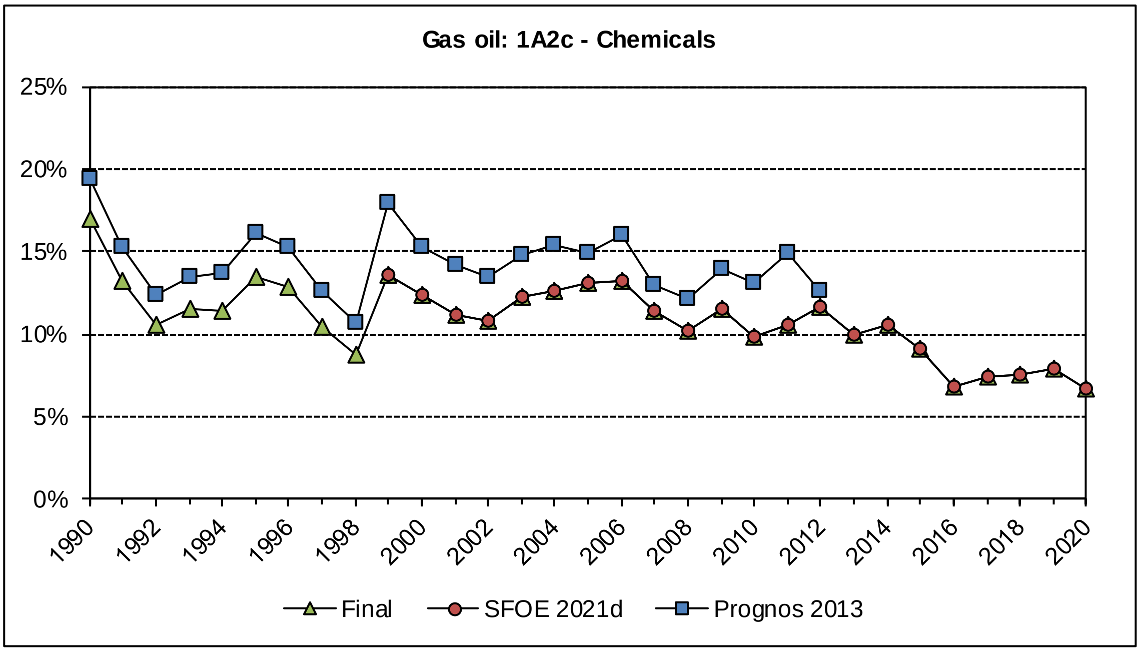


Figure 3-22 Illustrative example for combining time series with consistent overlap according to the 2006 IPCC Guidelines (IPCC 2006, Volume 1, chp. 5). The y-axis indicates the share of source category 1A2c of total gas oil consumption in the industry sector. The green triangles correspond to the share finally used to calculate the fuel consumption in 1A2c, based on the combination of the shares from the energy consumption statistics in the industry and services sectors (SFOE 2021d, orange dots since 1999) and the bottom-up industry model (Prognos 2013, blue squares from 1990 to 2012). Similar calculations are performed for each source category and fuel type.

*Bottom-up industry data*

Grey coloured boxes in Figure 3-21 represent source categories, i.e. 1A2a–d, 1A2f and 1A2g for which bottom-up data from the industry are used in order to disaggregate the fuel consumption within a particular source category. These data consist of validated and verified monitoring data from the Swiss emissions trading scheme implemented under the Ordinance for the Reduction of $CO_2$ Emissions (Swiss Confederation 2012) and are discussed in depth in the following chapters 3.2.6.2.2 to 3.2.6.2.8.

The bottom-up information provides activity data for specific industrial production processes and forms a subset of the total fuel consumption allocated to each source category by the approach described above. Therefore, the fuel consumptions of the bottom-up industry processes are subtracted from the total fuel consumption of the respective source category and the remaining fuel consumptions are considered as fuels used in boilers of each source category. This method ensures that the sum of fuel consumption over all processes of a source category corresponds to the total fuel consumption as documented in the energy consumption statistics in the industry and services sectors (SFOE 2021d).

There is a difference in calculating the emissions of precursors from boilers and bottom-up industry processes. For boilers, fuel consumption is used as activity data whereas for bottom-up processes production data is used.

*Further specific statistical data*

Fuel consumption of wood, wood waste, biogas and sewage gas in manufacturing industries is based on the Swiss wood energy statistics (SFOE 2021b) as well as on data from the Swiss renewable energy statistics (SFOE 2021a) and the statistics on combined heat and power generation in Switzerland (SFOE 2021c), respectively. Emissions from these sources are reported under 1A2gviii Other due to insufficient information regarding sectoral disaggregation.

### Emission factors (1A2)

The following table presents the emission factors of fuel consumption in source category 1A2 Manufacturing industries and construction (see also chp. 3.2.4.4).

Table 3-43 Emission factors for 1A2 Manufacturing industries and construction in 2020. Values that are highlighted in green are described in more detail in chp. 3.2.4.4.

| **1A2 Emission factors for GHG (mix of bottom-up and top-down approach (modelling); without source-category 1A2gvii Non-road vehicles and machinery)** | **$CO_2$ fossil** | **$CO_2$ biog.** | **$CH_4$** | **$N_2O$** |
|---|---|---|---|---|
| | t/TJ | t/TJ | kg/TJ | kg/TJ |
| Gas oil | 73.7 | | <3 *(lower IEF than default emission factor)* | 0.6 |
| Residual fuel oil | 77.0 | | <3 *(lower IEF than default emission factor)* | 0.6 |
| Liquefied petroleum gas | 65.5 | | <1 *(lower IEF than default emission factor)* | 0.1 |
| Petroleum coke | 91.4 | | <3 *(lower IEF than default emission factor)* | 0.6 |
| Other bituminous coal | 92.7 | | <10 *(lower IEF than default emission factor)* | 1.5 |
| Lignite | 96.1 | | <10 *(lower IEF than default emission factor)* | 1.5 |
| Natural gas | 56.2 | | <3 *(lower IEF than default emission factor)* | 0.1 |
| Other fossil fuels (including solvents, plastics, waste tyres and rubber (see 1A2f)) | 72.5 | 5.7 | 4.1 | 3.7 |
| Biomass (wood, biogas and other biogenic waste) | | 92.0 | 5.2 | 3.3 |

Other fossil fuels comprise various fossil waste-derived fuels used in 1A2f Cement production as well as cracker by-products, i.e. gasolio, heating gas and synthesis gas used for steam production in a chemical plant in source category 1A2c. The emission factors of $CO_2$, $CH_4$ and $N_2O$ are implied emission factors based on the fossil waste fuel mix. In addition, the $CH_4$ emission factor includes the total $CH_4$ emissions of the cement industry based on direct exhaust measurements at the chimneys of the cement plants (see documentation in EMIS 2022/1A2f Zementwerke_Feuerung), based on industry data and emission declarations according to the Ordinance on Air Pollution Control (Swiss Confederation 1985). Implied $CH_4$ emission factors of source category 1A2 for residual fuel oil, petroleum coke, other bituminous coal and lignite are thus lower than the default emission factors of source category 1A documented in chp. 3.2.4.4.3 (see detailed description below in chapter Cement (1A2f)).

The emission factors of the precursors $NO_x$, CO, NMVOC and $SO_2$ for all fuels in source category 1A2 are provided in Switzerland's Informative Inventory Report (FOEN 2022b, chp. 3.2.3.2.1). The emission factors for $NO_x$ and CO for natural gas and gas oil used in boilers are derived from a large number of air pollution control measurements of combustion installations (Leupro 2012). This study analysed a large dataset from various cantons in Switzerland that was collected between 2000 and 2011. The emission factors for $NO_x$ and CO for residual fuel oil, petroleum coke, other bituminous coal and lignite used in boilers are country-specific and documented in the Handbook on emission factors for stationary sources (SAEFL 2000). The implied emission factors for $NO_x$ decreased significantly over the reporting period. NMVOC and $SO_2$ emission factors are country-specific and documented in SAEFL (2000).

In contrast to combustion in boilers, emission factors of precursors for fuel combustion in bottom-up industry processes are based on bottom-up industry data. Production-weighted emission factors based on various air pollution control measurements under the Ordinance on Air Pollution Control (Swiss Confederation 1985) are used to derive the corresponding process-specific emission factors.

**Activity data (1A2)**

The following table shows the total fuel consumption reported in source category 1A2 as described above in the industry model, and displays the fuel switch within Swiss industry over the reporting period. Since 1990, the use of residual fuel oil and other bituminous coal has decreased strongly. In the same period, natural gas consumption has about doubled. Currently, natural gas consumption accounts for the largest share of fuels used within Swiss industry, followed by biomass and gas oil.

Currently, source category 1A2gviii Other comprising emissions from boilers and engines and 1A2f Non-metallic minerals are the two most important categories within source category 1A2 Manufacturing Industries and construction. 1A2e Food processing, beverages and tobacco and 1A2c Chemicals are the third and fourth most important fuel consumers, respectively.

Table 3-44 Activity data for fuel consumption in 1A2 Manufacturing industries and construction.

| 1A2 Manufacturing industries and constr. (stationary | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 89'956 | 90'576 | 89'115 | 92'575 | 91'604 |
| Gas oil | TJ | 22'910 | 24'471 | 25'892 | 25'317 | 21'137 |
| Residual fuel oil | TJ | 18'870 | 13'678 | 5'675 | 4'613 | 2'056 |
| Liquefied petroleum gas | TJ | 4'354 | 4'458 | 5'627 | 4'309 | 3'912 |
| Petroleum coke | TJ | 1'400 | 1'260 | 551 | 1'093 | 1'495 |
| Other bituminous coal | TJ | 13'476 | 7'303 | 5'866 | 4'799 | 4'348 |
| Lignite | TJ | 265 | 153 | 124 | 742 | 1'460 |
| Natural gas | TJ | 19'450 | 28'500 | 31'850 | 34'760 | 38'330 |
| Other fossil fuels | TJ | 2'556 | 2'818 | 4'053 | 4'525 | 5'183 |
| Biomass | TJ | 6'676 | 7'935 | 9'477 | 12'418 | 13'684 |

| 1A2 Manufacturing industries and constr. (stationary | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 85'354 | 86'540 | 88'144 | 82'646 | 81'202 | 82'305 | 82'676 | 79'870 | 79'452 | 76'532 |
| Gas oil | TJ | 17'314 | 17'575 | 18'007 | 12'444 | 12'725 | 12'812 | 11'489 | 10'871 | 10'071 | 8'854 |
| Residual fuel oil | TJ | 1'518 | 1'568 | 848 | 231 | 196 | 155 | 123 | 34 | 111 | 41 |
| Liquefied petroleum gas | TJ | 3'861 | 3'731 | 3'740 | 3'288 | 3'340 | 2'752 | 3'131 | 3'051 | 2'925 | 2'798 |
| Petroleum coke | TJ | 1'272 | 1'367 | 1'049 | 1'240 | 795 | 890 | 763 | 781 | 777 | 700 |
| Other bituminous coal | TJ | 3'868 | 3'794 | 3'910 | 2'403 | 1'946 | 1'517 | 1'634 | 1'665 | 1'450 | 1'153 |
| Lignite | TJ | 1'624 | 1'175 | 1'357 | 3'102 | 3'060 | 3'078 | 2'876 | 2'520 | 2'262 | 2'410 |
| Natural gas | TJ | 37'250 | 38'280 | 39'620 | 40'200 | 39'360 | 39'870 | 40'910 | 39'230 | 39'470 | 38'090 |
| Other fossil fuels | TJ | 5'307 | 4'883 | 5'186 | 5'270 | 5'252 | 5'926 | 5'912 | 6'513 | 6'679 | 6'805 |
| Biomass | TJ | 13'340 | 14'166 | 14'427 | 14'468 | 14'530 | 15'305 | 15'839 | 15'205 | 15'707 | 15'680 |

The following chapters describe the fuel consumption of the different source categories 1A2a–1A2gviii, the specific industrial production processes based directly on bottom-up industry data, and additional source-specific emission factors. Further information is documented in the respective EMIS documentation (EMIS 2022/1A2a-g).

### *3.2.6.2.2. Iron and steel (1A2a)*

The source category 1A2a Iron and steel consists both of fuels used in boilers and specific industrial production processes, i.e. reheating furnaces in steel plants and cupola furnaces in iron foundries.

There is no primary iron and steel production in Switzerland. Only secondary steel and iron production using recycled steel scrap occurs. Iron is produced in 14 iron foundries. About 75% of the iron is processed in induction furnaces and 25% in cupola furnaces using other bituminous coal as fuel. Part of the other bituminous coal acts also as carburization material as well as reducing agent. Since other bituminous coal first of all acts as fuel in cupola furnaces it was decided to report its $CO_2$ emissions in source category 1A2a. Furthermore, this allows to be consistent with the fuel use of other bituminous coal provided by the Swiss overall energy statistics (SFOE 2021). Additionally, also limestone is used as flux in cupola furnaces yielding geogenic $CO_2$ emissions. These emissions are reported in source category 2A4d Other carbonate uses. The share of induction furnaces increased since 1990 with a sharp increase in 2009 due to the closure of at least one cupola furnace. Induction furnaces use electricity for the melting process and therefore only process emissions occur, which are reported in source category 2C1 Iron and steel production. Due to the reduced iron production and the switch from cupola to induction furnaces in iron foundries, the consumption of other bituminous coal has decreased.

Today, steel is only produced in two steel production plants after closure of two plants in 1994. Both plants use electric arc furnaces (EAF) with carbon electrodes for melting the steel scrap. In these electric arc furnaces also so-called injection coal and petroleum coke for slag formation as well as natural gas are used. These fuel consumptions are reported under source category 1A2a Electric arc furnaces of steel production based on plant-specific data from monitoring reports of the Swiss ETS for the years 2005–2011 and from 2013 onwards. In addition, emissions from the reheating furnaces are reported in source category 1A2a. Since 1995, these furnaces use natural gas only for reheating the ingot moulds prior to the rolling mills. Process emissions from steel production are included in source category 2C1 Iron and steel production. Steel production and the related natural gas consumption was significantly reduced in 1995 and the use of residual fuel oil ceased with the closure of two steel companies. Since 1995, steel production increased continuously until 2004 to reach the same production level as 1990. Since then, steel production is about constant. Only in 2009, the production was considerably lower due to the economic crisis. One steel producer switched its production to high quality steel and therefore the specific energy use per tonne of steel produced increased between 1995 and 2000. This led to higher natural gas consumption.

Today fuel consumption of source category 1A2a consists mainly of natural gas but also liquefied petroleum gas, other bituminous coal, gas oil and small amounts of petroleum coke are used.

Table 3-45 Activity data fuel consumption in 1A2a Iron and steel.

| 1A2a Iron and steel | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 3'567 | 2'733 | 3'579 | 3'654 | 4'102 |
| Gas oil | TJ | 480 | 262 | 338 | 401 | 315 |
| Residual fuel oil | TJ | 346 | 131 | 20 | 39 | 51 |
| Liquefied petroleum gas | TJ | 408 | 193 | 286 | 217 | 219 |
| Petroleum coke | TJ | 85 | 46 | 56 | 72 | 47 |
| Other bituminous coal | TJ | 606 | 406 | 439 | 346 | 346 |
| Lignite | TJ | NO | NO | NO | NO | NO |
| Natural gas | TJ | 1'642 | 1'695 | 2'439 | 2'578 | 3'125 |

| 1A2a Iron and steel | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 4'145 | 3'962 | 3'850 | 4'005 | 4'286 | 4'169 | 4'622 | 4'767 | 4'431 | 4'419 |
| Gas oil | TJ | 271 | 172 | 139 | 86 | 136 | 134 | 123 | 127 | 97 | 81 |
| Residual fuel oil | TJ | 1.5 | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Liquefied petroleum gas | TJ | 226 | 438 | 438 | 388 | 393 | 327 | 368 | 358 | 342 | 327 |
| Petroleum coke | TJ | 37 | 42 | 53 | 81 | 69 | 78 | 77 | 71 | 57 | 43 |
| Other bituminous coal | TJ | 377 | 341 | 321 | 325 | 313 | 303 | 321 | 319 | 307 | 285 |
| Lignite | TJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Natural gas | TJ | 3'233 | 2'969 | 2'898 | 3'126 | 3'375 | 3'328 | 3'734 | 3'893 | 3'628 | 3'682 |

#### *3.2.6.2.3. Non-ferrous metals (1A2b)*

The source category 1A2b Non-ferrous metals consists both of fuels used in boilers and specific industrial production processes, i.e. secondary aluminium production and non-ferrous metal foundries, producing mainly copper alloys.

Until 1993, secondary aluminium production plants have been in operation using gas oil. Emissions from primary aluminium production in Switzerland are reported in source category 2C3 as induction furnaces have been used. The last primary aluminium production site closed down in April 2006.

Regarding non-ferrous metal industry in Switzerland, only casting and no production of non-ferrous metals occur. There is one large company and several small foundries, which are organized within the Swiss foundries association (Schweizerischer Giessereiverband, GVS) providing production data.

Fuel consumption of source category 1A2b represents only a small amount of the total fuel consumption in source category 1A2. Fuels consumed in 2020 are mainly natural gas as well as gas oil and small amounts of liquefied petroleum gas. Fuel consumption within this source category decreased since 1990 due to the closing down of the secondary aluminium production and the strong reduction of the non-ferrous metal production since 2000.

Table 3-46 Activity data fuel consumption in 1A2b Non-ferrous metals.

| 1A2b Non-ferrous metals | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 2'378 | 1'969 | 1'560 | 977 | 1'218 |
| Gas oil | TJ | 587 | 347 | 236 | 125 | 112 |
| Residual fuel oil | TJ | NO | NO | NO | NO | 0.024 |
| Liquefied petroleum gas | TJ | 27 | 17 | 15 | 7.1 | 7.7 |
| Petroleum coke | TJ | NO | NO | NO | NO | NO |
| Other bituminous coal | TJ | NO | NO | NO | NO | NO |
| Lignite | TJ | NO | NO | NO | NO | NO |
| Natural gas | TJ | 1'764 | 1'605 | 1'309 | 845 | 1'098 |

| 1A2b Non-ferrous metals | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 1'177 | 1'746 | 1'593 | 1'916 | 1'792 | 1'683 | 1'640 | 1'746 | 1'962 | 1'803 |
| Gas oil | TJ | 76 | 153 | 128 | 90 | 78 | 76 | 78 | 55 | 61 | 49 |
| Residual fuel oil | TJ | 0.023 | 0.78 | 23 | NO | 44 | NO | 3.7 | NO | NO | NO |
| Liquefied petroleum gas | TJ | 8.2 | 11 | 11 | 10 | 9.9 | 8.3 | 9.3 | 9.0 | 8.6 | 8.3 |
| Petroleum coke | TJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Other bituminous coal | TJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Lignite | TJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Natural gas | TJ | 1'093 | 1'581 | 1'430 | 1'816 | 1'660 | 1'598 | 1'549 | 1'682 | 1'892 | 1'746 |

#### *3.2.6.2.4. Chemicals (1A2c)*

In Switzerland, there are more than thirty chemical companies mainly producing fine chemicals and pharmaceuticals. Fossil fuels are mostly used for steam production and process heat. The process emissions from the production of chemicals such as ammonia, niacin, nitric acid, ethylene, acetic acid and sulphuric acid as well as silicon carbide are reported in source category 2B, see chp. 4.3.

There is one large company producing ammonia and ethylene by thermal cracking of liquefied petroleum gas and light virgin naphtha (see also descriptions in chp. 3.2.3 for feedstock use). As by-products from the cracking process, so-called heating gas and gasolio are produced, which are used thermally for steam production within the same plant. In 2018 the cracker process and the subsequent integrated production chain were modified yielding synthesis gas as additional cracker by-product. For reasons of confidentiality, fuel consumption and emissions of these by-products are included in Other fossil fuels of 1A2f in the reporting tables. The $CO_2$ emission factors of gasolio, heating gas and synthesis gas are plant specific based on monitoring reports of the Swiss ETS. In 2017 the fuel quality of gasolio and heating gas have been re-analysed by the production plant yielding new net calorific values and $CO_2$ emission factors. Due to changes in the cracker operation the composition of the heating gas has changed considerably. The further process modification in 2018 resulted again in changes of both net calorific value and $CO_2$ emission factor mainly for heating gas.

Since the fuel quality of gasolio and heating gas are of similar quality as residual fuel oil and gas oil, respectively, the same default IPCC emission factors (IPCC 2006) are assumed for $CH_4$ and $N_2O$ (see Table 3-15 and Table 3-17). For synthesis gas the same default IPCC emission factor as of natural gas is assumed for $N_2O$ (IPCC 2006). Whereas no $CH_4$ emissions are supposed from the combustion of synthesis gas.

Table 3-47 Emission factors for 1A2c Chemicals are documented in the confidential NIR, which is available to reviewers on request.

The fuels consumed in 2020 include mainly natural gas as well as minor amounts of gas oil. Fuel consumption in this source category has decreased by more than 20% between 1990 and 2020. Consumption of gas oil and residual fuel oil has decreased or been stopped in that period, while natural gas consumption has increased.

Table 3-48 Activity data fuel consumption in 1A2c Chemicals.

| 1A2c Chemicals | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 14'431 | 15'158 | 13'497 | 15'477 | 11'814 |
| Gas oil | TJ | 3'942 | 3'313 | 3'215 | 3'345 | 2'103 |
| Residual fuel oil | TJ | 1'434 | 693 | 252 | 36 | 66 |
| Liquefied petroleum gas | TJ | 15 | 13 | 12 | 10 | 7.5 |
| Petroleum coke | TJ | NO | NO | NO | NO | NO |
| Other bituminous coal | TJ | NO | NO | NO | NO | NO |
| Lignite | TJ | NO | NO | NO | NO | NO |
| Natural gas | TJ | 9'039 | 11'138 | 10'017 | 12'086 | 9'637 |
| Other fossil fuels | TJ | IE | IE | IE | IE | IE |

| 1A2c Chemicals | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 12'167 | 13'909 | 14'125 | 12'125 | 12'525 | 14'370 | 13'806 | 13'283 | 11'809 | 10'875 |
| Gas oil | TJ | 1'847 | 2'055 | 1'797 | 1'321 | 1'167 | 881 | 860 | 825 | 799 | 600 |
| Residual fuel oil | TJ | 0.16 | 0.16 | 1.2 | NO | NO | NO | NO | NO | NO | NO |
| Liquefied petroleum gas | TJ | 7.1 | 10 | 10 | 8.9 | 9.0 | 7.5 | 8.4 | 8.2 | 7.9 | 7.5 |
| Petroleum coke | TJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Other bituminous coal | TJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Lignite | TJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Natural gas | TJ | 10'312 | 11'845 | 12'317 | 10'795 | 11'349 | 13'482 | 12'937 | 12'450 | 11'001 | 10'268 |
| Other fossil fuels | TJ | IE | IE | IE | IE | IE | IE | IE | IE | IE | IE |

### *3.2.6.2.5. Pulp, paper and print (1A2d)*

Around ten paper producers and several printing facilities exist in Switzerland. The only cellulose production plant was closed in 2008. Thermal energy is mainly used for provision of steam used in the drying process within paper production. Emissions from use of carbonate in flue gas treatment in cellulose production is reported in 2A4d Other process use of carbonates.

Fuel consumption in 1A2d consists both of fuels used in boilers and specific industrial production processes. In this source category only biomass (biogenic waste) from cellulose production (until 2008) is included, based on data from the only production site. The emissions were calculated using a country-specific $CO_2$ emission factor (EMIS 2022/1A2d Zellulose-Produktion) and default factors for $CH_4$ and $N_2O$ (IPCC 2006, vol. 2, chp.2, table

2.3, sulphite lyes). Biomass (e.g. wood and wood waste) used in paper production is reported in source category 1A2gviii, because no statistical data exists to allocate biomass consumption to the specific industry sectors within 1A2 as explained in chp. 3.2.4.5.2. Therefore, from 2009 onwards, emissions from biomass are reported as "IE" in CRF Table1.A(a)s2.

The overall fuel consumption within the Swiss pulp and paper industry has considerably decreased since 1990, due to the closure of the cellulose production plant in 2008 and of several paper producers in the last years. The fuels used in 2020 are mainly natural gas as well as gas oil.

Table 3-49 Activity data of fuel consumption in 1A2d Pulp, paper and print.

| 1A2d Pulp, paper and print | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 11'760 | 13'700 | 11'577 | 11'379 | 6'773 |
| Gas oil | TJ | 1'188 | 1'751 | 1'403 | 1'456 | 852 |
| Residual fuel oil | TJ | 5'250 | 3'061 | 1'417 | 2'092 | 279 |
| Liquefied petroleum gas | TJ | 86 | 141 | 148 | 100 | 61 |
| Petroleum coke | TJ | NO | NO | NO | NO | NO |
| Other bituminous coal | TJ | NO | NO | NO | NO | NO |
| Lignite | TJ | NO | NO | NO | NO | NO |
| Natural gas | TJ | 3'151 | 7'389 | 6'916 | 5'678 | 5'581 |
| Biomass | TJ | 2'085 | 1'358 | 1'694 | 2'053 | NO |

| 1A2d Pulp, paper and print | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 6'051 | 5'374 | 5'474 | 4'643 | 3'655 | 2'982 | 2'851 | 2'073 | 2'151 | 2'057 |
| Gas oil | TJ | 561 | 623 | 711 | 297 | 383 | 410 | 288 | 293 | 345 | 282 |
| Residual fuel oil | TJ | 4.0 | 2.8 | 0.018 | 22 | 19 | 9.0 | 8.8 | NO | NO | NO |
| Liquefied petroleum gas | TJ | 62 | 67 | 67 | 60 | 60 | 50 | 57 | 55 | 53 | 50 |
| Petroleum coke | TJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Other bituminous coal | TJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Lignite | TJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Natural gas | TJ | 5'424 | 4'681 | 4'696 | 4'264 | 3'193 | 2'513 | 2'498 | 1'725 | 1'753 | 1'724 |
| Biomass | TJ | IE | IE | IE | IE | IE | IE | IE | IE | IE | IE |

#### *3.2.6.2.6. Food processing, beverages and tobacco (1A2e)*

In Switzerland, the source category 1A2e Food, beverages and tobacco includes around 200 companies. According to the national food industry association, the major part of revenues is provided by meat production, milk products and convenience food. Further productions comprise chocolate, sugar or baby food (Fial 2013). Fossil fuels are used for steam production and drying processes. Fuel consumption in 1A2e is exclusively based on information from the energy consumption statistics in the industry and services sectors (SFOE 2021d) and Prognos (2013).

In 2020, the fuels used in this category were mainly natural gas as well as gas oil and small amounts of liquefied petroleum gas (Table 3-50). Overall, there was a slight increase in fuel consumption between 1990 and 2020. This is due to the increased production in this sector. The consumption of residual fuel oil ceased and gas oil consumption has decreased, while natural gas and liquefied petroleum gas consumption has increased significantly.

Biomass (e.g. wood and wood waste) used in 1A2e Food processing, beverages and tobacco is reported in source category 1A2gviii, because no statistical data exists to allocate biomass consumption to the specific industry sectors within 1A2 as explained in chp. 3.2.4.5.2. Therefore, activity data and emissions from biomass are reported as "IE" in the CRF Table1.A(a)s2.

Table 3-50 Activity data fuel consumption in 1A2e Food processing, beverages and tobacco.

| 1A2e Food processing, beverages and tobacco | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 9'858 | 8'784 | 10'437 | 10'239 | 13'161 |
| Gas oil | TJ | 7'410 | 5'511 | 5'515 | 4'070 | 3'778 |
| Residual fuel oil | TJ | 1'160 | 466 | 137 | NO | NO |
| Liquefied petroleum gas | TJ | 204 | 308 | 535 | 534 | 659 |
| Petroleum coke | TJ | NO | NO | NO | NO | NO |
| Other bituminous coal | TJ | NO | NO | NO | NO | NO |
| Lignite | TJ | NO | NO | NO | NO | NO |
| Natural gas | TJ | 1'085 | 2'500 | 4'250 | 5'635 | 8'723 |
| Biomass | TJ | IE | IE | IE | IE | IE |

| 1A2e Food processing, beverages and tobacco | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 11'374 | 11'310 | 13'079 | 12'438 | 11'572 | 10'974 | 11'212 | 10'824 | 11'831 | 11'858 |
| Gas oil | TJ | 3'197 | 3'237 | 3'681 | 2'395 | 2'522 | 2'503 | 2'110 | 1'925 | 2'119 | 2'007 |
| Residual fuel oil | TJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Liquefied petroleum gas | TJ | 675 | 935 | 935 | 828 | 838 | 699 | 785 | 763 | 731 | 699 |
| Petroleum coke | TJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Other bituminous coal | TJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Lignite | TJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Natural gas | TJ | 7'502 | 7'138 | 8'463 | 9'215 | 8'212 | 7'772 | 8'318 | 8'137 | 8'981 | 9'153 |
| Biomass | TJ | IE | IE | IE | IE | IE | IE | IE | IE | IE | IE |

### *3.2.6.2.7. Non-metallic minerals (1A2f)*

The source category 1A2f Non-metallic minerals includes several large fuel consumers within mineral industry, e.g. cement, brick and tile, glass, and rock wool production. All fuel consumption of these specific industrial production processes are based on bottom-up industry data.

The fuels consumed in this source category are very diverse, depending on the fuel use within the specific industry process (see detailed documentation below). Except for brick and tile production (from 2013 onwards) bottom-up information is also available on the amount of biomass consumed. Therefore, all emissions from biomass used in these processes are reported in source category 1A2f.

Between 1990 and 2020, there has been a switch in fuel consumption from other bituminous coal and residual fuel oil to other fossil fuels, natural gas, lignite and biomass. The most important emission source within this category is cement production. Information on bottom-up data of fuel consumption and some source-specific emission factors are described in the following. Detailed data at process level cannot be provided, since they are mostly confidential. Therefore, aggregated data for 1A2f are shown in Table 3-51.

Table 3-51 Activity data fuel consumption in 1A2f Non-metallic minerals.

| 1A2f Non-metallic minerals | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 25'613 | 19'885 | 18'055 | 17'832 | 18'196 |
| Gas oil | TJ | 1'871 | 1'629 | 1'642 | 1'389 | 1'269 |
| Residual fuel oil | TJ | 5'382 | 5'578 | 3'649 | 2'420 | 1'519 |
| Liquefied petroleum gas | TJ | 523 | 498 | 468 | 324 | 102 |
| Petroleum coke | TJ | 550 | 300 | 480 | 638 | 1'130 |
| Other bituminous coal | TJ | 12'665 | 6'758 | 5'415 | 4'364 | 3'992 |
| Lignite | TJ | 265 | 153 | 124 | 737 | 1'348 |
| Natural gas | TJ | 1'769 | 1'566 | 1'496 | 1'861 | 2'048 |
| Other fossil fuels | TJ | 2'556 | 2'818 | 4'053 | 4'525 | 5'183 |
| Biomass | TJ | 33 | 586 | 728 | 1'575 | 1'604 |

| 1A2f Non-metallic minerals | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 17'801 | 16'956 | 17'119 | 17'677 | 16'484 | 16'518 | 16'536 | 16'716 | 16'643 | 16'222 |
| Gas oil | TJ | 1'238 | 1'097 | 1'174 | 1'204 | 1'098 | 1'020 | 1'118 | 1'078 | 1'117 | 997 |
| Residual fuel oil | TJ | 1'403 | 1'456 | 801 | 209 | 130 | 139 | 106 | 31 | 109 | 37 |
| Liquefied petroleum gas | TJ | 127 | 108 | 113 | 45 | 52 | 44 | 44 | 45 | 45 | 39 |
| Petroleum coke | TJ | 1'081 | 920 | 815 | 1'052 | 622 | 658 | 574 | 542 | 552 | 591 |
| Other bituminous coal | TJ | 3'474 | 3'403 | 3'478 | 1'973 | 1'498 | 1'089 | 1'210 | 1'206 | 1'085 | 767 |
| Lignite | TJ | 1'493 | 1'081 | 1'283 | 2'912 | 2'856 | 2'881 | 2'694 | 2'367 | 2'120 | 2'266 |
| Natural gas | TJ | 1'938 | 2'085 | 2'506 | 3'111 | 3'121 | 2'952 | 2'970 | 2'972 | 2'997 | 2'820 |
| Other fossil fuels | TJ | 5'307 | 4'883 | 5'186 | 5'270 | 5'252 | 5'926 | 5'912 | 6'513 | 6'679 | 6'805 |
| Biomass | TJ | 1'739 | 1'923 | 1'764 | 1'901 | 1'856 | 1'809 | 1'908 | 1'962 | 1'940 | 1'900 |

### Cement (1A2f)

*Methodology*

In Switzerland, there are six plants producing clinker and cement. The Swiss plants are rather small and do not exceed a production capacity of 3'000 tonnes of clinker per day. All of them use modern dry process technology. Cement industry emissions stem from incineration of a wide variety of standard fossil and (biogenic and fossil) waste-derived fuels used to generate the high temperatures needed for the calcination process.

*Emission factors*

The $CH_4$ emission factor includes the overall $CH_4$ emissions of the cement industry based on direct exhaust measurements at the chimneys of the cement plants. Therefore, these $CH_4$ emissions are reported under the fuel type other fossil fuels in the reporting tables.

Table 3-52 Emission factors for cement industry in 2020. Emission factors for $CO_2$ and $N_2O$ are fuel specific (see Table 3-13, Table 3-17 and Table 3-53).

| Cement industry (part of 1A2f) | $CO_2$ | $N_2O$ | $CH_4$ | $NO_x$ | NMVOC | $SO_2$ | CO |
|---|---|---|---|---|---|---|---|
| | t/TJ | | g/t clinker | | | | |
| Cement | fuel specific | | 7 | 790 | 67 | 280 | 2'600 |

The emission factors for $CO_2$ and $N_2O$ for standard fossil fuels are the same as used elsewhere (Table 3-13, Table 3-17). Regarding waste derived fuels, the NCVs and $CO_2$ emission factors for waste oil, solvents and residues from distillation, plastics, mix of special waste with saw dust (CSS), sewage sludge, wood waste, animal meal and saw dust are based on a study of Cemsuisse (Cemsuisse 2010a) providing measured values for the year 2010. A follow-up study of Cemsuisse (Cemsuisse 2018) provided measured values for the year 2017 for the three most relevant waste derived fuels – i.e. waste oil, solvents and residues from distillation and plastics – as well as for mix of special waste with saw dust (CSS). Emission factors between 2010 (the year of the previous assessment) and 2017 are interpolated, while constant values are used before the first and after the last year with available data.

The values for waste tyres and rubber are taken from Hackl and Mauschitz (2003). The biogenic fraction of waste tyres and rubber is based on an Austrian study and published by the German Ministry of Environment (UBA 2006). The emission factor of $N_2O$ is the same for all waste derived fuels and is taken from the IPCC Guidelines (IPCC 2006, vol. 2, chp. 2 table 2.3 industrial wastes).

Table 3-53 NCVs, fossil fractions as well as $CO_2$ (fossil and biogenic) and $N_2O$ emission factors of waste derived fuels (Other fossil fuels and Biomass) used in the cement industry. Where data for more than one year is available, values in between are interpolated and constant values are used before the first and after the last year with available data. Waste derived fuels marked with an asterisk are classified as biomass (e.g. in Table 3-51). Entries of "NA" mean that the respective fossil or biogenic fraction is zero.

| **Cement industry (part of 1A2f) Waste derived fuel** | **Data sources** | **NCV** | **Fraction fossil** | **EF $CO_2$ fossil+biog.** | **EF $CO_2$ fossil** | **EF $CO_2$ biog.** | **EF $N_2O$** |
|---|---|---|---|---|---|---|---|
| | | GJ/t | % | t $CO_2$/TJ | | | kg $N_2O$/TJ |
| Waste oil | Cemsuisse (2010a, 2018) | 32.5 *(2010)*<br>31.0 *(2017)* | 100.0 *(2010)*<br>92.7 *(2017)* | 74.4 *(2010)*<br>73.2 *(2017)* | 74.4 *(2010)*<br>67.9 *(2017)* | NA *(2010)*<br>5.3 *(2017)* | 4 |
| Waste coke from coke filters | Vock (2001)<br>Hackl and Mauschitz (2003) | 23.7 | 100 | 97 | 97 | NA | 4 |
| Mixed industrial waste | Cemsuisse, FOEN | 18.3 | 100 | 74 | 74 | NA | 4 |
| Other fossil waste fuels | Cemsuisse, FOEN | 20.9 | 100 | 97 | 97 | NA | 4 |
| Solvents and residues from distillation | Cemsuisse (2010a, 2018) | 23.6 *(2010)*<br>23.5 *(2017)* | 99.1 *(2010)*<br>89.7 *(2017)* | 74.0 *(2010)*<br>70.7 *(2017)* | 73.3 *(2010)*<br>63.4 *(2017)* | 0.7 *(2010)*<br>7.3 *(2017)* | 4 |
| Waste tyres and rubber | Hackl and Mauschitz (2003)<br>UBA (2006) | 26.4 | 73 | 84 | 61.3 | 22.7 | 4 |
| Plastics | Cemsuisse (2010a, 2018) | 25.2 *(2010)*<br>23.6 *(2017)* | 72.3 *(2010)*<br>76.6 *(2017)* | 84.7 *(2010)*<br>84.5 *(2017)* | 61.2 *(2010)*<br>64.7 *(2017)* | 23.5 *(2010)*<br>19.8 *(2017)* | 4 |
| Mix of special waste with saw dust (CSS)* | Cemsuisse (2010a, 2018) | 9.2 *(2010)*<br>9.1 *(2017)* | 21.5 *(2010)*<br>27.0 *(2017)* | 102.4 *(2010)*<br>112.2 *(2017)* | 22.0 *(2010)*<br>30.3 *(2017)* | 80.4 *(2010)*<br>81.9 *(2017)* | 4 |
| Sewage sludge (dried)* | Cemsuisse (2010a) | 9.4 | 0 | 94.5 | NA | 94.5 | 4 |
| Wood waste* | Cemsuisse (2010a) | 16.3 | 0 | 99.9 | NA | 99.9 | 4 |
| Animal meal* | Cemsuisse (2010a) | 16.8 | 0 | 86.7 | NA | 86.7 | 4 |
| Agricultural waste / other biomass* | Cemsuisse, FOEN | 12.7 | 0 | 110 | NA | 110 | 4 |

*Activity data*

Data on fuel consumption is provided by the industry, for recent years based on monitoring reports of the Swiss ETS as documented in the EMIS database (EMIS 2022/1A2f Zementwerke Feuerung).

In 2020, the Swiss cement industry used about two-thirds of waste derived fuels and one-third of standard fossil fuels. Today, fossil fuels used in cement industry are mainly lignite, plastics, waste tyres, waste oil and solvents and residues from distillation whereas petroleum coke and other bituminous coal are less important. Biogenic wastes contain mainly wood waste, sewage sludge and animal residues (animal meal). The main fossil fuel used in 1990 was other bituminous coal, but residual fuel oil, and waste oil were also of importance.

Fuel consumption in cement plants has decreased between 1990 and 2020. This is partly due to a decrease in production since 1990 and an increase in energy efficiency. In the same period, the fuel mix has changed significantly from mainly standard fossil fuels to the above mentioned mix of fuels.

In the reporting tables, the mainly biogenic waste derived fuels are reported under fuel type Biomass, whereas mainly fossil waste derived fuels are reported under fuel type Other fossil fuels (however, both fuel types also contain a fossil and a biogenic fraction, respectively, see Table 3-53).

Table 3-54 Activity data: Overview on fuel use in cement industry (part of 1A2f).

| Cement industry (part of 1A2f) | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 17'194 | 12'774 | 11'017 | 11'623 | 12'388 |
| Cement fossil without waste | TJ | 15'319 | 9'993 | 7'332 | 6'208 | 6'278 |
| Gas oil | TJ | NO | NO | NO | 72 | 5.4 |
| Residual fuel oil | TJ | 1'907 | 2'825 | 1'530 | 637 | 112 |
| Petroleum coke | TJ | 550 | 300 | 480 | 638 | 1'130 |
| Other bituminous coal | TJ | 12'235 | 6'547 | 5'176 | 4'120 | 3'662 |
| Lignite | TJ | 265 | 153 | 124 | 737 | 1'348 |
| Natural gas | TJ | 362 | 168 | 22 | 3.9 | 21.5 |
| Cement, waste derived fuel | TJ | 1'874 | 2'781 | 3'685 | 5'415 | 6'109 |
| Other fossil fuels | TJ | 1'842 | 2'196 | 2'997 | 3'931 | 4'580 |
| Waste oil | TJ | 1'170 | 1'485 | 1'520 | 1'411 | 1'253 |
| Waste coke from coke filters | TJ | 59 | 59 | 59 | 58 | NO |
| Mixed industrial waste | TJ | NO | NO | NO | NO | NO |
| Other fossil waste fuels | TJ | NO | NO | NO | NO | 45 |
| Solvents and residues from distillation | TJ | 283 | 181 | 426 | 976 | 1'189 |
| Waste tyres and rubber | TJ | 330 | 415 | 421 | 645 | 842 |
| Plastics | TJ | NO | 55 | 572 | 841 | 1'252 |
| Biomass | TJ | 33 | 586 | 688 | 1'484 | 1'530 |
| Mix of special waste with saw dust (CSS) | TJ | 23 | 135 | 158 | 133 | 123 |
| Sewage sludge (dried) | TJ | 9.4 | 128 | 333 | 494 | 477 |
| Wood waste | TJ | NO | 322 | NO | NO | 292 |
| Animal meal | TJ | NO | NO | 198 | 856 | 624 |
| Sawdust | TJ | NO | NO | NO | NO | 5.7 |
| Agricultural waste / other biomass | TJ | NO | NO | NO | NO | 7.3 |

| Cement industry (part of 1A2f) | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 12'187 | 11'462 | 11'866 | 12'339 | 11'348 | 11'583 | 11'476 | 11'474 | 11'478 | 11'213 |
| Cement fossil without waste | TJ | 5'859 | 5'406 | 5'512 | 5'847 | 4'917 | 4'544 | 4'354 | 3'965 | 3'736 | 3'465 |
| Gas oil | TJ | 0.68 | 0.10 | 88 | 75 | 87 | 50 | 56 | 63 | 106 | 54 |
| Residual fuel oil | TJ | 101 | 297 | 86 | 58 | 45 | 90 | 59 | NO | 63 | NO |
| Petroleum coke | TJ | 1'081 | 920 | 815 | 1'052 | 622 | 658 | 574 | 542 | 552 | 591 |
| Other bituminous coal | TJ | 3'167 | 3'097 | 3'203 | 1'713 | 1'267 | 826 | 938 | 938 | 831 | 528 |
| Lignite | TJ | 1'493 | 1'081 | 1'283 | 2'912 | 2'856 | 2'881 | 2'694 | 2'367 | 2'120 | 2'266 |
| Natural gas | TJ | 16 | 11 | 38 | 37 | 41 | 39 | 34 | 56 | 65 | 26 |
| Cement, waste derived fuel | TJ | 6'329 | 6'056 | 6'354 | 6'492 | 6'431 | 7'039 | 7'122 | 7'509 | 7'743 | 7'748 |
| Other fossil fuels | TJ | 4'685 | 4'225 | 4'599 | 4'596 | 4'582 | 5'234 | 5'219 | 5'550 | 5'805 | 5'852 |
| Waste oil | TJ | 1'170 | 839 | 876 | 923 | 1'142 | 1'567 | 1'311 | 1'336 | 1'466 | 1'460 |
| Waste coke from coke filters | TJ | NO | NO | NO | NO | NO | NO | 66 | 61 | 48 | 52 |
| Mixed industrial waste | TJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Other fossil waste fuels | TJ | 55 | 36 | 25 | 19 | 12 | 11 | 5.7 | 5.4 | NO | NO |
| Solvents and residues from distillation | TJ | 1'264 | 1'294 | 1'414 | 1'273 | 1'292 | 1'534 | 1'398 | 1'380 | 1'623 | 1'288 |
| Waste tyres and rubber | TJ | 1'033 | 964 | 985 | 1'021 | 958 | 951 | 1'041 | 1'045 | 1'041 | 1'018 |
| Plastics | TJ | 1'163 | 1'092 | 1'299 | 1'360 | 1'177 | 1'171 | 1'398 | 1'722 | 1'627 | 2'034 |
| Biomass | TJ | 1'644 | 1'831 | 1'756 | 1'896 | 1'850 | 1'805 | 1'903 | 1'959 | 1'937 | 1'897 |
| Mix of special waste with saw dust (CSS) | TJ | 96 | 100 | 96 | 103 | 80 | 98 | 78 | 73 | 58 | 0 |
| Sewage sludge (dried) | TJ | 483 | 527 | 418 | 428 | 420 | 479 | 499 | 519 | 512 | 553 |
| Wood waste | TJ | 409 | 586 | 732 | 886 | 896 | 811 | 840 | 840 | 861 | 867 |
| Animal meal | TJ | 614 | 572 | 479 | 457 | 412 | 409 | 470 | 522 | 475 | 441 |
| Sawdust | TJ | 24 | 17 | 32 | 21 | 42 | 7.9 | 5.6 | 5.4 | 31 | 36 |
| Agricultural waste / other biomass | TJ | 18 | 28 | NO | NO | NO | NO | 9.2 | NO | NO | NO |

### Lime (1A2f)

In Switzerland there is only one plant producing lime. Fossil fuels are used for the burning process (calcination) of limestone. From 1990 to 1993, other bituminous coal was the primary fuel. Between 1994 and 2012, bituminous coal was replaced by residual fuel oil. In 2013, the main kiln has been switched to natural gas.

### Container glass (1A2f)

Today, there exists only one production plant for container glass in Switzerland. Fuel consumption has drastically decreased over the reporting period due to a reduction in production. Until 2003, only residual fuel oil was used. From 2004 onwards, the share of natural gas has increased, reaching a stable share between 2006 and 2012. In autumn 2013, the plant has switched its glass kiln completely to natural gas.

**Tableware glass (1A2f)**

Today, there exists only one production plant for tableware glass in Switzerland. Fuel consumption for tableware glass currently includes only liquefied petroleum gas, as residual fuel oil was eliminated in 1995. Since 1990, fuel consumption has strongly decreased because of the closure of one production plant in 2006.

**Glass wool (1A2f)**

Glass wool is produced in two plants. Currently, fuel consumption for glass wool production includes only natural gas. Production of glass wool has increased since 1990.

**Fine ceramics (1A2f)**

In Switzerland, the main production of fine ceramics is sanitary ware produced by one big and some small companies. In earlier years, also other ceramics were produced as for example glazed ceramic tiles, electrical porcelain and earthenware. Since 2001, only sanitary ware is produced.

Until 2001, the fuel mix consisted of natural gas and gas oil. Since then, gas oil consumption decreased continuously, so that from 2010 onwards, only natural gas is consumed. Compared to the production of other fine ceramics, the production of sanitary ware is more energy-intensive. Therefore, the specific energy use per tonne of produced fine ceramics increased considerably between 1990 and 2001. This results in a lower reduction of fuel consumption compared to the reduction in production between 1990 and 2020.

**Brick and tile (1A2f)**

In Switzerland there are about 20 plants producing bricks and tiles. Mainly fossil fuels but also paper production residues, animal grease and wood are used for drying and burning of the clay blanks.

*Emission factors*

The $CO_2$ emission factors for wood and animal grease are based on a study of Cemsuisse (Cemsuisse 2010a), see Table 3-53, whereas the one for paper production residues is taken from a German study on secondary fuels (UBA 2006) as documented in the EMIS database (EMIS 2022/1A2f Ziegeleien).

For $CH_4$ and $N_2O$, emission factors of paper production residues and animal grease default values for wood waste and other liquid fuels, respectively, according to IPCC 2006 are used. For wood, the $CH_4$ emission factor according to the energy model for wood combustion (automatic chip boiler >500 kW, w/o wood processing companies), see chp. 3.2.4.5.2, and the default $N_2O$ emission factor from IPCC 2006 are used.

*Activity data*

Since 2013, plant-specific activity data – except for biomass – are available from monitoring reports of the Swiss ETS. Fuels used in the brick and tile production in 2020 are mainly natural gas but also residual fuel oil and gas oil. Apart from a production recovery in the years around 2004, the production has gradually decreased since 1990, which is also represented in the overall fuel consumption decrease. Regarding the fuels used, there has been a considerable shift from residual fuel oil to natural gas from 1990 onwards as well as to a lesser extent, a shift from liquefied petroleum gas and gas oil to natural gas from 2004 onwards. Small amounts of paper production residues, wood and animal grease are used since 2000.

**Rock wool (1A2f)**
In Switzerland there is one single producer of rock wool. Cupola furnaces are used for the melting of rocks at a temperature of 1500°C.

Currently, other bituminous coal and natural gas are used in the production process. Until 2004, also gas oil and liquefied petroleum gas were used. In 2005, these fuels were substituted by natural gas.

**Mixed goods (1A2f)**
The production of mixed goods mainly includes the production of bitumen for road paving. A total of 110 production sites are producing mixed goods at stationary production sites. The main fuels used are gas oil and increasingly also natural gas.

#### *3.2.6.2.8. Other (1A2g stationary)*

**Methodology (1A2g stationary)**
Source category 1A2giv Wood and wood products includes fuel consumption of fibreboard production. Fibreboards were produced in two companies in Switzerland until 2019, where thermal energy is used for heating and drying processes. Since 2020 only one plant is left.

Source category 1A2gviii Other covers fossil fuel combustion in boilers not further specified in manufacturing industries and construction, as well as combustion of wood, wood waste, biogas and sewage gas in all manufacturing industries. Methodologically, the fossil fuel consumption in boilers of 1A2gviii represents the residual entities of the industry installations that could not be allocated to any other source categories in 1A2a–f.

For more detailed descriptions on methodologies of biogas and sewage gas, see source categories 5B Biological treatment of solid waste (chp. 7.3) and 5D Wastewater treatment and discharge (chp.7.5), respectively.

This source category accounts for nearly 40% of the overall fuel consumption in 2020 of 1A2 Manufacturing industries and construction (stationary).

**Emission factors (1A2g stationary)**

The $CO_2$ emission factors for wood waste and animal grease in 1A2giv Wood and wood products are based on a study by Cemsuisse (2010a), see Table 3-53. For wood waste, the respective $CH_4$ and $N_2O$ emission factors of the energy model for wood combustion, see chp. 3.2.4.5.2, and IPCC 2006, respectively, are taken, whereas for animal grease, the default values of IPCC 2006 for other liquid biofuels are used. For biogas and sewage gas in 1A2gviii Other Boilers and Engines Industry, the same emission factors as for natural gas are assumed.

**Activity data (1A2g stationary)**

*1A2giv Wood and wood products*

In source category 1A2giv Wood and wood products, mainly wood waste as well as natural gas are used (Table 3-55). Since 1990, the production of fibreboard and thus the fuel consumption have increased significantly. The fuel mix has strongly shifted from fossil fuels to biomass (wood waste) between 1990 and 2020. Between 2001 and 2013, also animal grease was used for fibreboard production. Since 2004, data on annual fuel consumption is taken from monitoring reports of the industry as documented in the EMIS database (EMIS 2022/1A2giv).

*1A2gviii Other Boilers and Engines Industry*

Activity data for wood combustion is based on Swiss wood energy statistics (SFOE 2021b) whereas sewage and biogas consumption is based on data from the Swiss renewable energy statistics (SFOE 2021a) and the Statistics on combined heat and power generation in Switzerland (SFOE 2021c). Further information on wood energy consumption is provided in chp. 3.2.4.5.2.

Since 1990, the consumption of residual fuel oil and liquefied petroleum gas decreased. Solid fossil fuel consumption was quite stable, whereas biomass and natural gas consumption increased.

Table 3-55 Activity data fuel consumption in 1A2g iv Wood and wood products and 1A2gviii Other (stationary).

| **1A2giv: Wood and wood products, 1A2gviii: Other (stationary)** | **Unit** | **1990** | **1995** | **2000** | **2005** | **2010** |
|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 22'348 | 28'347 | 30'410 | 33'018 | 36'340 |
| Gas oil | TJ | 7'431 | 11'657 | 13'542 | 14'531 | 12'707 |
| Residual fuel oil | TJ | 5'298 | 3'749 | 199 | 26 | 142 |
| Liquefied petroleum gas | TJ | 3'091 | 3'288 | 4'164 | 3'116 | 2'855 |
| Petroleum coke | TJ | 765 | 914 | 15 | 383 | 318 |
| Other bituminous coal | TJ | 205 | 140 | 12 | 88 | 11 |
| Lignite | TJ | NO | NO | NO | 4.7 | 111 |
| Natural gas | TJ | 1'000 | 2'607 | 5'423 | 6'077 | 8'116 |
| Other fossil fuels | TJ | NO | NO | NO | NO | NO |
| Biomass | TJ | 4'558 | 5'992 | 7'054 | 8'790 | 12'080 |

| **1A2giv: Wood and wood products, 1A2gviii: Other (stationary)** | **Unit** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 32'639 | 33'282 | 32'904 | 29'841 | 30'887 | 31'610 | 32'009 | 30'460 | 30'626 | 29'298 |
| Gas oil | TJ | 10'124 | 10'239 | 10'377 | 7'050 | 7'342 | 7'788 | 6'913 | 6'568 | 5'534 | 4'839 |
| Residual fuel oil | TJ | 109 | 109 | 22 | 0.33 | 2.8 | 7.9 | 4.3 | 2.2 | 2.4 | 4.1 |
| Liquefied petroleum gas | TJ | 2'756 | 2'162 | 2'165 | 1'949 | 1'977 | 1'615 | 1'860 | 1'813 | 1'738 | 1'667 |
| Petroleum coke | TJ | 154 | 405 | 181 | 108 | 104 | 155 | 113 | 168 | 169 | 65 |
| Other bituminous coal | TJ | 16.4 | 50 | 110 | 105 | 134 | 125 | 102 | 140 | 58 | 101 |
| Lignite | TJ | 131 | 95 | 75 | 189 | 204 | 197 | 182 | 153 | 141 | 144 |
| Natural gas | TJ | 7'748 | 7'980 | 7'311 | 7'873 | 8'450 | 8'226 | 8'904 | 8'371 | 9'217 | 8'697 |
| Other fossil fuels | TJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Biomass | TJ | 11'601 | 12'243 | 12'663 | 12'567 | 12'674 | 13'496 | 13'931 | 13'243 | 13'767 | 13'781 |

### 3.2.6.3. Uncertainties and time-series consistency for 1A2 (stationary)

The uncertainty of emission estimates for source category 1A2 (stationary) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7.

Time series for 1A2 Manufacturing industries and construction are all considered consistent.

### 3.2.6.4. Category-specific QA/QC and verification for 1A2 (stationary)

The general QA/QC procedures are described in chp. 1.2.3. Furthermore QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

### 3.2.6.5. Category-specific recalculations for 1A2 (stationary)

The following recalculations were implemented in submission 2022. Major recalculations, which contribute significantly to the total differences in GHG emissions of sector 1 Energy between the latest and the previous submissions are presented also in chp. 10.1.2.1.

- 1A2: Reallocation of gas oil and natural gas use in boilers in manufacturing industries and construction based on SFOE (2021d) for the year 2019.
- 1A2f: The $CH_4$ emission factor for wood combustion (2000–2012) in 1A2f Brick and tile production was adjusted to the values of the revised country-specific emission factor model (previous submission, Zotter et al. 2022).
- 1A2gviii: Activity data (wood, wood waste) of combustion installations in source category 1A2gviii have been revised for 1990–2019 due to recalculations in the Swiss wood energy statistics (SFOE 2021b). The biggest changes were in automatic boilers >50 kW after 2005.

- 1A2gviii: Activity data of sewage gas from industrial wastewater treatment used in boilers and in engines have changed by less than 1% for the years 2015–2018. The data are taken from the national statistical report of renewable energies by SFOE and have been updated.
- 1A2gviii: Due to small recalculations of consumption of liquefied petroleum gas in the road transportation sector, the use of liquefied petroleum gas in 1A2gviii Other boilers has changed a little, too.

#### 3.2.6.6. Category-specific planned improvements for 1A2 (stationary)

There are no category-specific planned improvements.

### 3.2.7. Source category 1A4 – Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

#### 3.2.7.1. Source category description for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

Table 3-56 Key categories of 1A4 Other sectors. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 1A4a | Commercial; Gaseous Fuels | CO2 | L1, T1 |
| 1A4a | Commercial; Liquid Fuels | CO2 | L1, T1 |
| 1A4b | Residential; Gaseous Fuels | CO2 | L1, T1, L2 |
| 1A4b | Residential; Liquid Fuels | CO2 | L1, T1 |
| 1A4c | Agriculture and Forestry; Liquid Fuels | CO2 | L1, T1 |

Each of the source categories 1A4a, 1A4b, 1A4c contain the sum of emissions of stationary and mobile sources – the above statements on key categories hold for the aggregated emissions of 1A4a etc. only. The $CO_2$ emissions of 1A4a and 1A4b from Liquid Fuels are vastly dominated by the stationary sources, which means that the emissions of 1A4aii and 1A4bii only play a minor role within category 1A4a and 1A4b. For 1A4c, however, the emissions of 1A4cii are more important than those of 1A4ci (see also chp. 3.2.10.1.)

Table 3-57 Specification of source category 1A4 Other sectors.

| 1A4 | Source category | Specification |
|---|---|---|
| 1A4ai | Commercial/institutional: Stationary | Emissions from stationary fuel combustion in commercial and institutional buildings, including boilers, engines, turbines and different wood combustion installations |
| 1A4bi | Residential: Stationary | Emissions from stationary fuel combustion in households, including boilers, engines, turbines and different wood combustion installations |
| 1A4ci | Agriculture/Forestry/Fishing: Stationary | Emissions from stationary fuel combustion in agriculture, including different wood combustion installations, engines with biogas, heating of greenhouses and grass drying |

### 3.2.7.2. Methodological issues for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

#### Methodology (1A4 stationary)

$CO_2$ emissions from stationary combustion in source categories 1A4ai, 1A4bi and 1A4ci are estimated based on country-specific emission factors using a Tier 2 approach according to the decision tree for stationary combustion of the IPCC Guidelines (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1) for liquid, solid, gaseous fuels, biogas, wood consumption in bonfires and animal grease. For wood biomass, a Tier 3 approach using country-specific emission factors is applied.

A Tier 1 approach is applied with IPCC default emission factors for $CH_4$ emissions of residual fuel oil and gas oil for boilers and $N_2O$ emissions of all fuels and technologies (IPCC 2006). $CH_4$ emissions of gas oil used in engines, gaseous fuels and biogas are calculated by a Tier 2 approach using country-specific emission factors. $CH_4$ emissions of wood biomass are calculated by a Tier 3 approach using country-specific emission factors.

For the calculation of the emissions from the use of gas oil and natural gas the following sources are differentiated: (a) heat only boilers, (b) combined heat and power production in turbines and (c) combined heat and power production in engines.

Emissions from 1A4ci Other sectors (stationary) – Agriculture/Forestry/Fishing originate from fuel combustion for the heating of greenhouses and grass drying, as well as from wood combustion for heating in agriculture and forestry. For grass drying, information is provided by the Swiss association of grass drying plants (VSTB). For greenhouses, information is provided by the Energy Agency of the Swiss Private Sector (EnAW).

## Emission factors (1A4 stationary)

Table 3-58 Emission factors for stationary combustion in 1A4ai Other sectors commercial/institutional in 2020. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

| 1A4ai Other sectors: | $CO_2$ fossil | $CO_2$ biog. | $CH_4$ | $N_2O$ | $NO_x$ | NMVOC | $SO_2$ | CO |
|---|---|---|---|---|---|---|---|---|
| | t/TJ | | kg/TJ | | | | | |
| Gas oil (weighted average) | 73.7 | NA | 10 | 0.6 | 32 | 6 | 6.5 | 6.1 |
| Gas oil heat only boilers | 73.7 | NA | 10 | 0.6 | 32 | 6 | 6.5 | 6 |
| Gas oil engines | 73.7 | NA | 2 | 0.6 | 40 | 8 | 6.5 | 30 |
| Natural gas (weighted average) | 56.2 | NA | 2.3 | 0.1 | 18.3 | 1.9 | 0.5 | 12.1 |
| NG heat only boilers | 56.2 | NA | 1 | 0.1 | 16 | 2 | 0.5 | 9 |
| NG turbines | 56.2 | NA | 2 | 0.1 | 19 | 0.1 | 0.5 | 4.8 |
| NG engines | 56.2 | NA | 20 | 0.1 | 50 | 1 | 0.5 | 55 |
| Biomass (weighted average) | NA | 99.8 | 16.1 | 4 | 112.7 | 37.8 | 5.4 | 572 |
| Biomass (wood) | NA | 99.9 | 16.1 | 4 | 112.8 | 37.9 | 5.4 | 573 |
| Biogas (heat only boilers) | NA | 56.2 | 1 | 0.1 | 16.0 | 2.0 | 0.5 | 9 |

Table 3-59 Emission factors for stationary combustion in 1A4bi Other sectors residential in 2020. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

| 1A4bi Other sectors: Residential | $CO_2$ fossil | $CO_2$ biog. | $CH_4$ | $N_2O$ | $NO_x$ | NMVOC | $SO_2$ | CO |
|---|---|---|---|---|---|---|---|---|
| | t/TJ | | kg/TJ | | | | | |
| Gas oil (weighted average) | 73.7 | NA | 10 | 0.6 | 33 | 6 | 6.5 | 11 |
| Gas oil heat only boilers | 73.7 | NA | 10 | 0.6 | 33 | 6 | 6.5 | 11 |
| Gas oil engines | 73.7 | NA | 2 | 0.6 | 40 | 8 | 6.5 | 30 |
| Natural gas (weighted average) | 56.2 | NA | 1.2 | 0.1 | 15.1 | 4 | 0.5 | 12.4 |
| NG heat only boilers | 56.2 | NA | 1 | 0.1 | 15 | 4 | 0.5 | 12 |
| NG turbines | NO | NA | NO | NO | NO | NO | NO | NO |
| NG engines | 56.2 | NA | 20 | 0.1 | 30 | 1 | 0.5 | 55 |
| Other bituminous coal | 92.7 | NA | 300 | 1.5 | 65 | 100 | 350 | 1'000 |
| Biomass (wood, charcoal, bonfires) | NA | 100 | 45 | 3.9 | 94 | 110 | 8.0 | 1'444 |
| Wood | NA | 100 | 39 | 4.0 | 96 | 94 | 7.9 | 1'360 |
| Use of charcoal | NA | 112 | 200 | 1 | 50 | 600 | 11 | 4'000 |
| Bonfires | NA | 100 | 300 | 4 | 50 | 600 | 11 | 4'000 |

Table 3-60 Emission factors for stationary combustion in 1A4ci Agriculture/forestry/fishing in 2020. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

| 1A4ci Agriculture/forestry/fishing | $CO_2$ fossil | $CO_2$ biog. | $CH_4$ | $N_2O$ | $NO_x$ | NMVOC | $SO_2$ | CO |
|---|---|---|---|---|---|---|---|---|
| | t/TJ | | kg/TJ | | | | | |
| Grass drying (fossil, biogenic) (weighted average) | 61 | 97 | 4.8 | 0.8 | 69 | 93 | 77 | 531 |
| Gas oil | 74 | NA | 3 | 0.6 | NA | NA | NA | NA |
| Residual fuel oil | NO | NA | NO | NO | NA | NA | NA | NA |
| Natural gas | 56.2 | NA | 1 | 0.1 | NA | NA | NA | NA |
| Biomass | NA | 97 | 19 | 3.3 | NA | NA | NA | NA |
| Heating of greenhouses (fossil, biogenic) (weighted average) | 62 | NA | 1.6 | 0.3 | 22 | 2 | 2.4 | 6.7 |
| Gas oil | 73.7 | NA | 3 | 0.6 | 31.0 | 2 | 6.5 | 6 |
| Natural gas | 56.2 | NA | 1 | 0.1 | 18.5 | 2 | 0.5 | 7 |
| Other biomass combustion (weighted average) | NA | 72 | 17 | 1.5 | 50 | 8.9 | 2.4 | 225 |
| Biogas heat only boilers | NA | 56.2 | 1 | 0.1 | 16 | 2 | 0.5 | 9 |
| Biogas engines | NA | 56.2 | 20 | 0.1 | 20 | 1 | 0.5 | 55 |
| Wood combustion | NA | 99.2 | 11 | 4 | 102 | 23 | 6 | 527 |

### *Charcoal and bonfires*

Emission factors concerning $CO_2$, $CH_4$ and $N_2O$ emissions of charcoal use in the residential source categories (1A4bi) are taken from the IPCC Guidelines (IPCC 2006). Default emission factors according to the guidelines are also applied for $CH_4$ and $N_2O$ emissions resulting from bonfires. The $CO_2$ emission factor for bonfires is based on the value for wood combustion; see chp. 3.2.4.4. Emission factors of precursors are taken from the EMEP/EEA guidebook (2019) (Table 3.39).

### Activity data (1A4 stationary)

*General energy sources*

Activity data about the energy sources gas oil, residual fuel oil, natural gas and biomass are calculated by the Swiss energy model (see chp. 3.2.4.3 for further information). For other energy sources such as other bituminous coal, activity data is provided directly by the Swiss overall energy statistics (SFOE 2021). Grass drying activities for source category 1A4ci are reported by the Swiss association of grass drying plants (VSTB) (as standard tonne of dried grass) as documented in the EMIS database (EMIS 2022/1A4ci Grastrocknung). The fuel consumption for the heating of greenhouses is extrapolated from the information provided by the Energy Agency of the Swiss Private Sector (EnAW) as documented in the EMIS database (EMIS 2022/1A4ci Gewächshäuser).

Table 3-61 Activity data in 1A4a Commercial/Institutional (stationary).

| 1A4ai Other sectors (stationary): Commercial/institutional | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 72'354 | 80'124 | 76'796 | 83'381 | 79'434 |
| Gas oil | TJ | 52'977 | 54'379 | 48'777 | 51'197 | 46'525 |
| Gas oil heat only boilers | TJ | 52'953 | 54'204 | 48'426 | 50'880 | 46'406 |
| Gas oil engines | TJ | 24 | 175 | 351 | 318 | 119 |
| Natural gas | TJ | 16'399 | 21'843 | 23'552 | 26'732 | 25'307 |
| NG heat only boilers | TJ | 16'123 | 20'672 | 21'815 | 24'699 | 23'602 |
| NG turbines | TJ | 85 | 78 | NO | 28 | 23 |
| NG engines | TJ | 192 | 1'093 | 1'737 | 2'004 | 1'681 |
| Biomass (total) | TJ | 2'978 | 3'902 | 4'467 | 5'452 | 7'602 |
| Biomass (wood) | TJ | 2'939 | 3'871 | 4'439 | 5'406 | 7'498 |
| Biogas (heat only boilers) | TJ | 39 | 32 | 27 | 46 | 104 |

| 1A4ai Other sectors (stationary): Commercial/institutional | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 65'350 | 71'905 | 77'291 | 60'970 | 66'946 | 70'275 | 67'737 | 61'160 | 61'617 | 58'597 |
| Gas oil | TJ | 37'088 | 39'750 | 42'727 | 32'993 | 35'153 | 36'440 | 34'222 | 30'879 | 30'273 | 27'596 |
| Gas oil heat only boilers | TJ | 36'983 | 39'656 | 42'640 | 32'910 | 35'071 | 36'358 | 34'140 | 30'797 | 30'191 | 27'514 |
| Gas oil engines | TJ | 105 | 94 | 86 | 82 | 82 | 82 | 82 | 82 | 82 | 82 |
| Natural gas | TJ | 21'857 | 24'733 | 26'341 | 20'237 | 23'102 | 24'326 | 23'967 | 21'166 | 21'759 | 21'042 |
| NG heat only boilers | TJ | 20'277 | 23'180 | 24'844 | 18'801 | 21'666 | 22'890 | 22'531 | 19'730 | 20'323 | 19'606 |
| NG turbines | TJ | 17 | 4.9 | 7.3 | 7.3 | 7.3 | 7.3 | 7.3 | 7.3 | 7.3 | 7.3 |
| NG engines | TJ | 1'564 | 1'548 | 1'490 | 1'429 | 1'429 | 1'429 | 1'429 | 1'429 | 1'429 | 1'429 |
| Biomass (total) | TJ | 6'405 | 7'422 | 8'223 | 7'740 | 8'690 | 9'509 | 9'548 | 9'115 | 9'585 | 9'959 |
| Biomass (wood) | TJ | 6'322 | 7'347 | 8'165 | 7'693 | 8'669 | 9'484 | 9'524 | 9'102 | 9'570 | 9'944 |
| Biogas (heat only boilers) | TJ | 83 | 76 | 59 | 47 | 21 | 24 | 24 | 13 | 14 | 15 |

Table 3-62 Activity data in 1A4b Residential (stationary).

| 1A4bi Other sectors (stationary): Residential | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 185'308 | 189'294 | 170'485 | 186'058 | 182'065 |
| Gas oil | TJ | 136'887 | 133'548 | 116'295 | 124'024 | 111'731 |
| Gas oil heat only boilers | TJ | 136'887 | 133'544 | 116'242 | 123'961 | 111'695 |
| Gas oil engines | TJ | 0.59 | 4.5 | 53 | 63 | 36 |
| Natural gas | TJ | 25'864 | 34'088 | 36'261 | 42'633 | 48'229 |
| NG heat only boilers | TJ | 25'804 | 33'830 | 35'822 | 42'103 | 47'723 |
| NG turbines | TJ | NO | NO | NO | NO | NO |
| NG engines | TJ | 60 | 258 | 439 | 530 | 506 |
| Other bituminous coal | TJ | 630 | 460 | 130 | 400 | 400 |
| Biomass (wood, charcoal, bonfires) | TJ | 21'926 | 21'198 | 17'799 | 19'001 | 21'705 |
| Wood | TJ | 21'455 | 20'746 | 17'347 | 18'528 | 21'201 |
| Use of charcoal | TJ | 311 | 291 | 292 | 313 | 344 |
| Bonfires | TJ | 160 | 160 | 160 | 160 | 160 |

| 1A4bi Other sectors (stationary): Residential | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 146'111 | 161'283 | 172'563 | 135'061 | 144'771 | 150'929 | 144'805 | 133'038 | 133'898 | 124'335 |
| Gas oil | TJ | 86'989 | 94'103 | 99'373 | 75'136 | 79'406 | 81'340 | 76'113 | 67'901 | 66'642 | 59'375 |
| Gas oil heat only boilers | TJ | 86'955 | 94'072 | 99'344 | 75'109 | 79'379 | 81'312 | 76'085 | 67'874 | 66'615 | 59'348 |
| Gas oil engines | TJ | 34 | 32 | 29 | 27 | 27 | 27 | 27 | 27 | 27 | 27 |
| Natural gas | TJ | 40'910 | 47'043 | 50'957 | 42'357 | 46'096 | 48'825 | 48'335 | 45'915 | 47'575 | 47'195 |
| NG heat only boilers | TJ | 40'440 | 46'577 | 50'509 | 41'927 | 45'666 | 48'395 | 47'905 | 45'486 | 47'145 | 46'765 |
| NG turbines | TJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| NG engines | TJ | 470 | 466 | 448 | 430 | 430 | 430 | 430 | 430 | 430 | 430 |
| Other bituminous coal | TJ | 300 | 300 | 300 | 200 | 200 | 200 | 100 | 100 | 100 | 100 |
| Biomass (wood, charcoal, bonfires) | TJ | 17'912 | 19'837 | 21'932 | 17'368 | 19'069 | 20'564 | 20'258 | 19'122 | 19'582 | 17'665 |
| Wood | TJ | 17'408 | 19'333 | 21'429 | 16'854 | 18'555 | 20'070 | 19'724 | 18'608 | 19'097 | 17'102 |
| Use of charcoal | TJ | 344 | 344 | 343 | 354 | 354 | 334 | 374 | 354 | 325 | 404 |
| Bonfires | TJ | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 |

Table 3-63 Activity data in 1A4ci Agriculture/forestry/fishing (stationary).

| 1A4ci Other sectors (stationary): Agriculture/forestry/fishing | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 6'378 | 6'103 | 5'798 | 5'524 | 5'650 |
| Drying of grass | TJ | 1'895 | 1'544 | 1'223 | 994 | 739 |
| Gas oil | TJ | 1'156 | 942 | 746 | 607 | 451 |
| Residual fuel oil | TJ | NO | NO | NO | NO | NO |
| Natural gas | TJ | 739 | 602 | 477 | 388 | 288 |
| Biomass | TJ | NO | NO | NO | NO | NO |
| Heating of greenhouses | TJ | 4'000 | 4'000 | 4'000 | 3'735 | 3'677 |
| Gas oil | TJ | 3'490 | 3'490 | 3'490 | 3'133 | 1'803 |
| Natural gas | TJ | 510 | 510 | 510 | 601 | 1'874 |
| Other biomass combustion | TJ | 483 | 559 | 575 | 795 | 1'235 |
| Biogas heat only boilers | TJ | 39 | 32 | 27 | 46 | 104 |
| Biogas engines | TJ | 16 | 15 | 35 | 82 | 394 |
| Wood combustion | TJ | 428 | 513 | 513 | 667 | 738 |

| 1A4ci Other sectors (stationary): Agriculture/forestry/fishing | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 5'174 | 5'803 | 5'295 | 4'758 | 4'932 | 5'437 | 5'956 | 5'481 | 5'816 | 5'913 |
| Drying of grass | TJ | 891 | 685 | 458 | 524 | 431 | 492 | 610 | 545 | 684 | 721 |
| Gas oil | TJ | 543 | 418 | 106 | 104 | 89 | 86 | 118 | 116 | 124 | 148 |
| Residual fuel oil | TJ | NO | NO | 17 | 20 | 22 | 18 | 25 | 13 | NO | NO |
| Natural gas | TJ | 347 | 267 | 220 | 264 | 233 | 279 | 338 | 296 | 427 | 435 |
| Biomass | TJ | NO | NO | 114 | 136 | 88 | 109 | 129 | 120 | 132 | 138 |
| Heating of greenhouses | TJ | 3'121 | 3'671 | 3'389 | 2'800 | 2'900 | 2'899 | 3'238 | 2'754 | 2'732 | 2'537 |
| Gas oil | TJ | 1'269 | 1'647 | 1'496 | 1'095 | 1'165 | 1'066 | 1'145 | 930 | 916 | 788 |
| Natural gas | TJ | 1'852 | 2'025 | 1'893 | 1'705 | 1'735 | 1'834 | 2'093 | 1'824 | 1'816 | 1'749 |
| Other biomass combustion | TJ | 1'162 | 1'447 | 1'448 | 1'434 | 1'602 | 2'045 | 2'107 | 2'182 | 2'400 | 2'655 |
| Biogas heat only boilers | TJ | 83 | 76 | 59 | 47 | 21 | 24 | 24 | 13 | 14 | 15 |
| Biogas engines | TJ | 472 | 599 | 754 | 880 | 1'020 | 1'168 | 1'248 | 1'390 | 1'597 | 1'747 |
| Wood combustion | TJ | 608 | 772 | 636 | 506 | 561 | 853 | 835 | 780 | 788 | 893 |

*Charcoal and bonfires*

Besides the main fuels, also charcoal use and bonfires are accounted for in source category 1A4bi Other sectors (Stationary) – Residential. Charcoal is only used for charcoal grills. The total charcoal consumption under 1A4bi Other sectors (Stationary) – Residential is very small compared to other fuels used for heating purposes. The activity data are the sum of Swiss charcoal production as reported under 1A1c Manufacture of solid fuels and other energy industries and net imports provided by the Swiss overall energy statistics (SFOE 2021).

The total wood demand for bonfires is assumed to be constant over time (for further details see documentation in EMIS 2022/1A4bi Lagerfeuer).

#### 3.2.7.3. Uncertainties and time-series consistency for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

The uncertainty of emission estimates for source category 1A4 (stationary) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7.

Time series for 1A4 Other sectors are all considered to be consistent.

#### 3.2.7.4. Category-specific QA/QC and verification for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

The general QA/QC procedures are described in chp. 1.2.3. Furthermore QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

#### 3.2.7.5. Category-specific recalculations for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

The following recalculations were implemented in submission 2022. Major recalculations which contribute significantly to the total differences in GHG emissions of sector 1 Energy between the latest and the previous submissions are presented also in chp. 10.1.2.1.

- 1A4: Activity data (wood, wood waste) of combustion installations in source categories 1A4ai, 1A4bi and 1A4ci have been revised for 1990–2019 due to recalculations in the Swiss wood energy statistics (SFOE 2021b). The biggest changes were in automatic boilers >50 kW after 2005.
- 1A4a: Due to small recalculations of natural gas consumption for the year 2019, the activity data of boilers in 1A4a Commercial changed too.
- 1A4b: Due to small recalculations of natural gas consumption for the year 2019, the activity data of boilers in 1A4b Residential changed too.
- 1A4ci: The $CH_4$ emission factor for wood combustion (2013–2019) in 1A4ci Grass drying was adjusted to the values of the revised country-specific emission factor model (previous submission, Zotter et al. 2022).

#### 3.2.7.6. Category-specific planned improvements for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

There are no category-specific planned improvements.

### 3.2.8. Source category 1A2 – Manufacturing industries and construction (mobile 1A2gvii)

#### 3.2.8.1. Source category description for 1A2 Manufacturing industries and construction (mobile 1A2gvii)

Note for Key categories 1A2: *See chp. 3.2.6 and note that source category 1A2 contains the sum of emissions of stationary and mobile sources – the statement on key categories holds for the aggregated emission only. The $CO_2$ emissions of 1A2 from Liquid Fuels are dominated by the stationary sources. Only 41% (2020) of the $CO_2$ emissions of Liquid Fuels from 1A2 stem from mobile sources 1A2gvii.*

Table 3-64 Specification of source category 1A2 Manufacturing industries and construction (mobile).

| 1A2 | Source category | Specification |
|---|---|---|
| 1A2agvii | Mobile Combustion in manufacturing industries and construction | Industry sector: forklifts and snow groomers etc.<br>construction machines: excavators, loaders, dump trucks, mobile compressors etc. |

#### 3.2.8.2. Methodological issues for 1A2 Manufacturing industries and construction (mobile 1A2gvii)

**Methodology (1A2gvii)**

Based on the decision tree Fig. 3.3.1 in chp. “3. Mobile Combustion” in IPCC (2006) the emissions of industry and construction vehicles and machinery are calculated by a Tier 3 method with the non-road transportation model described in chp. 3.2.4.5.1.

$CO_2$ emissions from lubricants of gasoline 2-stroke engines are calculated by using the IPCC default $CO_2$ emission factor for lubricants, 73.3 t/TJ (IPCC 2006). However, these emissions are reported under source category 2D1 Lubricant use (see chp. 4.5.2.1). In contrast, $CH_4$ and $N_2O$ emissions from lubricant use in 2-stroke engines are reported in source category 1A2gvii, since the emission factors are based on measurements including 2-stroke engines.

**Emission factors (1A2gvii)**

- The $CO_2$ emission factors applied for the time series 1990–2020 for diesel oil, gasoline, liquefied petroleum gas and biodiesel and bioethanol are country-specific and are given in Table 3-13.

- The $CH_4$ and $N_2O$ emission factors are country-specific and are shown in Table 3-65 to Table 3-67 for diesel oil, gasoline and liquefied petroleum gas engines for all emission standards.
- For $SO_2$ from diesel oil, gasoline, gas oil and liquefied petroleum gas see Table A – 13 in Annex A3.1.4.
- The emission factors for precursors are country-specific and are given in FOEN (2015j).
- NMVOC is not modelled bottom-up. The NMVOC emissions are calculated as the difference between VOC and $CH_4$ emissions.
- The implied emission factors 2020 are shown in Table 3-68.

All emission factors (GHG, precursors) can be downloaded by query from the public part of the non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels.

Table 3-65 Emission factors $CH_4$ and $N_2O$ for industry and construction vehicles with diesel oil engines by emission standards including the year of entry into force.

| Gas | Power class | PreEU-A<br><1996 | PreEU-B<br>1996 | EU-I<br>2002/03 | EU-II<br>2002/04 | EU-IIIA<br>2006/08 | EU-IIIB<br>2011/12 | EU-IV<br>2014 |
|---|---|---|---|---|---|---|---|---|
| | kW | g/kWh | | | | | | |
| $CH_4$ | <18 | 0.0547 | 0.0547 | 0.0384 | 0.0240 | 0.0142 | 0.0142 | 0.0142 |
| $CH_4$ | 18–37 | 0.0578 | 0.0578 | 0.0221 | 0.0134 | 0.0089 | 0.0089 | 0.0089 |
| $CH_4$ | 37–56 | 0.0319 | 0.0319 | 0.0156 | 0.0110 | 0.0079 | 0.0055 | 0.0058 |
| $CH_4$ | 56–75 | 0.0319 | 0.0319 | 0.0156 | 0.0110 | 0.0079 | 0.0031 | 0.0031 |
| $CH_4$ | 75–130 | 0.0218 | 0.0218 | 0.0108 | 0.0084 | 0.0067 | 0.0031 | 0.0031 |
| $CH_4$ | 130–560 | 0.0218 | 0.0218 | 0.0103 | 0.0072 | 0.0053 | 0.0031 | 0.0031 |
| $CH_4$ | >560 | 0.0218 | 0.0218 | 0.0103 | 0.0072 | 0.0053 | 0.0031 | 0.0031 |
| $N_2O$ | 0–3000 | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 |

Table 3-66 Emission factors $CH_4$ and $N_2O$ for industry and construction vehicles with gasoline engines by emission standards including the year of enforcement.

| Gas | Power class | PreEU-A<br><1996 | PreEU-B<br>1996 | PreEU-C<br>2000 | EU-I<br>2004 | EU-II<br>2005/09 |
|---|---|---|---|---|---|---|
| | ccm | g/kWh | | | | |
| $CH_4$ | <66 | 2.040 | 2.040 | 2.040 | 1.394 | 1.394 |
| $CH_4$ | 66–100 | 1.360 | 1.360 | 1.360 | 1.088 | 1.088 |
| $CH_4$ | 100–225 | 0.680 | 0.680 | 0.680 | 0.408 | 0.408 |
| $CH_4$ | >225 | 0.680 | 0.680 | 0.680 | 0.340 | 0.306 |
| $N_2O$ | 0–3000 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |

Table 3-67 Emission factors $CH_4$ and $N_2O$ for industry and construction vehicles with liquefied petroleum gas engines (for all years).

| Gas | without catalyst | with catalyst |
|---|---|---|
| | g/kWh | |
| $CH_4$ | 0.552 | 0.035 |
| $N_2O$ | 0.05 | 0.05 |

Table 3-68 Implied emission factors 2020 for industry and construction vehicles.

| 1A2gvii Non-road vehicles and other machinery | $CO_2$ | $CH_4$ | $N_2O$ | $NO_x$ | NMVOC | $SO_2$ | CO |
|---|---|---|---|---|---|---|---|
| | t/TJ | kg/TJ | | | | | |
| Gasoline | 73.8 | 34.8 | 1.1 | 105 | 632 | 0.38 | 19'733 |
| Diesel oil | 73.3 | 0.47 | 3.3 | 208 | 20 | 0.47 | 102 |
| Liquefied petroleum gas | 65.5 | 0.67 | 2.4 | 96 | 8.8 | NA | 24 |
| Biodiesel | 73.3 | 0.40 | 2.8 | 177 | 17 | 0.40 | 87 |
| Bioethanol | 73.8 | 8.2 | 0.79 | 50 | 231 | 0.24 | 12'065 |

**Activity data (1A2gvii)**

Activity data for non-road (1A2gvii) are described in. chp. 3.2.4.5.1 (non-road transportation model). Values are taken from FOEN (2015j). Data on biofuels are provided by the statistics of renewable energies (SFOE 2015a). Activity data are shown in Table 3-69 and in Annex A3.1.3. Detailed data can be downloaded from the non-road database (INFRAS 2015a). Underlying activity data (vehicle stock, operating hours) of mobile non-road sources can also be downloaded by query from the public part of the non-road database (INFRAS 2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels.

Table 3-69 Activity data for industry and construction vehicles.

| 1A2gvii Non-road vehicles and other machinery | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 5'721 | 6'852 | 7'636 | 8'169 | 8'779 |
| Gasoline | TJ | 196 | 224 | 227 | 225 | 220 |
| Diesel oil | TJ | 5'359 | 6'380 | 7'106 | 7'626 | 8'254 |
| Liquefied petroleum gas | TJ | 165 | 248 | 294 | 290 | 269 |
| Biodiesel | TJ | NO | NO | 9.2 | 28 | 36 |
| Bioethanol | TJ | NO | NO | NO | NO | 0.0047 |

| 1A2gvii Non-road vehicles and other machinery | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 8'811 | 8'843 | 8'875 | 8'906 | 8'938 | 8'944 | 8'949 | 8'955 | 8'960 | 8'966 |
| Gasoline | TJ | 213 | 206 | 198 | 191 | 184 | 180 | 177 | 174 | 171 | 168 |
| Diesel oil | TJ | 8'283 | 8'312 | 8'341 | 8'370 | 8'399 | 8'380 | 8'361 | 8'342 | 8'323 | 8'304 |
| Liquefied petroleum gas | TJ | 260 | 252 | 243 | 235 | 226 | 215 | 203 | 192 | 180 | 168 |
| Biodiesel | TJ | 54 | 73 | 91 | 110 | 128 | 166 | 205 | 243 | 282 | 320 |
| Bioethanol | TJ | 0.26 | 0.51 | 0.76 | 1.0 | 1.3 | 2.0 | 2.7 | 3.3 | 4.0 | 4.7 |

### 3.2.8.3. Uncertainties and time-series consistency for 1A2gvii (mobile)

The uncertainty of emission estimates for source category 1A2gvii (mobile) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7. Uncertainties by fuel type are given in Table 3-26.

#### 3.2.8.4. Category-specific QA/QC and verification for 1A2gvii (mobile)

The general QA/QC procedures are described in chp. 1.2.3. Furthermore, QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

#### 3.2.8.5. Category-specific recalculations for 1A2gvii (mobile)

There were no recalculations implemented in submission 2022.

#### 3.2.8.6. Category-specific planned improvements for 1A2gvii (mobile)

No category-specific improvements are planned.

## 3.2.9. Source category 1A3 – Transport

### 3.2.9.1. Source category description for 1A3

Table 3-70 Key categories of 1A3 Transport. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 1A3a | Civil Aviation; Kerosene | CO2 | T1 |
| 1A3b | Road Transportation; Diesel oil | CO2 | L1, T1 |
| 1A3b | Road Transportation; Diesel oil | N2O | T1 |
| 1A3b | Road Transportation; Gasoline | CO2 | L1, T1 |
| 1A3b | Road Transportation; Gasoline | CH4 | T1 |
| 1A3b | Road Transportation; Gasoline | N2O | T1 |

Table 3-71 Specification of source category 1A3 Transport.

| 1A3 | Source category | Specification |
|---|---|---|
| 1A3a | Domestic aviation | LTO and Cruise;<br>Large (jet, turboprop) and small (piston) aircrafts, helicopters |
| 1A3bi | Road Transportation | Passenger cars |
| 1A3bii | | Light duty trucks |
| 1A3biii | | Heavy duty trucks and buses |
| 1A3biv | | Motorcycles |
| 1A3bv | | Other |
| 1A3c | Railways | Diesel locomotives |
| 1A3d | Domestic navigation | Passenger ships, motor and sailing boats on the Swiss lakes and the river Rhine |
| 1A3e | Other transportation - Pipeline compressors | Compressor station in Ruswil, Lucerne |

For information on international bunker fuel emissions from international aviation and navigation, see chp. 3.2.2.

## 3.2.9.2. Methodological issues for 1A3

### *3.2.9.2.1. Domestic aviation (1A3a)*

**Methodology (1A3a)**

The emissions of domestic aviation are modelled by a Tier 3A method (IPCC 2006, Volume 2, chp. 3 Mobile Combustion, Table 3.6.2 and figure 3.6.2) developed by FOCA (2006) and based on origin and destination of single movements by aircraft type according to detailed movement statistics. LTO emissions are modelled based on the individual engine type. The emissions of domestic aviation are modelled together with the international aviation reported in 1D1 (aviation bunker, see chp. 3.2.2.2.1).

FOCA is represented in the emissions technical working group (Committee on Aviation Environmental Protection CAEP, WG3) and in the modelling and database group (CAEP MDG) of the International Civil Aviation Organisation (ICAO). FOCA is directly involved in the development of ICAO guidance material for the calculation of aircraft emissions and in the update of the IPCC Guidelines (via the secretariat of ICAO CAEP). The Tier 3A method applied for the emission modelling is in line with the methods developed in the working groups mentioned. The modelling scheme for domestic aviation refers to aircraft basic data, activity data and emission factors that result in calculated emissions. Respective values are ultimately imported into the EMIS database as shown in Figure 3-23.

The Tier 3A method follows standard modelling procedures at the level of single aircraft movements based on detailed movement statistics. The primary key for all calculations is the aircraft tail number, which allows to calculate on the most precise level, namely on the level of the individual aircraft and engine type. Every aircraft is linked to the FOCA engine data base containing emission factors for more than 800 individual engine types with different power settings. Emissions in the landing/take-off (LTO) cycle are calculated with aircraft category dependent flight times and corresponding power settings. Cruise emissions are calculated based on the individual aircraft type and the trip distance for every flight. For piston-engine powered aircraft and helicopters, to the knowledge of FOCA, it has been the only provider of publicly available engine data and a full methodology. All piston engine data and study results have been published in 2007 (FOCA 2007a). The guidance on the determination of helicopter emissions has been published in 2009 (FOCA 2009a) and updated in 2015 (FOCA 2015a).

The movement database from Swiss airports registers the departure and destination airports of each flight. With this information, all flights from and to Swiss airports are differentiated into domestic and international flights prior to the emission calculation. The emissions of domestic flights are reported under 1A3a Domestic Aviation, the emissions of international flights are reported under 1D1 international aviation (international bunkers).

The emission factors used are either country-specific or taken from the ICAO engine emissions databank, from EMEP/EEA guidebook (EMEP/EEA 2019), Swedish Defence Research Agency (FOI) and Swiss FOCA measurements (precursors). Cruise emission factors are generally calculated from the values of the ICAO engine emissions databank, aircraft performance tables and from confidential airline data. Pollutant emission factors are adjusted to cruise conditions by using the Boeing Fuel Flow Method 2. For $N_2O$, the IPCC default emission factor of 2 kg/TJ is used (IPCC 2006). For the methane split of unburnt hydrocarbons, the 10% methane share for the LTO, given in IPCC 2006 is used. For cruise emissions, no methane is reported.

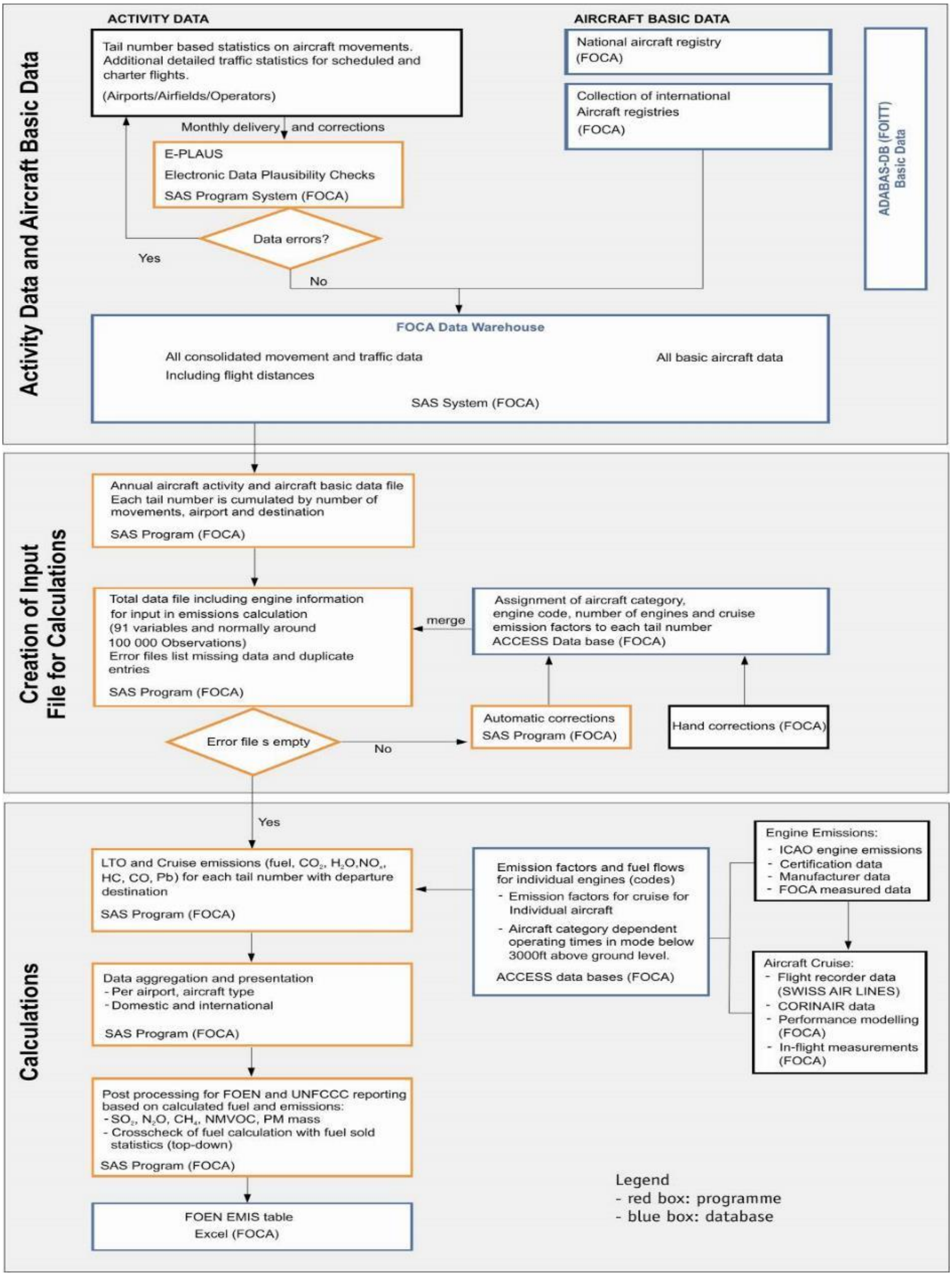


Figure 3-23 Modelling scheme (activity data, emission factors, emissions) for domestic aviation.

A complete emission modelling (LTO and cruise emissions for domestic and international flights) has been carried out by FOCA for 1990, 1995, 2000, 2002, 2004–2020. The results of the emission modelling have been transmitted from FOCA to FOEN in an aggregated form (FOCA 2006a, 2007–2021). FOEN calculated the implied emission factors 1990, 1995, 2000, 2002, 2004 and carried out a linear interpolation for the years in-between. The interpolated implied emission factors were multiplied with the annual fuel sold from Swiss overall energy statistics (SFOE in respective years), providing the missing emissions of domestic aviation for the years 1991–1994, 1996–1999, 2001 and 2003.

Details of emission factors and activity data follow below. Further tables containing more information are also given in Annex A3.1.1, more detailed descriptions of the emission modelling may be found in FOCA (2006).

### Emission factors (1A3a)

*Landing/take-off (LTO) cycle*

The FOCA engine emissions database consists of more than 800 individual engine data sets. Jet engine factors for engines above 26.7 kN thrust (emission certificated) are identical to the ICAO engine emissions database. Emission factors for lower thrust engines, piston engines and helicopters were taken from manufacturers or from own measurements. Emission factors for turboprops could be obtained in collaboration with the Swedish Defence Research Agency (FOI).

*Cruise*

The fuel flows of the whole Airbus fleet (which produces a great portion of the Swiss inventory) have been modelled on the basis of real operational aircraft data from flight data recorders (FDR) of Swiss International Airlines. GHG emission factors have been modelled on the basis of the ICAO engine databank and corrected to cruise conditions using FDR engine parameters and the Boeing Fuel Flow Method 2. For older aircraft types (pre 2003), part of the cruise emission factors were taken from the EMEP/EEA guidebook (EMEP/EEA 2019) and from former CROSSAIR (FOCA 1991). For new aircraft type entries, the FOCA models the cruise emission factors based on the aircraft type characteristics and the engine models fitted to the aircraft. The model uses proprietary aircraft information as well as public information from the ICAO engine database. For those aircraft types, which dominate the fuel consumption in Switzerland, flight data recorder information has been used to calibrate emission factors. The factors are updated periodically to take account of flight operational improvements, as well. Calculation results for international aviation emissions are periodically compared to Eurocontrol results. For piston engine aircraft and helicopters, Swiss FOCA has produced its own data, which were taken under real flight conditions (2005 data, FOCA 2009a, FOCA 2015a).

In 2015 and 2016, the FOCA Helicopter Emissions Calculation Guidance has been updated and implemented in the emissions calculation for the 2015 and 2016 emission inventory (FOCA 2015a, 2016a). Since then, FOCA uses engine power specific emission factors for most helicopters, taking into account lower power requirement per engine, if engines are installed in a twin engine configuration. On top of the few non-public manufacturer data sources, FOCA introduced 80 individual helicopter engine models replacing most of the generic engine assignments.

*Kyoto gases*

- $CO_2$: the emission factor for jet kerosene is country-specific and is based on measurements and analyses of fuel samples (see Table 3-13 and Table 3-72)
- $CH_4$, NMVOC (country-specific; CORINAIR): VOC emissions (see section “Precursors” below) of jet kerosene are split into $CH_4$ and NMVOC by a constant share of 0.1 ($CH_4$) and 0.9 (NMVOC) for LTO. For cruise flights, the VOC emissions do not contain $CH_4$. The implied emission factor for $CH_4$ for 2020 is shown in Table 3-72.
- The $N_2O$ emission factor for jet kerosene corresponds to the default value given by the 2006 IPCC Guidelines (IPCC 2006, Table 3.6.5), see Table 3-72. It is assumed that the emission factor for international cruise is sufficient for all kind of flight periods (LTO and cruise) and remains constant over the entire time period 1990–2020.

*Precursors (further details see Switzerland’s Informative Inventory Report (FOEN 2022b))*

- Assignment of emission factors for 1990 and 1995: The fleet that operated in and from Switzerland during those years has been analysed. The corresponding most frequent engines within an aircraft category (ICAO Code) have been assigned to every aircraft type.
- Assignment of emission factors for the year 2000, 2002 and 2004 to 2020: the actual engine of every single aircraft operating in and from Switzerland has been assigned. FOCA uses the aircraft tail number as the key variable which links activity data and individual aircraft engine information (see Annex A3.1.1 Table A – 7 Aircraft Engine Combinations).

FOCA determines the emission factors of different gases as given in Table 3-72.

Table 3-72 Implied emission factors of 1A3a in 2020. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

| **1A3a Aviation** | **$CO_2$ fossil** | **$CH_4$** | **$N_2O$** | **$NO_X$** | **NMVOC** | **$SO_2$** | **CO** |
|---|---|---|---|---|---|---|---|
| | kg/TJ | | | | | | |
| Kerosene, domestic, LTO | 72'800 | 19 | 2 | 204 | 169 | 18 | 5'261 |
| Kerosene, domestic, CR | 72'800 | NA | 2 | 266 | 81 | 21 | 865 |
| Kerosene, international, LTO | 72'800 | 2.9 | 2 | 331 | 26 | 23 | 279 |
| Kerosene, international, CR | 72'800 | NA | 2 | 395 | 5.8 | 23 | 38 |

**Activity data (1A3a)**

The statistical basis has been extended after 1996. Therefore, the modelling details are not exactly the same for the years 1990/1995 as for the subsequent years. The source for the 1990 and 1995 modelling are the movement statistics, which record information for every movement on airline, number of seats, Swiss airport, arrival/departure, origin/destination, number of passengers, distance. From 1996 onwards, every movement in the FOCA statistics also contains the individual aircraft tail number (aircraft registration). This is the key variable to connect airport data and aircraft data. The FOCA activity data contain both, instrument flight rules (IFR) traffic and visual flight rules (VFR) traffic. As visual flight rules traffic dominates the domestic flight activity, a complete inclusion of visual flight rules traffic is important. The statistics may contain more than one million records with individual tail numbers. All annual aircraft movements recorded are split into domestic and international flights (there are 166’758 aircraft movements in the total of scheduled and charter traffic in 2020 as provided by FOCA 2021). The number of aircraft movements in 2020 was clearly lower than usual due to the COVID-19 pandemic (e.g. 2019: 469’667 movements), which also leads to a strong reduction of fuel consumption from civil aviation (see Table 3-73).

*Handling of small aircraft and helicopters*

- Airports and most of the airfields report individual aircraft data (aircraft registration). FOCA may therefore compute the inventory for small aircraft with a Tier 3A method, too. However, for 1990 and 1995, the emissions data for non-scheduled, non-charter and General Aviation (helicopters etc.) could not be calculated with a Tier 3A method. Its fuel consumption is estimated to be 10% of the domestic fuel consumption. Data were taken from two FOCA studies (FOCA 1991, FOCA 1991a). For 2000–2007, all movements from airfields are known, which allows a more detailed modelling of the emissions (FOCA 2007a).
- Helicopter flights which do not take off from an official airport or airfield such as transport flights, flights for lumbering, animal transports, supply of alpine huts, heli-skiing and flight trainings in alpine regions cannot be recorded with the movement data base from airports and airfields. These emissions are taken into account using the statistics of the Swiss Helicopter Association (Unternehmensstatistik der Schweizer Helikopterunternehmen). These statistics are officially collected by FOCA and updated annually (see FOCA 2004 as illustrative example for all subsequent years). In this case, emissions are calculated based on operating hours of the helicopters, with emission factors taken from the helicopter study (see FOCA 2015a).
- Since 2007, the data of these helicopter statistics are included electronically in the data warehouse of the model and undergo first some plausibility checks (E-plaus software). In order to distinguish between single engine helicopters and twin engine helicopters a fix split of 87% for single engine helicopters and 13% for twin engine helicopters has been applied for the entire commitment period until 2014 based on investigations in 2004 (FOCA 2004). Since 2015, the statistics allows to assign the individual helicopters to the helicopter companies. All emissions from helicopter flights without using an official airport or an official airfield are considered domestic emissions.

*Fuel consumption*

Table 3-73 summarises the activity data for 1A3a Civil aviation. It also includes international aviation, which belongs to the memo items, international bunkers/aviation (1D1, see also chp. 3.2.2). In order to split the fuel consumption for domestic and international flights, the FOCA calculates the fuel for each domestic and international flight bottom-up. A first validation of this calculation can be done top down for the sum of all flights: The total annual aviation fuel sold known from robust energy statistics in a country should correspond very closely (within a few percent) to the modelled total fuel consumption of domestic and international flights together. In 2020, in contrast to other years, the modelled total fuel consumption in Switzerland was clearly higher than the fuel sold value (12%), so the model showed a clear overestimation. For domestic aviation, the statistical data did not show systematic changes, which could have caused differences to the modelling of pre 2020 years. However, for international aviation, which is dominated by large and scheduled aircraft in Switzerland, FOCA investigation revealed a much lower load factor due to the COVID-19 pandemic. The model fully accounts for the individual aircraft flying but calculates the fuel burn of normally loaded aircraft. In fact, many aircraft were flying lighter than usual, thus burning less fuel than usual on a given distance, which explains the 12% difference observed. A small additional effect reported by a Swiss carrier were more direct routes in Europe due to the low traffic volume. A cross comparison for the modelled difference for international aviation was done with Eurocontrol calculations for Switzerland's international flights, where the same phenomenon (overestimation by the model) was observed by Eurocontrol. For domestic flights, FOCA takes every movement including the smallest aircraft into account and applies conservative emission factors. An indication of this is the fact that Eurocontrol calculations for Switzerland's domestic flight fuel consumption is usually only around half the value reported by Switzerland. In summary, Switzerland reports the domestic fuel consumption according to the modelled value (conservative estimation), whereas the international fuel consumption (bunker) is scaled downwards so that the sum of domestic and international fuel consumption becomes identical with the fuel sold, as reported in the Swiss overall energy statistics.

Table 3-73 Fuel consumption of civil aviation in TJ separated for domestic/international and LTO/cruise. Domestic consumption and the corresponding emissions are reported under 1A3a, international consumption is reported under Memo items, international bunkers (FOCA 2007, 2007a, 2008–2021).

| **1A3a/1D1 Civil aviation** | **1990** | **1995** | **2000** | **2005** | **2010** |
|---|---|---|---|---|---|
| | Fuel consumption in TJ | | | | |
| Kerosene, domestic, LTO | 1'050 | 935 | 773 | 518 | 464 |
| Kerosene, domestic, CR | 2'401 | 2'139 | 1'768 | 1'184 | 1'230 |
| Kerosene, international, LTO (not part of national total) | 4'277 | 5'097 | 6'507 | 4'878 | 5'643 |
| Kerosene, international, CR (not part of national total) | 37'608 | 44'821 | 57'219 | 42'896 | 52'691 |
| Total Civil aviation | 45'334 | 52'993 | 66'267 | 49'477 | 60'028 |
| 1990 = 100% | 100% | 117% | 146% | 109% | 132% |

| **1A3a/1D1 Civil aviation** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
|---|---|---|---|---|---|---|---|---|---|---|
| | Fuel consumption in TJ | | | | | | | | | |
| Kerosene, domestic, LTO | 509 | 504 | 494 | 525 | 387 | 421 | 384 | 346 | 321 | 170 |
| Kerosene, domestic, CR | 1'306 | 1'371 | 1'323 | 1'396 | 1'500 | 1'511 | 1'257 | 1'234 | 1'250 | 910 |
| Kerosene, international, LTO (not part of national total) | 6'041 | 6'226 | 6'208 | 6'142 | 6'459 | 6'529 | 6'728 | 6'953 | 6'963 | 2'350 |
| Kerosene, international, CR (not part of national total) | 56'420 | 57'677 | 58'501 | 58'864 | 60'874 | 64'073 | 66'096 | 70'261 | 71'233 | 25'820 |
| Total Civil aviation | 64'277 | 65'778 | 66'526 | 66'927 | 69'220 | 72'534 | 74'465 | 78'793 | 79'767 | 29'250 |
| 1990 = 100% | 142% | 145% | 147% | 148% | 153% | 160% | 164% | 174% | 176% | 65% |

#### *3.2.9.2.2. Road transportation (1A3b)*

### Methodology (1A3b)

*Choice of method*

- The $CO_2$ emissions are calculated by a Tier 2 method based on the decision tree Fig. 3.2.2 in chp. 3. Mobile Combustion in IPCC (2006).
- The $CH_4$ and the $N_2O$ emissions are calculated by a Tier 3 method based on the decision tree Fig. 3.2.3 in chp. 3. Mobile Combustion in IPCC (2006).
- The use of urea in urea-based catalysts is reported in chp. 4.5.2.2 under Urea use in SCR catalysts of diesel engines (2D3d) as recommended in the reporting table's footnotes.
- $CO_2$ emissions from the use of lubricants as an additive in 2-stroke motorcycles are reported in chp. 4.5.2.1 under 2D1 Non-energy products from fuels and solvent use / lubricant use. Non-$CO_2$ emissions are reported under 1A3biv.

*Connections between road model, non-road model and Swiss overall energy statistics*

For the source categories related to transport, INFRAS developed a territorial emission model for 1A3b Road transportation and a model for non-road vehicles and machinery (mobile sources categories 1A2gvii, 1A3c, 1A3d, 1A4aii, 1A4bii, 1A4cii, 1A5b excl. military aviation). The general method of the road transportation model is described in the following paragraphs and Annex A3.1.2 (INFRAS 2017c, INFRAS 2019a, Matzer et al. 2019).

Due to fluctuating fuel price differences in the vicinity of the national borders, gas stations sell varying amounts of fuels to foreign car owners. This amount of fuel is referred to as "fuel tourism". Fuel tourism is not captured by the territorial road transportation model.

The Swiss overall energy statistics (SFOE 2021) provide information on the total amount of fuel sold, i.e. the sum of territorial consumption **and** fuel tourism. From the amount of fuel sold, the consumption modelled by the territorial road and non-road models – i.e. fuel used – is subtracted. The resulting difference represents the amount of fuel tourism plus statistical differences. The amount of fuel tourism is regularly estimated in ex-post analysis, latest update by SFOE (2021e). The results for fuel tourism clearly show that the difference between fuels sales and fuels determined by the traffic model tend to overestimate the "true" fuel tourism. It is concluded that the difference also contains potential underestimation of the mileage and other statistical biases. Therefore, the difference between fuel sold and fuel used in the traffic model is indicated in the NIR as "fuel tourism and statistical differences". The value for fuel tourisms can be negative (in case of net fuel imports – e.g. the case for diesel oil in the years 2014–2019 since it was cheaper in the neighbouring countries) or positive (in case of net fuel exports – the case for gasoline in most years, since it is cheaper in Switzerland). It is assumed that no fuel tourism takes place with non-road vehicles and therefore the fuel tourism and the statistical difference is attributed to 1A3b Road transportation for gasoline, diesel oil, natural gas, bioethanol and biodiesel (see Figure 3-9, Figure 3-16 and Figure 3-19). The statistical difference for biogas is attributed to 1A4ai Other sectors (stationary) – commercial/institutional (see Figure 3-18) and the one from liquefied petroleum gas to 1A2gvii Other (boilers) (see Figure 3-13). In the reporting tables, activity data and emissions from fuel tourism and statistical difference are reported in the most appropriate categories. In submission 2022, the CRF reporter produced an error due to negative values in some source categories for some years for $CH_4$. The negative values occurred because of the way the fuel tourism and statistical difference was integrated in the reporting tables (CRF Table1.A(a)s3). Therefore, the distribution of fuel tourism amongst the source categories 1A3bi, 1A3bii and 1A3biii had to be changed. The new distribution is not intuitive for diesel oil and gaseous fuels, but there is currently no other solution which does not lead to an error from the CRF reporter. The distribution of fuel tourism and statistical differences does not affect total fuels sold and has no effect on the total emissions reported. The distribution is conducted as follows:

- Emissions from gasoline: fuel tourism and statistical difference is proportionally distributed amongst source categories 1A3bi, 1A3bii and 1A3biii according to annual consumption data within these categories.
- Emissions from diesel oil: fuel tourism and statistical difference is distributed amongst source categories 1A3bi and 1A3biii. The distribution is conducted in proportion to annual consumption data within these two source categories, but due to negative $CH_4$ emission values, 10% of the fuel tourism had to be reallocated from source category 1A3biii to category 1A3bi for all years.
- Emissions from gaseous fuels: fuel tourism and statistical difference is completely allocated to source category 1A3biii.
- Emissions from biomass: fuel tourism and statistical difference is proportionally distributed amongst source categories 1A3bi, 1A3bii and 1A3biii according to annual consumption data within these categories.

Figure 3-24 shows how the models and the Swiss overall energy statistics are linked to determine the GHG emissions from road and non-road transportation:

- $CO_2$ emissions are calculated by using fuel sales and country-specific $CO_2$ emission factors.
- $CH_4$ and $N_2O$ emissions are calculated in three steps (the same procedure also applies to precursor gases):
  - From fuel used and country-specific $CH_4$ and $N_2O$ emission factors, the territorial emissions are calculated.
  - The differences between fuels sold and fuels used (territorial) are interpreted as fuel tourism and statistical differences. These amounts of gasoline and diesel oil are multiplied with implied $CH_4$ and $N_2O$ emission factors, which are deduced from the territorial road transportation model (including weighted averages over all vehicle categories), to form the $CH_4$ and $N_2O$ emissions resulting from fuel tourism and statistical differences.
  - The sum of $CH_4$ and $N_2O$ emissions from the territorial model and $CH_4$ and $N_2O$ from fuel tourism and statistical differences represents the total $CH_4$ and $N_2O$ emissions as reported in 1A3b Road transportation.

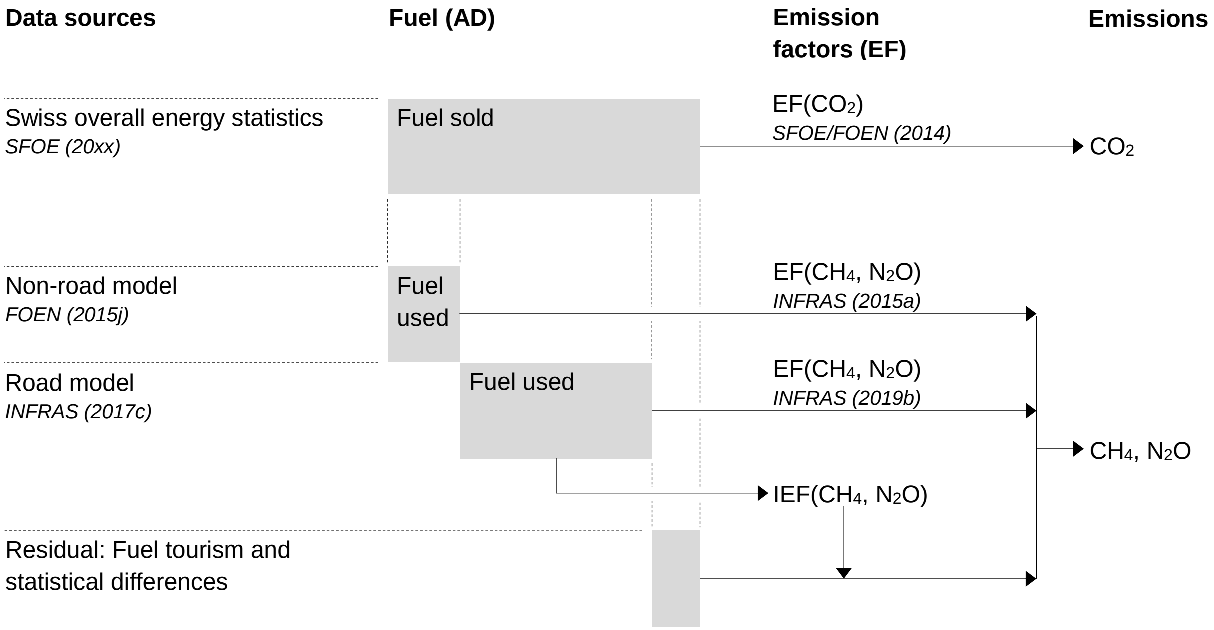


Figure 3-24 Connections between fuel sold and fuel used for road and non-road transportation. Fuel sold is provided by the Swiss overall energy statistics (minus Liechtenstein's gasoline and diesel oil consumption and bunker fuels for navigation). Fuel used results from the territorial road and non-road models. The residual fuel consists of fuel tourism and statistical differences. Its emissions are calculated by means of implied emission factors deduced from the territorial road model. The diagram holds separately for gasoline and diesel oil. SFOE (20xx) stands for the latest Swiss overall energy statistics.

*Methodology of the territorial road transportation model*

The emission computation is based on two sets of data:

- Emission factors: specific emissions in grams per activity data unit.
- Traffic activity data:
  - vehicle kilometres travelled (hot emissions, evaporative losses during operation)
  - number of starts/stops
  - vehicle stock (cold start, evaporative losses from gasoline passenger cars, light duty vehicles and motorcycles)
  - fuel consumption per vehicle category

Emissions are calculated as follows:

Hot emissions: $E_{hot} = VKT \cdot EF_{hot}$

Cold start excess emissions: $E_{start} = N_{start} \cdot EF_{start}$

Evaporation soak and diurnal VOC emissions: $E_{evap,i} = N_{evap,i} \cdot EF_{evap,i}$,

Evaporation running VOC losses: $E_{evap-RL} = VKT \cdot EF_{Evap-RL}$

with

- $EF_{hot}$, $EF_{start}$, $EF_{evap,i}$, $EF_{evap-RL}$ : Emission factors for ordinary driving conditions (hot engine), cold start excess emissions, and evaporative (VOC) emissions (after stops, diurnal losses, and running losses)
- *VKT:* Vehicle km travelled
- $N_{start}$: Number of starts
- $N_{evap,i}$: Number of stops, or number of vehicles. *i* runs over two evaporation categories:
  a) evaporation soak emissions, i.e. emissions after stopping when the engine is still hot; and
  b) evaporation diurnal emissions, i.e. emissions due to daily air temperature differences.
  For a) the corresponding activity is the number of stops, for b) it is the number of vehicles.
- Emission factors are differentiated for all fuel types: Gasoline (4-stroke), gasoline (2-stroke), diesel oil, liquefied petroleum gas bioethanol, biodiesel, gas (CNG), biogas. In terms of vehicle categories, the emission factors are weighted according to the fleet composition in Switzerland (within HBEFA).

$CO_2$ emissions from lubricant use in 2-stroke engines are calculated from the gasoline consumption of 2-stroke motorcycles, assuming a lubricant content of 2% in the gasoline. Note that the road transportation model distinguishes 2-stroke (including 2% lubricant) and 4-stroke gasoline (without lubricant). It is assumed that the whole amount of lubricant is being oxidised. The resulting $CO_2$ emissions are reported in source category 2D1 Lubricant use. In contrast, $CH_4$ and $N_2O$ emissions from lubricant use are reported in source category 1A3biv, since the emission factors are deduced from measurements on motorcycles including 2-stroke engines.

Cold start excess emissions for $N_2O$ were originally not accounted for in the model described. During the in-country review in 2016, the ERT identified a potential underestimation. Switzerland therefore estimated $N_2O$ cold start excess emissions for passenger cars and light duty vehicles by means of emission factors from the EMEP/EEA guidebook, as recommended by the ERT. The corresponding emission factors per Euro class are documented in the EMEP/EEA guidebook on p. 72 ff. (EMEP/EEA 2019).

**Emission factors (1A3b)**

*$CO_2$*

- The country-specific $CO_2$ emission factors are described in chp. 3.2.4.4.2. Values are shown in Table 3-13 (gasoline, diesel oil, biofuels) and in Table 3-14 (natural gas, biogas). The values in 2020 are also shown in Table 3-74.
- The same emission factors are also applied for the calculation of the emissions resulting from fuel tourism and statistical differences.
- Emission factors for 2-stroke gasoline: For the gasoline part of the fuel, the $CO_2$ emission factor for gasoline according to Table 3-13 is applied. For the lubricant part of the fuel, the IPCC default $CO_2$ emission factor for lubricants is applied (see Table

4-38, IPCC 2006). The resulting emissions from the gasoline part are reported under 1A3biv, the emissions from the lubricant part, however, under source category 2D1 Lubricant use (see chp. 4.5.2.1).

*$CH_4$*

- Country-specific emission factors are applied. For details including data sources see below ("*Country-specific emission factors").* Emission factors are applied based on HBEFA 4.1 (INFRAS 2019b).
- $CH_4$ emissions from fuel tourism and statistical difference: From the territorial model, implied emission factors for $CH_4$ are derived per fuel type corresponding to mean emission factors for Switzerland including all vehicle categories (see Figure 3-24). These factors are then applied to calculate the emissions resulting from fuel tourism. This approach has been verified by comparing implied emission factors with the neighbouring countries (see chp. 3.2.9.4).
- For biofuels, no country-specific emission factors for $CH_4$ are available. Therefore, the same emission factors as for fossil fuels have been used (e.g. emission factor for gasoline was used for bioethanol, and emission factor for diesel oil for biodiesel).

*$N_2O$*

- $N_2O$ emissions from territorial traffic under hot operating condition: Country-specific emission factors are used, details see below (INFRAS 2019b).
- Cold start $N_2O$ emission factors for gasoline, diesel oil, natural gas and liquefied petroleum gas vehicles are based on the EMEP/EEA guidebook (EMEP/EEA 2019) (see Annex A3.1.2 for details).
- $N_2O$ emissions from fuel tourism and statistical difference: The same approach as for $CH_4$ is applied (see paragraph above) by means of mean emission factors (country-specific).
- For biofuels no country-specific EFs for $N_2O$ are available. Therefore, the same emission factors as for fossil fuels have been used (e.g. emission factor for gasoline was used for bioethanol, and emission factor for diesel oil for biodiesel).

*Country-specific emission factors*

Emission factors for gases other than $CO_2$ are derived from "emission functions" which are determined from a compilation of measurements from various European countries with programmes using similar driving cycles (legislative as well as standardized real-world cycles, like "Common Artemis Driving Cycle" (CADC)). The method was developed in 1990–1995 and has been extended and updated in 2000, 2004, 2010, 2017 and latest 2019. These emission factors are compiled in the "Handbook of Emission Factors for Road Transport" (HBEFA, see INFRAS 2019b). The latest version 4.1 is presented on the website (http://www.hbefa.net/) and documented in INFRAS (2019a) and Matzer et al. (2019). Further descriptions can also be found in the former publication INFRAS (2017c). The emission factors are differentiated by so-called "traffic situations", which represent characteristic patterns of driving behaviour determined by road type, speed limit, area type (rural/urban), traffic density, and road gradient. They serve as a key to the disaggregation of the activity data. The underlying database contains dynamic fleet compositions simulating the release of new exhaust technologies and the fading out of old technologies. Further details are shown in Annex A3.1.2.

*Implied emission factors for GHG and precursors*

The following Table 3-74 presents mean emission factors for GHG and precursors in 2020 in kg per TJ fuel consumption. More or less pronounced decreases of the emission factors have occurred in the last years due to new emission regulations and subsequent new exhaust technologies (optimized combustion, use of catalytic converters, particle filters, lower limits for sulphur content in diesel fuels). Early models of catalytic converters represented substantial sources of $N_2O$, leading to an emission increase of this gas until 1998. More recent converter technologies have overcome this problem resulting in a decrease of the (mean) emission factor.

Table 3-74 Implied emission factors in 2020 for road transportation. For more details see Annex A3.1.2. The implied emission factors in the CRF tables are slightly different because of the distribution of fuel tourism and statistical differences in the CRF tables (see chapter 3.2.9.2.2).

| **1A3b Road Transportation Gasoline / Bioethanol** | **$CO_2$** | **$CH_4$** | **$N_2O$** | **$NO_X$** | **NMVOC** | **$SO_2$** | **CO** |
|---|---|---|---|---|---|---|---|
| | kg/TJ | | | | | | |
| 1A3bi Passenger cars | 73'800 | 4.0 | 0.65 | 35 | 49 | 0.38 | 543 |
| 1A3bii Light duty vehicles | 73'800 | 10 | 2.5 | 109 | 128 | 0.38 | 2794 |
| 1A3biii Heavy duty vehicles | 73'800 | 19 | 0.80 | 767 | 545 | 0.38 | 658 |
| 1A3biv Motorcycles | 73'800 | 50 | 1.2 | 84 | 254 | 0.38 | 2304 |
| 1A3bv Other, gasoline evaporation | NO | NO | NO | NO | 25 | NO | NO |
| 1A3bi-iii Fuel tourism and statistical differences | 73'800 | 5.8 | 0.70 | 38 | 82 | 0.38 | 644 |

| **1A3b Road Transportation Diesel / Biodiesel** | **$CO_2$** | **$CH_4$** | **$N_2O$** | **$NO_X$** | **NMVOC** | **$SO_2$** | **CO** |
|---|---|---|---|---|---|---|---|
| | kg/TJ | | | | | | |
| 1A3bi Passenger cars | 73'300 | 3.8 | 3.5 | 271 | 4.1 | 0.47 | 47 |
| 1A3bii Light duty vehicles | 73'300 | 1.1 | 2.4 | 314 | 2.0 | 0.47 | 50 |
| 1A3biii Heavy duty vehicles | 73'300 | 0.09 | 3.7 | 158 | 3.7 | 0.47 | 57 |
| 1A3biv Motorcycles | NO | NO | NO | NO | NO | NO | NO |
| 1A3bv Other, gasoline evaporation | NO | NO | NO | NO | NO | NO | NO |
| 1A3bi-iii Fuel tourism and statistical differences | 73'300 | 2.6 | 3.8 | 272 | 4.1 | 0.52 | 55 |

| **1A3b Road Transportation Natural gas / Biogas** | **$CO_2$** | **$CH_4$** | **$N_2O$** | **$NO_X$** | **NMVOC** | **$SO_2$** | **CO** |
|---|---|---|---|---|---|---|---|
| | kg/TJ | | | | | | |
| 1A3bi Passenger cars | 56'200 | 15 | 4.8 | 33 | 1.3 | NA | 174 |
| 1A3bii Light duty vehicles | 56'200 | 7.2 | 13 | 15 | 0.62 | NA | 1270 |
| 1A3biii Heavy duty vehicles | 56'200 | 13 | NE | 80 | 1.1 | NA | 37 |
| 1A3biv Motorcycles | NO | NO | NO | NO | NO | NO | NO |
| 1A3bv Other, gasoline evaporation | NO | NO | NO | NO | NO | NO | NO |
| 1A3bi-iii Fuel tourism and statistical differences | 56'200 | 13 | 4.3 | 47 | 1.2 | NA | 262 |

| **1A3b Road Transportation Liquified petroleum gas** | **$CO_2$** | **$CH_4$** | **$N_2O$** | **$NO_X$** | **NMVOC** | **$SO_2$** | **CO** |
|---|---|---|---|---|---|---|---|
| | kg/TJ | | | | | | |
| 1A3bi Passenger cars | 65'500 | 2.3 | 1.3 | 42 | 3.5 | NA | 526 |
| 1A3bii Light duty vehicles | NO | NO | NO | NO | NO | NO | NO |
| 1A3biii Heavy duty vehicles | NO | NO | NO | NO | NO | NO | NO |
| 1A3biv Motorcycles | NO | NO | NO | NO | NO | NO | NO |
| 1A3bv Other, gasoline evaporation | NO | NO | NO | NO | NO | NO | NO |
| 1A3bi-iii Fuel tourism and statistical differences | NO | NO | NO | NO | NO | NO | NO |

**Activity data (1A3b)**

*Energy-related activity data (basis for modelling the $CO_2$ emissions)*

The Swiss overall energy statistics (SFOE 2021) provides the amount of liquid fuels (gasoline, diesel oil) and gaseous fuels (CNG) sold in Switzerland for road transportation. From the amount of liquid fuels sold, Liechtenstein's sales, Switzerland's non-road consumption, bunker fuel emissions and fugitive emissions from transmission, storage and fuelling of gasoline (reported under 1B2av Distribution of oil products) are subtracted. Amounts of liquefied petroleum gas used for road transportation are very small and not provided in the Swiss overall energy statistics. Therefore, the liquefied petroleum gas consumption for road transportation is entirely based on the road transportation model.

The consumption of biofuels is based on the Swiss overall energy statistics (SFOE 2021), the Swiss renewable energy statistics (SFOE 2021a) and the Federal Office for Customs and Border Security (FOCBS 2021). The NCV of biogas is assumed to be equal to the NCV of natural gas since the raw biogas is treated to reach the same quality level including its energetic properties as natural gas (see NCV time series for natural gas and biogas in Table 3-11).

Table 3-75 shows the split of fuel sales into territorial road transportation model, the territorial non-road transportation model and fuel tourism including statistical differences.

- The relevant numbers for 1A3b Road transportation are given as two different contributions in the rows “on road fuel consumption (model)” and “fuel tourism and statistical differences”.
- Consumption of biofuels for road transportation (biodiesel, bioethanol and biogas) starts in Switzerland in 1997.

Table 3-75 Split of fuel sales between territorial “on-road consumption (model)”, “non-road consumption (models)” and “fuel tourism and statistical differences“ (residual value to sold amounts) for gasoline, diesel oil, natural gas (CNG), liquefied petroleum gas, and biofuels (vegetable/waste oil is included in the numbers of Biodiesel) in PJ. Numbers may not add to totals due to rounding.

| **Activity data for on-road and non-road categories** | **Source category** | **1990** | **1995** | **2000** | **2005** | **2010** |
|---|---|---|---|---|---|---|
| | | | | PJ | | |
| **Gasoline** | | | | | | |
| on-road consumption (model) | 1A3b | 137 | 135 | 147 | 136 | 120 |
| fuel tourism and statistical differences | 1A3b | 16 | 14 | 19 | 14 | 12 |
| non-road consumption (models) | 1A2gvii; 1A3dii; 1A4aii,bii,cii; 1A5b | 2.4 | 2.4 | 2.3 | 2.1 | 1.9 |
| Gasoline sold in Switzerland | | 156 | 151 | 168 | 152 | 134 |
| **Diesel oil** | | | | | | |
| on-road consumption (model) | 1A3b | 38 | 42 | 48 | 61 | 82 |
| fuel tourism and statistical differences | 1A3b | -2.2 | -6.1 | -6.0 | -2.0 | 1.3 |
| non-road consumption (models) | 1A2gvii; 1A3c,dii; 1A4cii; 1A5b | 11 | 12 | 14 | 14 | 15 |
| Diesel oil sold in Switzerland | | 47 | 48 | 55 | 72 | 98 |
| **Natural gas** | | | | | | |
| on-road consumption (model) | 1A3b | NO | NO | NO | 0.052 | 0.55 |
| fuel tourism and statistical differences | 1A3b | NO | NO | NO | 0.038 | 0.16 |
| non-road consumption (models) | | NO | NO | NO | NO | NO |
| Natural gas sold in on- and non-road categories in Switzerland | | NO | NO | NO | 0.090 | 0.71 |
| **Liquified petroleum gas (LPG)** | | | | | | |
| on-road consumption (model) | 1A3b | NO | NO | NO | NO | NO |
| non-road consumption (models) | 1A2gvii | 0.17 | 0.25 | 0.29 | 0.29 | 0.27 |
| LPG sold in on- and non-road categories in Switzerland | | 0.17 | 0.25 | 0.29 | 0.29 | 0.27 |
| **Biodiesel** | | | | | | |
| on-road consumption (model) | 1A3b | NO | NO | 0.042 | 0.18 | 0.30 |
| non-road consumption (models) | 1A2gvii; 1A3c,dii; 1A4cii; 1A5b | NO | NO | 0.017 | 0.050 | 0.064 |
| Biodiesel sold in Switzerland | | NO | NO | 0.060 | 0.23 | 0.37 |
| **Bioethanol** | | | | | | |
| on-road consumption (model) | 1A3b | NO | NO | NO | 0.019 | 0.055 |
| non-road consumption (models) | 1A2gvii; 1A3dii; 1A4bii; cii; 1A5b | NO | NO | NO | NO | 0.000037 |
| Bioethanol sold in Switzerland | | NO | NO | NO | 0.019 | 0.055 |
| **Biogas** | | | | | | |
| on-road consumption (model) | 1A3b | NO | NO | NO | 0.030 | 0.14 |
| non-road consumption (models) | | NO | NO | NO | NO | NO |
| Biogas sold in Switzerland | | NO | NO | NO | 0.030 | 0.14 |

| **Activity data for on-road and non-road categories** | **Source category** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | PJ | | | | |
| **Gasoline** | | | | | | | | | | | |
| on-road consumption (model) | 1A3b | 116 | 111 | 107 | 103 | 98 | 94 | 92 | 90 | 89 | 76 |
| fuel tourism and statistical differences | 1A3b | 11 | 11 | 10 | 10 | 5.9 | 6.4 | 5.5 | 5.8 | 6.6 | 8.3 |
| non-road consumption (models) | 1A2gvii; 1A3dii; 1A4aii,bii,cii; 1A5b | 1.9 | 1.8 | 1.8 | 1.7 | 1.7 | 1.7 | 1.6 | 1.6 | 1.6 | 1.6 |
| Gasoline sold in Switzerland | | 129 | 124 | 119 | 114 | 106 | 102 | 99 | 98 | 97 | 86 |
| **Diesel oil** | | | | | | | | | | | |
| on-road consumption (model) | 1A3b | 86 | 91 | 96 | 100 | 103 | 106 | 107 | 106 | 107 | 94 |
| fuel tourism and statistical differences | 1A3b | -0.35 | 1.3 | 1.0 | -0.08 | -5.2 | -7.1 | -7.8 | -5.5 | -6.2 | 0.70 |
| non-road consumption (models) | 1A2gvii; 1A3c,dii; 1A4cii; 1A5b | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Diesel oil sold in Switzerland | | 100 | 107 | 111 | 114 | 113 | 114 | 114 | 115 | 115 | 109 |
| **Natural gas** | | | | | | | | | | | |
| on-road consumption (model) | 1A3b | 0.39 | 0.39 | 0.39 | 0.40 | 0.39 | 0.41 | 0.39 | 0.41 | 0.41 | 0.31 |
| fuel tourism and statistical differences | 1A3b | 0.31 | 0.29 | 0.31 | 0.27 | 0.24 | 0.19 | 0.18 | 0.18 | 0.17 | 0.21 |
| non-road consumption (models) | | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Natural gas sold in on- and non-road categories in Switzerland | | 0.70 | 0.68 | 0.70 | 0.67 | 0.63 | 0.60 | 0.57 | 0.59 | 0.58 | 0.52 |
| **Liquified petroleum gas (LPG)** | | | | | | | | | | | |
| on-road consumption (model) | 1A3b | 0.015 | 0.015 | 0.015 | 0.015 | 0.018 | 0.020 | 0.021 | 0.020 | 0.020 | 0.020 |
| non-road consumption (models) | 1A2gvii | 0.26 | 0.25 | 0.24 | 0.23 | 0.23 | 0.21 | 0.20 | 0.19 | 0.18 | 0.17 |
| LPG sold in on- and non-road categories in Switzerland | | 0.27 | 0.27 | 0.26 | 0.25 | 0.24 | 0.23 | 0.22 | 0.21 | 0.20 | 0.19 |
| **Biodiesel** | | | | | | | | | | | |
| on-road consumption (model) | 1A3b | 0.27 | 0.29 | 0.23 | 0.50 | 1.2 | 2.5 | 4.2 | 5.9 | 6.0 | 5.4 |
| non-road consumption (models) | 1A2gvii; 1A3c,dii; 1A4cii; 1A5b | 0.10 | 0.13 | 0.16 | 0.19 | 0.23 | 0.29 | 0.36 | 0.43 | 0.49 | 0.56 |
| Biodiesel sold in Switzerland | | 0.37 | 0.42 | 0.39 | 0.70 | 1.5 | 2.8 | 4.5 | 6.3 | 6.4 | 5.9 |
| **Bioethanol** | | | | | | | | | | | |
| on-road consumption (model) | 1A3b | 0.083 | 0.093 | 0.078 | 0.16 | 0.58 | 0.79 | 0.97 | 1.2 | 1.3 | 1.3 |
| non-road consumption (models) | 1A2gvii; 1A3dii; 1A4bii; cii; 1A5b | 0.0022 | 0.0043 | 0.0065 | 0.0086 | 0.011 | 0.017 | 0.023 | 0.029 | 0.035 | 0.041 |
| Bioethanol sold in Switzerland | | 0.085 | 0.10 | 0.084 | 0.17 | 0.59 | 0.80 | 1.0 | 1.2 | 1.4 | 1.3 |
| **Biogas** | | | | | | | | | | | |
| on-road consumption (model) | 1A3b | 0.10 | 0.10 | 0.12 | 0.11 | 0.13 | 0.12 | 0.13 | 0.12 | 0.13 | 0.12 |
| non-road consumption (models) | | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Biogas sold in Switzerland | | 0.10 | 0.10 | 0.12 | 0.11 | 0.13 | 0.12 | 0.13 | 0.12 | 0.13 | 0.12 |

*Mileage-related activity data (basis for modelling of the non-$CO_2$ emissions by means of a traffic model)*

The activity data are derived from different data sources:

- Vehicle stock: The federal vehicle registration database IVZ (run by the Federal Roads Office FEDRO) contains vehicle stock data including all parameters needed for the emission modelling (vehicle category, engine capacity, fuel type, total weight, vehicle age and exhaust technology). The data are not public, but the overall vehicle stock numbers are published by the Swiss Federal Statistical Office (SFSO 2021e). With the help of a fleet turnover model, the vehicle categories are assigned emission standards based on age and thereby split up into “sub-segments”, which are used to link with the specific emission factors of the same categorisation (vehicle category, size class, fuel type, emission standard [“Euro classes”]).
- The specific mileage per vehicle category is an input from the Swiss Federal Statistical Office (SFSO 2021e, 2021f). It is based on periodical surveys/Mikrozensus (ARE 2002, ARE/SFSO 2005, 2012, 2017). By means of the vehicle stock data (see paragraph above), the specific mileage per vehicle category can be derived (SFSO 2021e, SFOE 2021e, INFRAS 2017).
- Numbers of starts/stops: Derived from vehicle stock and periodical surveys/Mikrozensus (ARE/SFSO 2005, 2012, 2017).

The total mileage of each vehicle category is differentiated by “traffic situations” (characteristic patterns of driving behaviour) which serve as a key to select the appropriate emission factors, which are also available per traffic situation. The relative shares of the traffic situations are derived from a national road traffic model (operated by the Federal Office of Spatial Development, see ARE 2016). The traffic model is based on an origin-destination matrix that is assigned to a network of about 20’000 road segments. The model is calibrated partly bottom-up and partly top-down: bottom-up by a number of traffic counts from the national traffic-counter network, and top-down by the total of the mileage per vehicle category. The assignment of traffic situations to the modelled mileage is described in INFRAS (2017). The traffic model in combination with consumption factors (per vehicle category, size class, fuel type, emissions standard and per traffic situation) allows to calculate the territorial road traffic consumption of gasoline and diesel oil.

Table 3-76 shows the time series of the mileage per vehicle category. The total mileage has constantly been increasing since 1995. This trend was halted in 2020, as total mileages decreased compared to the years before due to the restrictions related to the COVID-19 pandemic. The major part of vehicle kilometres was driven by passenger cars over the whole period. In the same period, on-road fuel consumption increased less strongly, indicating improved fuel efficiency. This effect is also reflected in Table 3-77 that shows the specific fuel consumption per vehicle-km. Average consumption and the specific consumption for most of the vehicle categories have decreased in the period 1990–2020.

Table 3-76 Mileages in millions of vehicle kilometres. PC: passenger cars, LDV: light duty vehicles, HDV: heavy duty vehicles).

| Veh. category | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | million vehicle-km | | | | |
| PC | 42'649 | 41'324 | 45'613 | 48'040 | 52'066 |
| LDV | 2'600 | 2'746 | 2'957 | 3'228 | 3'502 |
| HDV | 1'992 | 2'107 | 2'273 | 2'120 | 2'226 |
| Coaches | 108 | 110 | 99 | 106 | 118 |
| Urban Bus | 174 | 192 | 200 | 229 | 244 |
| 2-Wheelers | 2'025 | 1'563 | 1'700 | 1'785 | 1'852 |
| Sum | 49'548 | 48'043 | 52'841 | 55'507 | 60'009 |
| (1990=100%) | 100% | 97% | 107% | 112% | 121% |

| Veh. category | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| | million vehicle-km | | | | | | | | | |
| PC | 52'696 | 53'721 | 54'695 | 55'641 | 56'620 | 57'737 | 58'735 | 59'344 | 59'833 | 52'055 |
| LDV | 3'635 | 3'776 | 3'874 | 3'998 | 4'129 | 4'269 | 4'392 | 4'530 | 4'668 | 4'668 |
| HDV | 2'258 | 2'229 | 2'243 | 2'236 | 2'235 | 2'235 | 2'242 | 2'238 | 2'226 | 1'937 |
| Coaches | 122 | 124 | 125 | 128 | 131 | 134 | 136 | 139 | 142 | 142 |
| Urban Bus | 250 | 254 | 262 | 267 | 272 | 281 | 280 | 291 | 300 | 255 |
| 2-Wheelers | 1'877 | 1'899 | 1'904 | 1'920 | 1'937 | 1'976 | 2'008 | 2'046 | 2'068 | 1'799 |
| Sum | 60'838 | 62'003 | 63'102 | 64'188 | 65'324 | 66'631 | 67'793 | 68'588 | 69'237 | 60'856 |
| (1990=100%) | 123% | 125% | 127% | 130% | 132% | 134% | 137% | 138% | 140% | 123% |

Table 3-77 Specific fuel consumption of road transport, excluding fuel tourism and statistical differences. Numbers include additional fuel consumption by cold starts.

| Veh. Category | Fuel | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| | | MJ / veh-km | | | | |
| PC | Gasoline | 3.15 | 3.23 | 3.29 | 3.21 | 3.08 |
| | Diesel oil | 3.34 | 3.16 | 3.05 | 2.75 | 2.72 |
| | LPG | NO | NO | NO | NO | NO |
| | CNG | NO | NO | NO | NO | 2.08 |
| LDV | Gasoline | 3.85 | 3.75 | 3.65 | 3.62 | 3.55 |
| | Diesel oil | 4.54 | 4.51 | 4.33 | 3.98 | 3.78 |
| | CNG | NO | NO | NO | NO | 2.40 |
| HDV | Gasoline | NO | NO | NO | NO | NO |
| | Diesel oil | 11.3 | 11.7 | 11.7 | 12.3 | 11.9 |
| | CNG | NO | NO | NO | 10.5 | 13.2 |
| Coach | Diesel oil | 12.7 | 12.6 | 12.3 | 12.0 | 11.6 |
| Urban Bus | Gasoline | NO | NO | NO | NO | NO |
| | Diesel oil | 16.3 | 16.7 | 16.8 | 16.8 | 16.3 |
| | CNG | NO | NO | NO | NO | 17.0 |
| 2-Wheeler | Gasoline | 1.49 | 1.66 | 1.48 | 1.59 | 1.53 |
| Average | | 3.53 | 3.67 | 3.69 | 3.55 | 3.38 |
| (1990=100%) | | 100% | 104% | 104% | 101% | 96% |

| Veh. Category | Fuel | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MJ / veh-km | | | | | | | | | |
| PC | Gasoline | 3.02 | 2.96 | 2.90 | 2.83 | 2.75 | 2.67 | 2.60 | 2.52 | 2.47 | 2.41 |
| | Diesel oil | 2.71 | 2.70 | 2.68 | 2.66 | 2.62 | 2.58 | 2.53 | 2.49 | 2.49 | 2.49 |
| | LPG | 2.99 | 2.96 | 2.94 | 2.92 | 2.86 | 2.84 | 2.82 | 2.83 | 2.81 | 2.80 |
| | CNG | 2.02 | 2.00 | 1.91 | 1.91 | 1.82 | 1.85 | 1.77 | 1.81 | 1.76 | 1.66 |
| LDV | Gasoline | 3.52 | 3.47 | 3.42 | 3.37 | 3.31 | 3.25 | 3.18 | 3.09 | 3.05 | 3.00 |
| | Diesel oil | 3.75 | 3.73 | 3.72 | 3.71 | 3.68 | 3.63 | 3.55 | 3.46 | 3.42 | 3.39 |
| | CNG | 2.70 | 2.69 | 2.55 | 2.55 | 2.44 | 2.48 | 2.38 | 2.41 | 2.35 | 2.23 |
| HDV | Gasoline | 9.15 | 9.15 | 9.16 | 9.15 | 9.11 | 9.11 | 9.07 | 9.05 | 9.00 | 8.97 |
| | Diesel oil | 11.9 | 11.8 | 11.7 | 11.6 | 11.5 | 11.4 | 11.1 | 10.9 | 10.9 | 10.8 |
| | CNG | 13.0 | 13.0 | 12.5 | 12.7 | 12.2 | 12.6 | 12.2 | 10.9 | 10.7 | 9.33 |
| Coach | Diesel oil | 11.7 | 10.7 | 10.6 | 10.5 | 10.3 | 10.2 | 10.0 | 9.70 | 9.67 | 9.46 |
| Urban Bus | Gasoline | NO | NO | NO | NO | NO | NO | NO | 9.41 | 9.39 | 9.38 |
| | Diesel oil | 16.2 | 16.1 | 16.1 | 15.9 | 15.7 | 15.5 | 15.1 | 14.9 | 14.9 | 14.9 |
| | CNG | 16.6 | 16.7 | 16.0 | 16.0 | 15.4 | 15.9 | 15.4 | 16.0 | 15.7 | 15.0 |
| 2-Wheeler | Gasoline | 1.55 | 1.56 | 1.54 | 1.58 | 1.63 | 1.59 | 1.59 | 1.62 | 1.63 | 1.62 |
| Average | | 3.34 | 3.27 | 3.22 | 3.16 | 3.09 | 3.03 | 2.95 | 2.89 | 2.85 | 2.83 |
| (1990=100%) | | 94% | 93% | 91% | 90% | 88% | 86% | 84% | 82% | 81% | 80% |

For modelling of evaporative emissions, the stock, the mileage and the number of stops of gasoline passenger cars, light duty vehicles and motorcycles are used. For modelling cold start excess emissions, also the numbers of starts of passenger cars and light duty vehicles are used as activity data. The corresponding numbers are summarised in Table 3-78. Vehicle stock figures correspond to registration data. The starts and stops per vehicle are based on specific surveys (ARE/SFSO 2005, 2012, 2017).

Table 3-78 Vehicle stock numbers (gasoline vehicles only – relevant for diurnal evaporation) and average number of starts per vehicle per day (gasoline, diesel oil, and CNG vehicles).

| Veh. Category | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | stock in 1000 veh. (gasoline/bioeth.) | | | | |
| PC | 2'839 | 3'049 | 3'305 | 3'263 | 2'955 |
| LDV | 167 | 164 | 148 | 112 | 77 |
| 2-Wheelers | 764 | 688 | 712 | 746 | 765 |
| | starts per veh. per day | | | | |
| PC | 2.94 | 2.68 | 2.91 | 2.52 | 2.56 |
| LDV | 1.97 | 1.97 | 1.96 | 1.96 | 1.96 |

| Veh. Category | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| | stock in 1000 veh. (gasoline/bioeth.) | | | | | | | | | |
| PC | 2'924 | 2'878 | 2'833 | 2'784 | 2'737 | 2'687 | 2'685 | 2'702 | 2'701 | 2'727 |
| LDV | 73 | 69 | 64 | 61 | 58 | 56 | 54 | 51 | 52 | 54 |
| 2-Wheelers | 775 | 779 | 792 | 801 | 812 | 820 | 834 | 855 | 866 | 863 |
| | starts per veh. per day | | | | | | | | | |
| PC | 2.54 | 2.53 | 2.54 | 2.55 | 2.55 | 2.56 | 2.58 | 2.59 | 2.59 | 2.24 |
| LDV | 1.96 | 1.96 | 1.96 | 1.96 | 1.96 | 1.96 | 1.96 | 1.94 | 2.05 | 1.97 |

Further details are given in Annex A3.1.2.

#### *3.2.9.2.3. Railways (1A3c)*

**Methodology (1A3c)**

As mentioned in chp. 3.2.4.5.1, the emissions are calculated by the non-road transportation model. The following methods are used:

- Tier 2 for $CO_2$ (based on decision tree Fig. 3.4.1 in IPCC 2006)
- Tier 3 for $CH_4$, $N_2O$ and precursors (based on decision tree Fig. 3.4.2 in IPCC 2006).

The entire Swiss railway system is electrified. Electric locomotives are used in passenger as well as freight railway traffic. Diesel locomotives are used for shunting purposes in marshalling yards and for construction activities only.

Emissions are calculated for the years 1990, 1995, 2000, 2005 etc. up to 2020 based on fuel used. For the years in-between, the emissions are interpolated linearly.

**Emission factors (1A3c)**

Only diesel oil is being used as fuel, therefore all emission factors refer to diesel oil.

- The $CO_2$ emission factor applied for the time series 1990–2020 for diesel oil is country-specific and is given in Table 3-13.
- The $CH_4$ and $N_2O$ emission factors of diesel locomotives are shown in Table 3-79.
- The emission factors for precursors are country-specific and are given in FOEN (2015j). More details concerning the emission factor for $SO_2$ are shown in

Table A – 13 (row diesel oil). NMVOC emissions are calculated as the difference between VOC and $CH_4$ emissions.

- Implied emission factors 2020 are shown in Table 3-80.

All emission factors (GHG, precursors) can be downloaded by query from the public part of the non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS (2015a)).

Table 3-79 $CH_4$ and $N_2O$ emission factors for rail vehicles

| Gas | Power class | Rail vehicles with diesel oil engines | | | | |
|---|---|---|---|---|---|---|
| | | PreEU <2000 | UIC1 2000 | UIC2 2003 | EU3a 2006 | EU3b 2012 |
| | kW | g/kWh | | | | |
| $CH_4$ | <18 | 0.0547 | 0.0384 | 0.024 | 0.0142 | 0.0142 |
| $CH_4$ | 18–37 | 0.0578 | 0.0221 | 0.0134 | 0.0089 | 0.0089 |
| $CH_4$ | 37–56 | 0.0319 | 0.0156 | 0.011 | 0.0079 | 0.0055 |
| $CH_4$ | 56–75 | 0.0319 | 0.0156 | 0.011 | 0.0079 | 0.0031 |
| $CH_4$ | 75–130 | 0.0218 | 0.0108 | 0.0084 | 0.0067 | 0.0031 |
| $CH_4$ | >130 | 0.0218 | 0.0103 | 0.0072 | 0.0053 | 0.0031 |
| $N_2O$ | all | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 |

Table 3-80 Implied emission factors 2020 for rail vehicles. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

| 1A3c Railways | $CO_2$ fossil | $CO_2$ biog. | $CH_4$ | $N_2O$ | $NO_X$ | NMVOC | $SO_2$ | CO |
|---|---|---|---|---|---|---|---|---|
| | kg/TJ | | | | | | | |
| Diesel oil | 73'300 | NA | 1.3 | 3.6 | 986 | 116 | 0.47 | 534 |
| Biodiesel | NA | 73'300 | 1.1 | 3.0 | 843 | 99 | 0.40 | 456 |

**Activity data (1A3c)**

Activity data for non-road, including 1A3c Railways, are described in chp. 3.2.4.5.1 (non-road transportation model). Values are taken from FOEN (2015j). Data on biofuels are provided by the statistics of renewable energies (SFOE 2015a). Activity data are shown in Table 3-81 and in Annex A3.1.3.

Underlying activity data (vehicle stock, operating hours) of mobile non-road sources can be downloaded by query from the public part of the non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS (2015a)).

Table 3-81 Activity data (diesel oil consumption) for railways.

| 1A3c Railways | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Diesel oil | TJ | 390 | 441 | 455 | 472 | 492 |
| Biodiesel | TJ | NO | NO | 0.59 | 1.7 | 2.1 |
| Total Railways | TJ | 390 | 441 | 456 | 474 | 494 |
| 1990 = 100% | | 100% | 113% | 117% | 121% | 127% |

| 1A3c Railways | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Diesel oil | TJ | 471 | 451 | 431 | 410 | 390 | 388 | 387 | 385 | 383 | 382 |
| Biodiesel | TJ | 2.9 | 3.7 | 4.4 | 5.2 | 5.9 | 7.7 | 9.4 | 11 | 13 | 15 |
| Total Railways | TJ | 474 | 455 | 435 | 416 | 396 | 396 | 396 | 396 | 396 | 396 |
| 1990 = 100% | | 122% | 117% | 112% | 107% | 102% | 102% | 102% | 102% | 102% | 102% |

### *3.2.9.2.4. Domestic navigation (1A3d)*

**Methodology (1A3d)**

Based on the decision tree Fig. 3.5.1 Box 1 of the 2006 IPCC Guidelines (IPCC 2006) the emissions of navigation are calculated by a Tier 2 method with the non-road transportation model described in chp. 3.2.4.5.1.

There are passenger ships, dredgers, fishing boats, motor and sailing boats on the lakes and rivers of Switzerland. The emissions are calculated for the years 1990, 1995, 2000, 2005 etc. up to 2020 based on fuel used. For the years in-between, the emissions are linearly interpolated.

On the river Rhine as well as on Lake Geneva and Lake Constance, some of the boats cross the border. Fuels bought in Switzerland but used for international navigation are therefore reported as bunker fuels (memo items, chp. 3.2.2.).

$CO_2$ emissions from lubricants of gasoline 2-stroke engines are calculated by using the IPCC default $CO_2$ emission factor for lubricants, 73.3 t/TJ (IPCC 2006). However, these emissions are reported in source category 2D1 Lubricant use (see chp. 4.5.2.1). In contrast, $CH_4$ and $N_2O$ emissions from lubricant use are reported in source category 1A3d Domestic navigation, since the emission factors are deduced from measurements including 2-stroke engines.

**Emission factors (1A3d)**

- The $CO_2$ emission factor applied for the time series 1990–2020 for diesel oil, gasoline and gas oil are country-specific and are given in Table 3-13.
- The $CH_4$ and $N_2O$ emission factors are country-specific and are shown below in Table 3-82 to Table 3-84 for all fuel types and emission standards.
- For $SO_2$ the emission factors are country-specific. See also Table A – 13 in Annex A3.1.4 rows diesel oil, gasoline, gas oil.
- The emission factors for precursors are country-specific and are given in FOEN (2015j).
- NMVOC is not modelled bottom-up. The NMVOC emissions are calculated as the difference between VOC and $CH_4$ emissions.
- The implied emission factors 2020 are shown in Table 3-85.

All emission factors (GHG, precursors) can be downloaded by query from the public part of the non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS (2015a)).

Table 3-82 $CH_4$ and $N_2O$ emission factors for ships with diesel engines.

| Gas | Power class | Ships with diesel oil engines | | | | |
|---|---|---|---|---|---|---|
| | | Pre SAV (<1995) | SAV 1995 | EU-I 2003 | EU-II 2008 | EU-IIIA 2009 |
| | kW | g/kWh | | | | |
| $CH_4$ | <18 | 0.0547 | 0.0547 | 0.0384 | 0.0240 | 0.0142 |
| $CH_4$ | 18–37 | 0.0578 | 0.0578 | 0.0221 | 0.0134 | 0.0089 |
| $CH_4$ | 37–56 | 0.0319 | 0.0319 | 0.0156 | 0.0110 | 0.0079 |
| $CH_4$ | 56–75 | 0.0319 | 0.0319 | 0.0156 | 0.0110 | 0.0079 |
| $CH_4$ | 75–130 | 0.0218 | 0.0218 | 0.0108 | 0.0084 | 0.0067 |
| $CH_4$ | >130 | 0.0218 | 0.0218 | 0.0103 | 0.0072 | 0.0053 |
| $N_2O$ | all | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 |

Table 3-83 $CH_4$ and $N_2O$ emission factors for ships with gasoline engines by emission standards including the year of enforcement.

| Gas | Power class | Boats with 2-stroke gasoline engines | | | Boats with 4-stroke gasoline engines | | |
|---|---|---|---|---|---|---|---|
| | | Pre SAV <1995 | SAV 1995 | SAV/EU 2007 | Pre SAV <1995 | SAV 1995 | SAV/EU 2007 |
| | kW | g/kWh | | | g/kWh | | |
| $CH_4$ | <18 | 18.2 | 1.54 | 1.75 | 1.25 | 1.10 | 1.25 |
| $CH_4$ | 18–37 | 18.2 | 0.84 | 0.91 | 1.00 | 0.60 | 0.65 |
| $CH_4$ | 37–56 | 18.2 | 0.42 | 0.56 | 1.00 | 0.30 | 0.40 |
| $CH_4$ | 56–75 | 18.2 | 0.42 | 0.56 | 1.00 | 0.20 | 0.30 |
| $CH_4$ | 75–130 | 18.2 | 0.42 | 0.56 | 1.00 | 0.17 | 0.25 |
| $CH_4$ | 130–560 | 18.2 | 0.42 | 0.56 | 1.00 | 0.10 | 0.25 |
| $N_2O$ | 0–300 | 0.01 | 0.01 | 0.01 | 0.03 | 0.03 | 0.03 |

Table 3-84 $CH_4$ and $N_2O$ emission factors for steamboats by the year of enforcement.

| Gas | steamboats | | |
|---|---|---|---|
| | <2000 | 2000-2004 | >2004 |
| | g/kWh | | |
| $CH_4$ | 0.0218 | 0.0103 | 0.0072 |
| $N_2O$ | 0.035 | 0.035 | 0.035 |

Table 3-85 Implied emission factors 2020 for navigation. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

| 1A3d Navigation | $CO_2$ fossil | $CO_2$ biog. | $CH_4$ | $N_2O$ | $NO_X$ | NMVOC | $SO_2$ | CO |
|---|---|---|---|---|---|---|---|---|
| | kg/TJ | | | | | | | |
| Gasoline | 73'800 | NA | 22 | 1.9 | 544 | 414 | 0.38 | 8'700 |
| Diesel oil | 73'300 | NA | 1.4 | 3.4 | 796 | 226 | 0.47 | 504 |
| Gas oil | 73'700 | NA | 0.24 | 0.73 | 26 | 1.6 | 4.7 | 6.9 |
| Biodiesel | NA | 73'300 | 1.2 | 2.9 | 680 | 193 | 0.40 | 431 |
| Bioethanol | NA | 73'800 | 13 | 1.3 | 350 | 255 | 0.24 | 5'507 |

## Activity data (1A3d)

Activity data for navigation (1A3d) are described in chp. 3.2.4.5.1 (non-road transportation model). Values are taken from FOEN (2015j). Data on biofuels are provided by the statistics of renewable energies (SFOE 2015a). Activity data are shown in Table 3-86 and in Annex A3.1.3.

Underlying activity data (vehicle stock, operating hours) of mobile non-road sources can be downloaded by query from the public part of the non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (INFRAS 2015a).

Table 3-86 Fuel consumption of (domestic) navigation.

| 1A3d Domestic navigation | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Gasoline | TJ | 701 | 654 | 616 | 565 | 535 |
| Diesel oil | TJ | 738 | 724 | 792 | 800 | 868 |
| Gas oil | TJ | 110 | 139 | 147 | 150 | 159 |
| Biodiesel | TJ | NO | NO | 1.0 | 2.9 | 3.8 |
| Bioethanol | TJ | NO | NO | NO | NO | 0.013 |
| Total Navigation | TJ | 1'550 | 1'517 | 1'556 | 1'518 | 1'565 |
| 1990 = 100% | | 100% | 98% | 100% | 98% | 101% |

| 1A3d Domestic navigation | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Gasoline | TJ | 530 | 526 | 522 | 518 | 514 | 512 | 511 | 509 | 508 | 506 |
| Diesel oil | TJ | 870 | 872 | 874 | 876 | 878 | 873 | 867 | 862 | 857 | 851 |
| Gas oil | TJ | 157 | 156 | 154 | 153 | 151 | 150 | 149 | 148 | 147 | 146 |
| Biodiesel | TJ | 5.7 | 7.6 | 9.5 | 11 | 13 | 17 | 21 | 25 | 29 | 33 |
| Bioethanol | TJ | 0.79 | 1.6 | 2.3 | 3.1 | 3.9 | 6.3 | 8.6 | 11 | 13 | 16 |
| Total Navigation | TJ | 1'564 | 1'563 | 1'562 | 1'561 | 1'560 | 1'559 | 1'557 | 1'556 | 1'554 | 1'552 |
| 1990 = 100% | | 101% | 101% | 101% | 101% | 101% | 101% | 100% | 100% | 100% | 100% |

### *3.2.9.2.5. Other transportation (1A3e)*

## Methodology (1A3e)

The emissions are calculated with a Tier 2 method (the 2006 IPCC Guidelines (IPCC 2006) do not contain a decision tree to determine the Tier level specifically).

Source 1A3e includes only pipeline transportation (1A3ei) from a compressor station located in Ruswil. Emissions of $CO_2$, $CH_4$, $N_2O$, $NO_x$, CO, NMVOC and $SO_2$ are reported. The compressor station uses a centrifugal compressor according to Transitgas AG (the company operating the compressor station and the pipeline network).

**Emission factors (1A3e)**

- The $CO_2$ emission factor applied for the time series 1990–2020 for natural gas is country-specific and is given in Table 3-14.
- The $CH_4$ emission factor corresponds to the one used for gas turbines in Switzerland (SAEFL 2000) as suggested by expert judgement. The $CH_4$ EF is assumed to be 5 g/GJ up to 1995 and 2 g/GJ from 2000 onwards, with linear interpolation in between. This corresponds with the fact that a catalyst was fitted to the system, which reduced the $CH_4$ emissions of the gas turbine.
- For $N_2O$ emission factors the IPCC 2006 default value (Table 3-17) is used as displayed in Table 3-87.
- The emission factors for precursors are mostly country-specific. The $NO_x$ emission factor stems from the Factsheet Emission Factors Furnaces (FOEN 2015k). NMVOC and $SO_x$ emission factors stem from section “Gasturbinen; Erdgas” in SAEFL (2000). More details concerning the emission factor for $SO_2$ are shown in Table A – 11 (row natural gas). The CO emission factor is a default factor from the EMEP/EEA guidebook (EMEP/EEA 2019).
- The emission factors 2020 are shown in Table 3-87.

Table 3-87 Emission factors of 1A3ei Pipeline transportation / compressor station located in Ruswil in 2020. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

| 1A3e Other transportation | $CO_2$ fossil | $CH_4$ | $N_2O$ | $NO_X$ | NMVOC | $SO_2$ | CO |
|---|---|---|---|---|---|---|---|
| | kg/TJ | | | | | | |
| Gas | 56'200 | 2 | 0.1 | 19 | 0.1 | 0.5 | 5 |

**Activity data (1A3e)**

The data on fuel consumption for the operation of the compressor station in Ruswil is based on the Swiss overall energy statistics (SFOE 2021; Table 17).

Table 3-88 Activity data of 1A3e.

| 1A3ei Pipeline transport | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Natural gas | TJ | 560 | 310 | 340 | 1'070 | 830 |
| 1990=100% | | 100% | 55% | 61% | 191% | 148% |

| 1A3ei Pipeline transport | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Natural gas | TJ | 840 | 810 | 410 | 830 | 760 | 340 | 470 | 490 | 600 | 540 |
| 1990=100% | | 150% | 145% | 73% | 148% | 136% | 61% | 84% | 88% | 107% | 96% |

### 3.2.9.3. Uncertainties and time-series consistency for 1A3

The uncertainty of emission estimates for source category 1A3 is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7. Uncertainties by fuel type are given in Table 3-26.

Time series for 1A3 Transport are all considered consistent.

### 3.2.9.4. Category-specific QA/QC and verification for 1A3

**General**

The general QA/QC measures are described in chp. 1.2.3. Furthermore, QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

**Specific: Domestic aviation (1A3a)**

*Emissions*

Total calculated emissions for domestic and international flights have been compared between different years. The development of total emissions with time is consistent with a fleet renewal of former Swissair in the early nineties, the technological improvements and changes in fleet composition.

*Emission factors*

- From total fuel consumption, total distance, number of passengers (without freight) per aircraft type, the fuel consumption per 100 passenger km has been calculated (backward calculation). The result of 2 to 10 kg fuel per 100 passenger km is in line with expectations for 1990 passenger fleets. Current modern fleets are in the order of 2.5 kg fuel per 100 passenger km. During the COVID-19 pandemic, the seat load factor was exceptionally low and therefore, a calculation of the fuel consumption per 100 passenger km is not representative.
- The implied emission factors were calculated for 2020 and compared with previous years.

*Activity data*

- In an independent Tier 3B calculation, EUROCONTROL performed a fuel calculation for Switzerland’s international flights, based on collected Instrument Flight Rules flight plan data and single movements. The results for the years 2004, 2005 and 2007 matched the FOCA calculations by more than 97.4%. The FOCA results were generally 1% to 2% higher but included the total number of actual flight movements of all flights, including visual flight rules and non-scheduled flights such as helicopter movements in alpine regions.
- Comparison between total movement numbers in the calculation and in the corresponding published statistics. Example: In 1990 calculation, FOCA considered all flights for which there was a form ‘Traffic report to the airport authorities’ filled in (total heavy aircraft). The total number of movements in 1990 is 263’951 (without Basel). The published number of movements for scheduled and charter flights in 1990 is: 263’952 (without Basel).
- The bottom-up calculation of total fuel matches the total fuel sold within a few percent, except for 2020, where the difference is larger due to the COVID-19 pandemic.
- Real-world fuel consumption was compared with modelled consumption for selected aircraft of four Swiss airlines. The difference between the two methods was smaller than 1%.

**Specific: Road transportation (1A3b)**

Comparison between the 2006 IPCC Guideline's default (IPCC 2006) and Switzerland's emission factors:

- $CO_2$ (see also Table 3-27): IPCC default value for gasoline is 69.3 t/TJ and for diesel oil 74.1 t/TJ (IPCC 2006, Table 3.2.1). Switzerland's emission factors vary between 73.8 and 73.9 t/TJ for gasoline – 6% higher than IPCC – and between 73.3 and 73.6 t/TJ for diesel oil – about 1% below IPCC default value (IPCC 2006).
- $CH_4$: The IPCC default emission factor for gasoline motors with oxidation catalysts is 25 kg/TJ with an uncertainty range from 7.5 to 86 kg/TJ (IPCC 2006, Table 3.2.2). Switzerland's emission factor for gasoline passenger cars varied between 27.5 kg/TJ and 4.0 kg/TJ throughout the time series and is therefore in the lower part of and below IPCC's uncertainty range. For diesel oil, the IPCC default emission factors lie in the range of 1.6–9.5 kg/TJ (IPCC 2006), whereas Switzerland's range is on a lower level (0.8–3.7 kg/TJ).
- $N_2O$: The IPCC default emission factor for gasoline motors with oxidation catalysts lies in the uncertainty range 2.6–24 kg/TJ (IPCC 2006, Table 3.2.2). Switzerland's emission factor for gasoline passenger cars varied between 5.3 kg/TJ and 0.6 kg/TJ and is therefore in the lower part of and below IPCC's uncertainty range. For diesel oil the IPCC default emission factors lies in the range of 1.3–12 kg/TJ (IPCC 2006), whereas Switzerland's range is lower (0.2–3.5 kg/TJ).

The international project for the update of the emission factors for road vehicles is overseen by a group of external national and international experts that guarantees an independent quality control. For the update of the modelling of Switzerland's road transport emissions, which has last been carried out between 2019–2020 in the framework of the update of Switzerland's energy perspectives, several experts from the federal administration have accompanied the project. The results have undergone extensive plausibility checks and comparisons with earlier estimates.

The emission factors $CH_4$ and $N_2O$ used for the modelling of 1A3b Road Transportation are taken from version 4.1 of the Handbook Emission Factors for Road Transport (HBEFA) (INFRAS 2019b), which is also applied in Germany, Austria, Netherlands, and Sweden. The Swiss emission factors for $CH_4$ and $N_2O$ used in 1A3b Road transportation were additionally compared with those shown in the CRF from Germany and a good match was found. Possible small differences might result from a varying fleet composition.

Use of implied emission factors from the territorial model to calculate emissions for fuel tourism: This approach has been verified by comparing implied emission factors with the neighbouring countries. The differences turned out to be small between Switzerland, Austria, and Germany because all three countries used the same emission factors (INFRAS 2010), whereas there were some differences when comparing with France and Italy that use other emission factors (COPERT, EEA 1997). Nevertheless, the use of the implied Swiss emission factors seemed to be the consistent approach. It must be noted, that this comparison was carried out with version 3.1 of the "Handbook of Emission Factors for Road Transport", whereas the current emissions are based on version 4.1. It is expected that an update of this comparison would result in similarly low differences with the neighbouring countries, since the underlying measurement data in the inventory models are the same (given the neighbouring countries also work with an eventually updated COPERT version).

The activity data for gasoline and diesel oil of the road transportation model (consumption without tank tourism and statistical difference) is verified due to the fact that more than 90% of the gasoline and diesel oil sold 2020 in Switzerland, as reported by the Swiss overall energy statistic (SFOE 2021), is consumed by the road transportation model (see Table 3-75).

### 3.2.9.5. Category-specific recalculations for 1A3

The following recalculations were implemented in submission 2022. Major recalculations, which contribute significantly to the total differences in emissions of sector 1 Energy between the latest and the previous submissions are presented also in chp. 10.1.2.1.

- 1A/1A3b: Due to recalculations in sector 1B2a of fugitive NMVOC emissions from gasoline storage tanks the total amount of gasoline used in sector 1A Fuel combustion activities changes a little for the years 1990–2019. This recalculation leads to changes for all greenhouse gases for the years 1990–2019.
- 1A3b: The $CO_2$ emission factor for biogas in road transportation was not identical with the one for biogas used otherwise in the Swiss inventory. Thus, the emission factor was adapted to the one used in other biogas processes in the Swiss inventory. This leads to a recalculation of the $CO_2$ emissions from biomass for the years 1997–2019.
- 1A3b: The $CO_2$ emission factor for natural gas was adapted to the one used for natural gas in the Swiss inventory (see Table 3-14). This leads to a recalculation of $CO_2$ emissions from gaseous fuels for the years 2018–2019.
- 1A3b: Mileage for vehicle categories were adapted based on more precise data available through the IVZ database (Information system for traffic admission by FEDRO). Furthermore, the analysis of vehicle starts and stops was updated based on data available from ARE/SFSO (2012, 2017). This recalculation leads to changes for all greenhouse gases for the years 1990–2019.
- 1A3b: Small recalculations for all greenhouse gases for the years 1990–2019 due to newly defined roundings of activity data and emission factors.

### 3.2.9.6. Category-specific planned improvements for 1A3

No category-specific improvements are planned.

## 3.2.10. Source category 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

### 3.2.10.1. Source category description for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

#### Key categories 1A4

See key categories mentioned in chp. 3.2.7.1, Table 3-56.

Table 3-89 Specification of source category 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors (1A4aii, 1A4bii, 1A4cii).

| 1A4 | Source category | Specification |
|---|---|---|
| 1A4aii | Commercial/ institutional | Emission from non-road vehicles (professional gardening) and motorised equipment |
| 1A4bii | Residential | Emissions from mobile machinery (hobby, gardening) and motorised equipment |
| 1A4cii | Agriculture/forestry | Emisions from non-road vehicles and machinery in agriculture and forestry |

### 3.2.10.2. Methodological issues for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

#### Methodology (1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors)

Based on the decision tree Fig. 3.3.1 in chp. "3. Mobile Combustion" in the 2006 IPCC Guidelines (IPCC 2006), the emissions of vehicles and machinery in 1A4 are calculated by a Tier 3 method with the non-road transportation model described in chp. 3.2.4.5.1.

$CO_2$ emissions from lubricants of gasoline 2-stroke engines are calculated by using the IPCC default $CO_2$ emission factor for lubricants, 73.3 t/TJ (IPCC 2006). However, these emissions are reported under source category 2D1 Lubricant use (see chp. 4.5.2.1). In contrast, $CH_4$ and $N_2O$ emissions from lubricant use in 2-stroke engines are reported in the corresponding source category in 1A4 Other non-road machinery sources in residential, commercial, agriculture and forestry sectors, since the emission factors are based on measurements including 2-stroke engines.

#### Emission factors (1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors)

In Off-road vehicles and other machinery in categories 1A4aii Commercial/institutional and 1A4bii Residential, only gasoline (and a small share of bioethanol) is being used as fuel. In category 1A4cii Agricultural/forestry/fishing, mainly diesel oil is consumed (more than 80%, see Table 3-91) and only a small amount (less than 20%) of gasoline (e.g. chainsaws) or biodiesel/bioethanol.

- The $CO_2$ emission factors applied for the time series 1990–2020 are country-specific and are given in Table 3-13.
- The $CH_4$ and $N_2O$ emission factors are country-specific and are shown in Table 3-65 and Table 3-66 for diesel oil and gasoline engines for all emission standards.
- For $SO_2$ the emission factors are country-specific. See also Table A – 13 in Annex A3.1.4 for diesel oil, gasoline, gas oil.
- The emission factors for precursors are country-specific and are given in FOEN (2015j).
- NMVOC is not modelled bottom-up. The NMVOC emissions are calculated as the difference between VOC and $CH_4$ emissions.
- Implied emission factors 2020 are shown in Table 3-90.

All emission factors (GHG, precursors) can be downloaded by query from the public part of the non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS (2015a)).

Table 3-90 Implied emission factors 2020 for 1A4 – Other non-road machinery sources in residential, commercial agriculture and forestry sectors(1A4aii – 1A4cii mobile). Emission factors that are highlighted in green are described in chp. 3.2.4.4.

| 1A4 Non-road machinery | $CO_2$ fossil | $CO_2$ biog. | $CH_4$ | $N_2O$ | $NO_X$ | NMVOC | $SO_2$ | CO |
|---|---|---|---|---|---|---|---|---|
| | kg/TJ | | | | | | | |
| 1A4aii Gardening professional | | | | | | | | |
| Gasoline | 73'800 | NA | 83 | 1.2 | 185 | 1'339 | 0.38 | 26'760 |
| Bioethanol | NA | 73'800 | 16 | 1.0 | 84 | 467 | 0.24 | 15'764 |
| 1A4bii Gardening | | | | | | | | |
| Gasoline | 73'800 | NA | 42 | 1.4 | 155 | 881 | 0.38 | 25'422 |
| Bioethanol | NA | 73'800 | 16 | 1.0 | 92 | 455 | 0.24 | 15'789 |
| 1A4cii Forestry and agriculture | | | | | | | | |
| Gasoline | 73'800 | NA | 80 | 1.2 | 178 | 1'387 | 0.38 | 24'532 |
| Diesel oil | 73'300 | NA | 1.0 | 3.0 | 367 | 42 | 0.47 | 212 |
| Biodiesel | NA | 73'300 | 0.9 | 2.5 | 314 | 36 | 0.40 | 181 |
| Bioethanol | NA | 73'800 | 19 | 0.91 | 79 | 550 | 0.24 | 14'989 |

**Activity data (1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors)**

Activity data are described in chp. 3.2.4.5.1 (non-road transportation model) and are shown in Table 3-91 and in Annex A3.1.3.

Underlying activity data (vehicle stock, operating hours) of mobile non-road sources can be downloaded by query from the public part of the non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS 2015a).

Table 3-91 Activity data for non-road vehicles and machinery in 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors.

| 1A4 Non-road machinery | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| 1A4aii Gardening professional | | | | | | |
| Gasoline | TJ | 191 | 245 | 295 | 295 | 287 |
| Bioethanol | TJ | NO | NO | NO | NO | 0.0039 |
| 1A4bii Gardening | | | | | | |
| Gasoline | TJ | 142 | 155 | 165 | 166 | 163 |
| Bioethanol | TJ | NO | NO | NO | NO | 0.0034 |
| 1A4cii Forestry and agriculture | | | | | | |
| Gasoline | TJ | 1'160 | 1'070 | 963 | 824 | 689 |
| Diesel oil | TJ | 4'269 | 4'604 | 4'920 | 4'802 | 4'882 |
| Biodiesel | TJ | NO | NO | 6.4 | 17 | 21 |
| Bioethanol | TJ | NO | NO | NO | NO | 0.012 |
| Total 1A4 non-road machinery | TJ | 5'761 | 6'073 | 6'349 | 6'103 | 6'042 |
| Relative values 1A4 (1990 = 100%) | | 100% | 105% | 110% | 106% | 105% |

| 1A4 Non-road machinery | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1A4aii Gardening professional | | | | | | | | | | | |
| Gasoline | TJ | 280 | 273 | 266 | 260 | 253 | 251 | 250 | 248 | 247 | 245 |
| Bioethanol | TJ | 0.24 | 0.48 | 0.72 | 0.95 | 1.2 | 1.9 | 2.6 | 3.3 | 4.0 | 4.7 |
| 1A4bii Gardening | | | | | | | | | | | |
| Gasoline | TJ | 162 | 160 | 159 | 158 | 156 | 155 | 154 | 153 | 152 | 151 |
| Bioethanol | TJ | 0.21 | 0.43 | 0.64 | 0.85 | 1.1 | 1.7 | 2.3 | 2.9 | 3.6 | 4.2 |
| 1A4cii Forestry and agriculture | | | | | | | | | | | |
| Gasoline | TJ | 665 | 641 | 616 | 592 | 568 | 551 | 535 | 519 | 503 | 486 |
| Diesel oil | TJ | 4'876 | 4'870 | 4'864 | 4'859 | 4'853 | 4'835 | 4'817 | 4'800 | 4'782 | 4'764 |
| Biodiesel | TJ | 32 | 42 | 53 | 63 | 74 | 96 | 118 | 140 | 162 | 184 |
| Bioethanol | TJ | 0.66 | 1.3 | 2.0 | 2.6 | 3.3 | 4.8 | 6.4 | 8.0 | 9.6 | 11 |
| Total 1A4 non-road machinery | TJ | 6'015 | 5'989 | 5'962 | 5'936 | 5'909 | 5'898 | 5'886 | 5'874 | 5'862 | 5'851 |
| Relative values 1A4 (1990 = 100%) | | 104% | 104% | 103% | 103% | 103% | 102% | 102% | 102% | 102% | 102% |

### 3.2.10.3. Uncertainties and time-series consistency for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

The uncertainty of emission estimates for source category 1A4 Other sectors (mobile) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7. Uncertainties by fuel type are given in Table 3-26.

### 3.2.10.4. Category-specific QA/QC and verification for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

The general QA/QC procedures are described in chp. 1.2.3. Furthermore QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

### 3.2.10.5. Category-specific recalculations for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

There were no recalculations implemented in submission 2022.

### 3.2.10.6. Category-specific planned improvements for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

No category-specific improvements are planned.

## 3.2.11. Source category 1A5b – Other (mobile)

### 3.2.11.1. Source category description for 1A5b (mobile)

Source category 1A5b – Other (mobile) is not a key category.

All of the Swiss source categories of 1A5 refer to mobile sources of military activities (1A5b). Stationary activities (1A5a) are not occurring.

Table 3-92 Specification of Swiss source category 1A5 Other.

| 1A5 | Source category | Specification |
|---|---|---|
| 1A5bi | Military aviation | Emissions from military aircrafts |
| 1A5bii | Military non-road vehicles and machines | Emissions from machines like power generators, tanks, bulldozers, boats etc. |

### 3.2.11.2. Methodological issues for 1A5b Other (mobile)

#### *3.2.11.2.1. Military aviation (1A5bi)*

**Methodology (1A5bi Other, military aviation)**

To calculate the emissions from military aviation, a Tier 2 method is used for $CO_2$, while a Tier 1 method is used for $CH_4$ and $N_2O$.

**Emission factors (1A5bi Other, military aviation)**

- The $CO_2$ emission factor applied for the time series 1990–2020 for kerosene is country-specific and is given in Table 3-13.
- $CH_4$: Because there is no split in LTO and cruise flights in military aviation, the $CH_4$ emission factor of 1A3a Civil aviation (see chp. 3.2.9.2.1) cannot be applied. Therefore, the Tier 1 emission factor from IPCC 2006, table 3.6.5 is used.
- $N_2O$: As for 1A3a Civil aviation, the Tier 1 IPCC default value is used (IPCC 2006, table 3.6.5).
- $NO_x$, NMVOC, CO: average emission factors for military aircraft are calculated by the Federal Office of Civil Aviation (FOCA) based on collaborative measurement efforts of FOCA and the Federal Department of Defence, Civil Protection and Sport (DDPS) and the FOCA aircraft engine data bank. The fuel consumption per aircraft type in the year 2016–2017 is provided by DDPS (DDPS 2018b). The emission factors stay constant for the whole time series from 1990 onwards.
- $SO_2$: the emission factor is taken from the EMEP/EEA guidebook (EMEP/EEA 2019, Table 3.11, row “Switzerland/CCD” (where: CCD means: climb/cruise/descent)) and is assumed to be constant over the period 1990–2020.
- Implied emission factors 2020 are shown in Table 3-93.

Table 3-93 Implied emission factors 1A5bi military aviation in 2020. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

| 1A5 Other: Military aviation | $CO_2$ fossil | $CH_4$ | $N_2O$ | $NO_X$ | NMVOC | $SO_2$ | CO |
|---|---|---|---|---|---|---|---|
| | kg/TJ | | | | | | |
| Jet kerosene | 72'800 | 0.5 | 2 | 232 | 33 | 23 | 235 |

### Activity data (1A5bi Other, military aviation)

Fuel consumption data for 1990–2020 is available on an annual basis (DDPS 2021). A very small fraction of fuel is consumed for training abroad and might be allocated under "International aviation" (assumed to be less than 3% of total military aviation consumption). Since the exact numbers for the fuels used abroad is not known, it is not subtracted from the total consumption but included under national military aviation, as recommended by the 2006 IPCC Guidelines (IPCC 2006, chp. 3.6.1.4).

Table 3-94 Activity data (fuel consumption) for military aviation.

| 1A5 Other: Military aviation | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Jet kerosene | TJ | 2'733 | 1'955 | 1'794 | 1'624 | 1'592 |

| 1A5 Other: Military aviation | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jet kerosene | TJ | 1'420 | 1'527 | 1'542 | 1'615 | 1'567 | 1'627 | 1'469 | 1'457 | 1'303 | 1'365 |

## *3.2.11.2.2. Military non-road vehicles (1A5bii Other, military machinery)*

### Methodology (1A5bii Other, military machinery)

Emissions are calculated as part of the non-road transportation model (chp. 3.2.4.5.1) corresponding to a Tier 3 according to the decision tree Fig. 3.3.1 in chp. 3. Mobile Combustion in IPCC (2006).

$CO_2$ emissions from lubricants of gasoline 2-stroke engines are calculated by using the IPCC default $CO_2$ emission factor for lubricants, 73.3 t/TJ (IPCC 2006). However, these emissions are reported under source category 2D1 Lubricant use (see chp. 4.5.2.1). In contrast, $CH_4$ and $N_2O$ emissions from lubricant use in 2-stroke engines are reported in source category 1A5bii, since the emission factors are based on measurements including 2-stroke engines.

### Emission factors (1A5bii Other, military machinery)

- The $CO_2$ emission factors applied for the time series 1990–2020 for diesel oil, gasoline and biofuels are country-specific as shown in Table 3-13.
- The $CH_4$ and $N_2O$ emission factors are country-specific and are shown in Table 3-65 and Table 3-66 for diesel oil and gasoline engines for all emission standards.
- For $SO_2$ the emission factors are country-specific. See Table A – 13 in Annex A3.1.4, rows diesel oil, gasoline.
- The emission factors for precursors are country-specific and are given in FOEN (2015j).

- NMVOC is not modelled bottom-up. The NMVOC emissions are calculated as the difference between VOC and $CH_4$ emissions.
- Implied emission factors are shown in Table 3-95.

All emission factors (GHG, precursors) can be downloaded by query from the public part of the non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS (2015a)).

Table 3-95 Implied emission factors 1A5bii military non-road vehicles 2020. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

| 1A5bii Military non-road | $CO_2$ fossil | $CO_2$ biog. | $CH_4$ | $N_2O$ | $NO_X$ | NMVOC | $SO_2$ | CO |
|---|---|---|---|---|---|---|---|---|
| | kg/TJ | | | | | | | |
| Gasoline | 73'800 | NA | 38 | 1.5 | 133 | 714 | 0.38 | 24'543 |
| Diesel | 73'300 | NA | 0.66 | 3.0 | 307 | 27 | 0.47 | 139 |
| Biodiesel | NA | 73'300 | 0.56 | 2.6 | 262 | 23 | 0.40 | 119 |
| Bioethanol | NA | 73'800 | 10 | 1.1 | 70 | 291 | 0.24 | 15'556 |

**Activity data (1A5bii Other, military machinery)**

Activity data for military non-road vehicles (1A5bii) are described in. chp. 3.2.4.5.1 (non-road transportation model). Values are taken from FOEN (2015j). Data on biofuels are provided by the statistics of renewable energies (SFOE 2015a). Activity data are shown in Table 3-96 and in Annex A3.1.3.

Underlying activity data (vehicle stock, operating hours) of mobile non-road sources can be downloaded by query from the public part of the non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS 2015a).

Table 3-96 Activity data (fuel consumption) for military non-road vehicles.

| 1A5bii Military non-road | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 239 | 248 | 252 | 257 | 275 |
| Gasoline | TJ | 19 | 19 | 19 | 19 | 18 |
| Diesel | TJ | 220 | 228 | 233 | 238 | 256 |
| Biodiesel | TJ | NO | NO | 0.30 | 0.86 | 1.1 |
| Bioethanol | TJ | NO | NO | NO | NO | 0.00038 |

| 1A5bii Military non-road | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total fuel consumption | TJ | 275 | 275 | 275 | 275 | 275 | 274 | 273 | 272 | 271 | 270 |
| Gasoline | TJ | 18 | 18 | 17 | 17 | 17 | 17 | 16 | 16 | 16 | 16 |
| Diesel | TJ | 256 | 255 | 255 | 254 | 254 | 252 | 250 | 248 | 246 | 244 |
| Biodiesel | TJ | 1.7 | 2.2 | 2.8 | 3.3 | 3.9 | 5.0 | 6.1 | 7.2 | 8.3 | 9.4 |
| Bioethanol | TJ | 0.023 | 0.046 | 0.069 | 0.092 | 0.11 | 0.18 | 0.25 | 0.31 | 0.38 | 0.45 |

### 3.2.11.3. Uncertainties and time-series consistency for 1A5b Other (mobile)

The uncertainty of emission estimates for source category 1A5b Other (mobile) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7. Uncertainties by fuel type are given in Table 3-26.

### 3.2.11.4. Category-specific QA/QC and verification for 1A5b Other (mobile)

The general QA/QC measures are described in chp. 1.2.3. Furthermore, QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

The activity data of military aviation (1A5b), kerosene consumption, is provided by the Federal Department of Defence, Civil Protection and Sport. For a compatibility check with the emission database of civil aviation, they are sent to the FOCA (office of the Federal Department of the Environment, Transport, Energy and Communications).

### 3.2.11.5. Category-specific recalculations for 1A5b Other (mobile)

There were no recalculations implemented in submission 2022.

### 3.2.11.6. Category-specific planned improvements for 1A5b Other (mobile)

No category-specific improvements are planned.

# 3.3. Source category 1B – Fugitive emissions from fuels

## 3.3.1. Source category description for 1B

Table 3-97 Key categories of 1B Fugitive emissions from fuels. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 1B2 | Oil and Natural Gas Energy Production; All Fuels | CH4 | L1, T1 |

The only relevant source categories of fugitive emissions in Switzerland are:

- Oil (1B2a)
- Natural gas (1B2b)
- Venting and flaring (1B2c)

## 3.3.2. Source category 1B1 – Solid Fuels

Coal mining is not occurring in Switzerland. There are no greenhouse gas emissions from coal handling.

## 3.3.3. Source category fugitive emissions from 1B2a – Oil

### 3.3.3.1. Source category description for 1B2a

In Switzerland, oil production is not occurring. Fugitive emissions in the oil industry result exclusively from the refineries and several fuel handling stations. At the beginning of 2015, one of the two refineries ceased operation. The extents of the two existing oil pipelines in Switzerland are approximately 40 km and 70 km, respectively. The pipelines are mainly laid underground.

Table 3-98 Specification of source category fugitive emissions from 1B2a Oil in Switzerland.

| 1B2 | Source category | Specification |
|---|---|---|
| 1B2aiii | Fugitive emissions oil: Transport | Emissions only stem from pipeline transport |
| 1B2aiv | Fugitive emissions oil: Refining / storage | Emissions from oil refining process |
| 1B2av | Fugitive emissions oil: Distribution of oil products | Distribution of oil products (from gasoline storage tanks and gasoline stations)<br>(only precursor emissions NMVOC) |

### 3.3.3.2. Methodological issues for 1B2a

**Methodology (1B2a)**

According to the decision tree for crude oil transport, refining and upgrading, Switzerland estimates 1B2a fugitive emissions from oil based on a Tier 3 (for 1B2aiii Fugitive emissions oil: Transport) and a Tier 2 (for 1B2aiv Fugitive emissions oil: Refining / storage, 1B2av Fugitive emissions oil: Distribution of oil products) approach (IPCC 2006, Volume 2 Energy, chp. 4 Fugitive Emissions, Figure 4.2.3 and for precursors EMEP/EEA 2019, Figure 3-1).

For source 1B2a fugitive emissions from oil, fugitive emissions of $CH_4$ are reported. They occur only in 1B2aiii Transport and 1B2aiv Refining/storage. Indirect $CO_2$ emissions resulting from $CH_4$ and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9. As no CO emissions occur in source category 1B2a, from this source category no indirect $CO_2$ emissions from CO are included in CRF Table6 as documented in chp. 9.

**Emission factors (1B2a)**

Crude oil transportation (1B2aiii): In Switzerland crude oil is transported by underground pipelines only. According to experts from the pipeline operator, there are no emissions along the pipelines but only at the pig trap. There is one pig trap per pipeline and one pipeline per refinery. Based on expert estimates 0.5 $m^3$ air saturated with VOC are emitted per week and pig trap. This leads to $CH_4$ emissions of 1–2 kg per year. The $CH_4$ to NMVOC ratio is assumed to be 1:10.

For oil refining and storage (1B2aiv), country-specific emission factors for $CH_4$ and NMVOC are used. The emission factors for $CH_4$ are delineated from an emission estimation project in one of the refineries in 1992 called CRISTAL (Raffinerie de Cressier 1992). The emission factor from the other refinery is assumed to be twice as high, because the technology of the plant is older. Then a weighted mean based on the quantity of crude oil used in both refineries was calculated (for further details see the internal documentation of the EMIS database, EMIS 2022/1B2aiv). This emission factor is used for all the years until 1995. For the years 2007–2019 total NMVOC emissions from 1A1b, 1B2aiv and 1B2c correspond to those reported in the Swiss Pollutant Release and Transfer Register (PRTR) from the two refineries. For 2020, the emission factor is the same as for 2019, because data from PRTR is not available during data collection for the inventory. Therefore, emission factors in 1B2aiv are adapted to reach the total NMVOC emissions as reported in the Swiss Pollutant Release and Transfer Register. Between the years 1995 and 2007, the emission factors are interpolated linearly. The ratio between $CH_4$ and NMVOC stays at 1:10 for all the years.

The emission factors for $SO_x$ emissions from Claus units in refineries are country-specific and based on measurements and data from industry and expert estimates.

For oil distribution from storage tanks and gasoline stations (1B2av), the NMVOC emission factor is country-specific, based on a model which takes annual gasoline sales and technical equipment of gasoline stations and storage tanks into account (see internal database documentation in EMIS 2022/1B2av Benzinumschlag Tanklager and EMIS 2022/1B2av Benzinumschlag Tankstellen). An expert team (Weyer and Partner AG) is in charge of providing annual updates of the modelled NMVOC emissions based on their own database of Swiss storage tanks and gasoline vapour recovery systems. The model is calibrated with spot checks of the gas recovery systems of gas stations.

Table 3-99 Emission factors for fugitive emissions of source category 1B2a Oil in 2020.

| Source/fuel | Unit | $CO_2$ | $CH_4$ | $N_2O$ | $NO_x$ | NMVOC | $SO_2$ | CO |
|---|---|---|---|---|---|---|---|---|
| 1B2a Oil | | | | | | | | |
| 1B2ai Exploration | g/t | NO | NO | NO | NO | NO | NO | NO |
| 1B2aii Production | g/t | NO | NO | NO | NO | NO | NO | NO |
| 1B2aiii Transport of crude oil by pipelines (number of refineries) | g/No. | NA | 1'000 | NA | NA | 10'000 | NA | NA |
| 1B2aiv Refining/Storage of crude oil | g/t | NA | 7.0 | NA | NA | 75 | 5 | NA |
| 1B2av Distribution of oil products: Gasoline storage tank | g/GJ | NA | NA | NA | NA | 1.1 | NA | NA |
| 1B2av Distribution of oil products: Gasoline station | g/GJ | NA | NA | NA | NA | 9.3 | NA | NA |

### Activity data (1B2a)

As crude oil is transported per pipeline to the refineries in Switzerland, activity data for oil transport (1B2aiii) reflects the number of pipelines, which is equal to the number of refineries. Activity data for oil refining and storage (1B2aiv) is the amount of crude oil imported. This data is provided by Avenergy Suisse (Avenergy 2021) in their annual statistics and also reported in the Swiss overall energy statistics (SFOE 2021).

For oil distribution from storage tanks and gasoline stations (1B2av), gasoline sales based on the Swiss overall energy statistics (SFOE 2021), corrected for consumption of Liechtenstein, are used as activity data.

Table 3-100 Activity data for fugitive emissions from 1B2a Oil.

| 1B2a Oil products | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| 1B2aiii Transport of crude oil by pipelines (number of refineries) | No. | 2 | 2 | 2 | 2 | 2 |
| 1B2aiv Refining/Storage (amount of crude oil imported) | kt | 3'127 | 4'657 | 4'649 | 4'877 | 4'546 |
| 1B2av Gasoline distribution (amount of gasoline sold) | TJ | 156'516 | 151'672 | 168'353 | 152'182 | 134'129 |

| 1B2a Oil products | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | *1990 vs. 2020 (%)* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1B2aiii Transport of crude oil by pipelines (number of refineries) | No. | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | *-50%* |
| 1B2aiv Refining/Storage (amount of crude oil imported) | kt | 4'452 | 3'455 | 4'935 | 4'975 | 2'836 | 3'006 | 2'889 | 3'076 | 2'789 | 2'857 | *-9%* |
| 1B2av Gasoline distribution (amount of gasoline sold) | TJ | 128'941 | 124'386 | 118'717 | 113'956 | 105'664 | 102'367 | 99'223 | 97'654 | 96'850 | 85'769 | *-45%* |

### 3.3.3.3. Uncertainties and time-series consistency for 1B2a

Based on expert judgement, a preliminary uncertainty assessment of all sources in source category 1B2a results in medium confidence in the emissions estimate (see Table 1-10).

Time series for 1B2a Oil are all considered consistent.

#### 3.3.3.4. Category-specific QA/QC and verification for 1B2a

The general QA/QC measures are described in chp. 1.2.3 and partly also in chp. 3.2.4.8. No further source-specific activities undertaken for fugitive emissions from oil (1B2a).

#### 3.3.3.5. Category-specific recalculations for 1B2a

The following recalculations were implemented in submission 2022. Major recalculations which contribute significantly to the total differences in emissions of sector 1 Energy between the latest and the previous submissions are presented also in chp. 10.1.2.1.

- 1B2a: NMVOC and therefore also the correlated $CH_4$ emission factors in 1B2aiv are adapted for the year 2018 to reach the total NMVOC emissions as reported in the Swiss Pollutant Release and Transfer Register (PRTR). Data for the latest year is not available in the PRTR early enough for the data collection for the inventory. Therefore, the emissions are recalculated once the PRTR data is available.
- 1B2a: $CH_4$ emission factors for 1B2aiv Refinery leakage were updated for submission 2022 for the years 2018 and 2019.
- 1B2a: Small recalculation in the energy statistics (SFOE 2021) concerning the amount of crude oil imported in the year 2019.

#### 3.3.3.6. Category-specific planned improvements for 1B2a

No category-specific improvements are planned.

### 3.3.4. Source category fugitive emissions from 1B2b – Natural gas

#### 3.3.4.1. Source category description for 1B2b

Emissions from natural gas production (1B2bii) are only occurring for the years of operation of the single production plant in Switzerland from 1985–1994. Other emissions in this source category occur from natural gas transmission (1B2biv) and distribution (1B2bv). Emissions from accidents in the gas pipeline system are reported under source category 1B2bvi Other Leakage.

Table 3-101 Specification of source category fugitive emissions from 1B2b Natural gas in Switzerland.

| 1B2 | Source category | Specification |
|---|---|---|
| 1B2bii | Fugitive emissions attributed to natural gas: Production | Emissions from natural gas production (1990-1994 only). |
| 1B2biv | Fugitive emissions attributed to natural gas: Transmission | Emissions from natural gas transmission. |
| 1B2bv | Fugitive emissions attributed to natural gas: Distribution | Emissions from natural gas distribution. |
| 1B2bvi | Fugitive emissions attributed to natural gas: Other Leakage | Emissions from other leakage (accident events, so far one in 2010 and one in 2011). |

### 3.3.4.2. Methodological issues for 1B2b

**Methodology (1B2b)**

According to the decision tree for natural gas systems (IPCC 2006, Volume 2 Energy, chp. 4 Fugitive Emissions, Figure 4.2.1), Switzerland follows a Tier 1 approach for fugitive emissions concerning 1B2bii Production and a Tier 2 approach for fugitive emissions attributed to 1B2biv Transmission and storage as well as 1B2bv Distribution.

Emissions from source category 1B2 are key (see Table 3-97). However, the contribution from 1B2bii is small and therefore the use of a Tier 1 method for this source category is justified. The emissions from source category 1B2bii are calculated based on annual production data and default emission factors (IPCC Tier 1 approach). Production data under 1B2bii occur for the years 1990–1994 only because the single production site was closed in 1994.

For emission calculations from source category 1B2biv, 1B2bv and 1B2bvi, country-specific emission factors and activity data are available. Emissions are calculated with a country-specific method which first assesses the losses of natural gas in the gas network including pipelines, fittings and gas devices, as these data represent the activity data. Based on the gas losses, $CO_2$, $CH_4$ and NMVOC emissions are calculated with country-specific emission factors which reflect the composition of the gas lost.

Emissions from gas transmission (source category 1B2biv) include emissions from transport pipelines including the transit pipeline and the single compressor station. Emissions comprise leakages from gas pipelines, small-scale damages, maintenance work and leakages of pipeline fittings. Gas storages are considered as components of the distribution network and the respective emissions are included in source category 1B2bv.

Source category 1B2bv Distribution covers emissions from the gas distribution pipelines and network components (e.g. control units, fittings and gas meters) as well as fugitive emissions at the end users. Emission calculations for the gas distribution network are based on the length, material and pressure of the gas pipelines. Fugitive emissions at the end users arise from on-site and indoor pipelines and the permanent leakiness of the different gas appliances in households, industry and natural gas fuelling stations. In the calculations, the number and kind of end users and connected gas appliances are considered.

Indirect $CO_2$ emissions resulting from $CH_4$ and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9. As no CO emissions occur in source category 1B2b, from this source category no indirect $CO_2$ emissions from CO are included in CRF Table6 as documented in chp. 9.

**Emission factors (1B2b)**

For natural gas production, $CO_2$, $CH_4$ and NMVOC default emission factors are taken from the 2006 IPCC Guidelines (IPCC 2006) as documented in the internal emission database documentation (EMIS 2022/1B2b Diffuse Emissionen Erdgas).

Emission factors for transmission, distribution and other leakages (source categories 1B2biv, 1B2bv, and 1B2bvi) are calculated based on the weighted average $CO_2$, $CH_4$, and NMVOC concentrations and net calorific values of natural gas as annually reported by the Swiss Gas and Water Industry Association (SGWA) for the different import stations (see Quantis 2014 and EMIS 2022/1B2b Diffuse Emissionen Erdgas).

Table 3-102 Emission factors for fugitive emissions of source category 1B2b Natural gas in 2020.

| 1B2b Natural gas | Unit | $CO_2$ | $CH_4$ | $N_2O$ | $NO_x$ | NMVOC | $SO_2$ | CO |
|---|---|---|---|---|---|---|---|---|
| 1B2bii Production | g/GJ | NO | NO | NO | NO | NO | NO | NO |
| 1B2biv Transmission | g/GJ | 559 | 17'931 | NA | NA | 1'399 | NA | NA |
| 1B2bv Distribution | g/GJ | 559 | 17'931 | NA | NA | 1'399 | NA | NA |
| 1B2bvi Other Leakage | g/GJ | NO | NO | NO | NO | NO | NO | NO |

**Activity data (1B2b)**

Activity data for fugitive emissions from gas production (1B2bii) are the actual gas production data for the years 1990–1994 (SFOE 2021).

For gas transmission (1B2biv), distribution (1B2bv), and other leakage (1B2bvi), the activity data have been reassessed in a study by Quantis (2014) and the corresponding calculation model is updated regularly. The activity data represent the amount of natural gas lost from the gas network and are shown in Table 3-103.

For source categories 1B2biv and 1B2bv, information regarding the gas transport and distribution network from the Swiss Gas and Water Industry Association (SGWA) is used to derive the activity data (see Quantis 2014 and EMIS 2022/1B2b Diffuse Emissionen Erdgas).

For transmission pipelines a constant emission factor per pipeline length is applied accounting for losses from purging and cleaning flows, pipeline damages and leaky fittings and mountings. For the one compressor station a constant emission rate based on the physical power of the turbines is employed including emissions due to shutting down and starting of the gas turbines, leakages at regulating valves and fittings, maintenance and gasometry work.

The calculation of losses from source category 1B2bv Distribution follows a detailed country-specific approach that considers losses from the pipeline network as well as losses at the end users.

The calculated gas losses from the pipeline network depend on the length, material and pressure of the pipelines. Gas losses due to permanent leakiness, small-scale damages, network maintenance and the network components are evaluated separately. As no applicable loss rates are available for the network compounds in Switzerland (installed control units, fittings, storage systems and gas meters), a fixed percentage is applied to the permanent gas losses.

Regarding the end users, gas losses from on-site and indoor pipelines as well as gas losses due to the permanent leakiness of gas appliances are evaluated. Pipeline loss rates apply to the number of households, industrial users and gas fuelling stations separately. Regarding the gas appliances, different loss rates are assigned to the number of gas heating systems, gas cooking stoves and gas fuelling stations.

For some (earlier) years in the time series, sufficient input data are not available to calculate the gas losses. For these years, polynomial interpolations are applied to assess the activity data.

For significant emission events due to accidents the Swiss Pollutant Release and Transfer Register is considered, and emissions are attributed to source category 1B2bvi Other Leakage. So far, two events have been reported by the transit pipeline operator, one in 2010 and one in 2011.

Fugitive emissions from pipelines are the major emission source in source category 1B2b. Fugitive emissions from damages and ruptures of the pipelines, maintenance of the pipelines and the components are very small (Quantis 2014). Total $CH_4$ emissions from gas transmission and distribution decreased due to gradual replacement of cast-iron pipes with polyethylene pipes.

Table 3-103 Activity data (amount of gas lost) for fugitive emissions from 1B2b Natural gas.

| 1B2b Natural Gas | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| 1B2bii Production | GJ | 130'000 | NO | NO | NO | NO |
| 1B2biv Transmission | GJ | 28'226 | 30'874 | 32'571 | 33'491 | 34'595 |
| 1B2bv Distribution | GJ | 710'246 | 817'028 | 655'267 | 512'036 | 449'418 |
| 1B2bvi Other Leakage | GJ | NO | NO | NO | NO | 35'444 |

| 1B2b Natural Gas | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 1990 vs. 2020 (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1B2bii Production | GJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | - |
| 1B2biv Transmission | GJ | 34'569 | 34'483 | 34'852 | 35'125 | 35'468 | 35'743 | 35'884 | 35'809 | 36'096 | 36'079 | 28% |
| 1B2bv Distribution | GJ | 441'857 | 435'545 | 399'993 | 389'310 | 388'251 | 390'185 | 383'203 | 377'827 | 376'672 | 376'495 | -47% |
| 1B2bvi Other Leakage | GJ | 28'114 | NO | NO | NO | NO | NO | NO | NO | NO | NO | - |

### 3.3.4.3. Uncertainties and time-series consistency for 1B2b

According to the assessment by Quantis (2014), an uncertainty of 30% is estimated for fugitive $CH_4$ emissions from natural gas pipelines in Switzerland.

A preliminary uncertainty assessment of all other sources in source category 1B2 based on expert judgement results in medium confidence in the emissions estimate (see Table 1-10).

Time series for 1B2b Natural gas are all considered consistent.

### 3.3.4.4. Category-specific QA/QC and verification for 1B2b

The general QA/QC measures are described in chp. 1.2.3.

As suggested by the 2006 IPCC Guidelines (IPCC 2006) the gas industry was involved in the reassessment of fugitive emissions from the natural gas system in 2014 (Quantis 2014) and 2016 (EMIS 2022/1B2b Diffuse Emissionen Erdgas).

#### 3.3.4.5. Category-specific recalculations for 1B2b

The following recalculations were implemented in submission 2022. Major recalculations which contribute significantly to the total differences in emissions of sector 1 Energy between the latest and the previous submissions are presented also in chp. 10.1.2.1.

- 1B2b: Small recalculation of natural gas consumption for the year 2019 leads also to recalculation of natural gas losses in 2019.

#### 3.3.4.6. Category-specific planned improvements for 1B2b

No category-specific improvements are planned.

### 3.3.5. Source category 1B2c – Venting and flaring

#### 3.3.5.1. Source category description for 1B2c

In Switzerland, oil production is not occurring, and only one production site for natural gas production was operational from 1985–1994. Therefore, emissions from flaring result primarily from the torches, which were operational at the two refineries (1B2ci Flaring). Since 2015, there is only one refinery in operation. In addition, $CO_2$ emissions from $H_2$ production in one of the two refineries are also reported under 1B2c.

Table 3-104 Specification of source category 1B2c Venting and flaring in Switzerland.

| 1B2 | Source category | Specification |
|---|---|---|
| 1B2ci | Fugitive emissions attributed to venting and flaring: Flaring oil | The combustion of excess gas at the oil refinery (flaring) only. |
| 1B2ci | Fugitive emissions attributed to venting and flaring: $H_2$ production | Emissions from $H_2$ production (butane and natural gas). |
| 1B2cii | Fugitive emissions attributed to venting and flaring: Flaring gas | Emissions from gas production (1990-1994 only). |

#### 3.3.5.2. Methodological issues for 1B2c

**Methodology (1B2c)**

For source category 1B2ci Flaring, Oil, emissions of $CO_2$ as well as $CH_4$, $N_2O$, $NO_x$, CO and NMVOC are considered. According to the decision tree for crude oil transport, refining and upgrading, Switzerland follows a Tier 3 method for $CO_2$ emissions and a Tier 2 method for all further pollutants attributed to 1B2ci Flaring, Oil in order to estimate fugitive emissions under 1B2c fugitive emissions from venting and flaring (IPCC 2006, Volume 2 Energy, chp. 4 Fugitive Emissions, Figure 4.2.3). For $CO_2$ emission calculations, country-specific $CO_2$ emission factors and activity data are available from the refining industry.

Emissions from gas production are calculated by a Tier 1 method according to 1B2c fugitive emissions from venting and flaring according to the decision tree for natural gas systems (IPCC 2006, Volume 2 Energy, chp. 4 Fugitive Emissions, Figure 4.2.1). For source category 1B2cii Flaring, Gas, emissions of $CO_2$ as well as $CH_4$, $N_2O$ and NMVOC are considered.

One of the refining plants produces $H_2$. Until 2017, butane was used for the production of $H_2$, leading to process emissions of $CO_2$. During 2017, additionally to butane, the refinery started to use natural gas in its hydrogen production unit. Emissions are estimated based on plant-specific data (Tier 3 method).

Since the $CO_2$ emission factors assume an oxidation of 100%, no indirect emissions need to be accounted for. Therefore, no indirect emissions from this source category are included in CRF Table6 as documented in chp. 9.

**Emission factors (1B2c)**

Emission factors concerning flaring of refinery gas during the refining process are documented in the internal emission database documentation (EMIS 2022/1B2c Raffinerie Abfackelung). The emission factor for $CO_2$ is based on a study from Frischknecht et al. (1996), the emission factor for $N_2O$ is based on the expert estimate in the German NIR 2019 (UBA 2019), and those for the other greenhouse gases and precursors base on a study from USEPA (1995b) and data from the refining industry.

Since 2005 (with the exception of 2012), the refining industry provides annual data on the $CO_2$ emissions from flaring under the Federal Act on the Reduction of $CO_2$ Emissions (Swiss Confederation 2011) based on daily measurements of $CO_2$ emission factors of the flared gases. From these data, annual emission factors are derived. Since 2005, the evolution of the other emission factors ($CH_4$, $N_2O$, $NO_x$, CO and NMVOC) is assumed to vary proportionally to the $CO_2$ emission factor. Emission factors are considered confidential and are available to reviewers on request.

The emissions from flaring in the gas production facility are calculated based on default emission factors provided in the 2006 IPCC Guidelines.

$CO_2$ emission factors for $H_2$ production are confidential. Data are available to reviewers on request.

Table 3-105 Emission factors for 1B2c Venting and flaring in 2020.

| Source/fuel | Unit | $CO_2$ | $CH_4$ | $N_2O$ | $NO_x$ | NMVOC | $SO_2$ | CO |
|---|---|---|---|---|---|---|---|---|
| 1B2ci Flaring Oil | g/t | C | C | C | C | C | C | C |
| 1B2ci H2 production refinery (butane) | g/GJ | NO | NA | NA | NA | NA | NA | NA |
| 1B2ci H2 production refinery (natural gas) | g/GJ | C | NA | NA | NA | NA | NA | NA |
| 1B2cii Flaring gas: per amount of natural gas produced | g/GJ | NO | NO | NO | NA | NO | NA | NA |

**Activity data (1B2c)**

Before 2005, the amount of flared gas during the refining process is assumed to be proportional to the amount of crude oil processed in the refineries. Avenergy Suisse (formerly the Swiss petroleum association EV) provides data on the use of crude oil on an annual basis (Avenergy 2021). Between 2001 and 2004, one of the two refineries made major changes to their installations (new cracker, new flaring installation) and their standard operation process. Therefore, emissions from flaring decreased significantly thereafter. Since 2005, the industry provides data on the amount of gas flared.

For gas production, the amount flared is estimated based on the amount of gas produced.

For $H_2$ production in one of the refining plants, annual data on butane and natural gas consumption are provided by the industry since 2005, when the $H_2$ production unit was installed. Data are confidential and they are available to reviewers on request.

Table 3-106 Activity data for 1B2c Venting/flaring.

| 1B2c Venting and flaring | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| 1B2ci Flaring Oil | kt | C | C | C | C | C |
| 1B2ci: H2 production in refinery (butane and natural gas) | GJ | NO | NO | NO | C | C |
| 1B2cii Flaring Gas: Amount of natural gas produced | GJ | NO | NO | NO | NO | NO |

| 1B2c Venting and flaring | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1B2ci Flaring Oil | kt | C | C | C | C | C | C | C | C | C | C |
| 1B2ci: H2 production in refinery (butane and natural gas) | GJ | C | C | C | C | C | C | C | C | C | C |
| 1B2cii Flaring Gas: Amount of natural gas produced | GJ | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |

### 3.3.5.3. Uncertainties and time-series consistency for 1B2c

A preliminary uncertainty assessment of all sources in source category 1B2 based on expert judgement results in medium confidence in the emissions estimate (see Table 1-10).

Consistency: Time series for 1B2c Venting and flaring are all considered consistent.

### 3.3.5.4. Category-specific QA/QC and verification for 1B2c

The general QA/QC measures are described in chp. 1.2.3. No category-specific QA/QC activities were undertaken.

### 3.3.5.5. Category-specific recalculations for 1B2c

- 1B2c (IPCC code: 1B2biii2), gas production, flaring: For $CH_4$, the emission factor was corrected and is from IPCC 2006 (vol. 2, chp. 4.2.2.3, Table 4.2.4 (Tier 1 method). This affects emissions from 1985 to 1994.
- 1B2c: The $CH_4$ emission factor for flaring gas in the refinery was corrected due to an error in the calculations using the conversion factor from g/L to g/t crude oil.

### 3.3.5.6. Category-specific planned improvements for 1B2c

No category-specific improvements are planned.

## 3.4. Source category 1C – $CO_2$ transport and storage

$CO_2$ transport and storage is not occurring in Switzerland.

# 4. Industrial processes and product use (IPPU)

| Responsibilities for sector Industrial processes and product use (IPPU) | |
|---|---|
| Overall responsibility | Sabine Schenker (FOEN) |
| Method updates & authors | Sabine Schenker (FOEN), Cornelia Stettler (Carbotech; F-gases) |
| EMIS database operation | Anouk-Aimée Bass (FOEN; F-gases), Sabine Schenker (FOEN) |
| Annual updates (NIR text, tables, figures) | Dominik Eggli (Meteotest), Pascal Graf (Meteotest), Beat Rihm (Meteotest), Cornelia Stettler (Carbotech; F-gases) |
| Quality control (NIR annual updates) | Gavin Roberts (Carbotech; F-gases), Regine Röthlisberger (FOEN), Adrian Schilt (FOEN), Felix Weber (INFRAS) |
| Internal review | Flavio Malaguerra (FOEN, SF6), Stefan Reimann (EMPA; F-gases), Regine Röthlisberger (FOEN), Sabine Schenker (FOEN), Adrian Schilt (FOEN; F-gases) |

## 4.1. Overview

This chapter provides information on the estimation of the GHG emissions from sector 2 Industrial processes and product use. The following source categories are reported:

- 2A Mineral industry
- 2B Chemical industry
- 2C Metal industry
- 2D Non-energy products from fuels and solvent use
- 2E Electronics industry
- 2F Product uses as substitutes for ozone-depleting substances (ODS)
- 2G Other product manufacture and use
- 2H Other

Emissions within this sector comprise GHG emissions as by-products from industrial processes and also emissions of F-gases during production, use and disposal. Emissions from fuel combustion in industry are reported in source category 1A2 under sector 1 Energy.

According to the 2006 IPCC Guidelines this sector provides also information on the GHG emissions from solvent and product use. $CO_2$ emissions from solvent and partly from product use are due to post-combustion of NMVOC in order to reduce NMVOC in exhaust gases. The disposal of solvents is reported in the waste energy sector (waste derived fuels, chp. 3.2.6).

Indirect $CO_2$ emissions resulting from fossil $CH_4$, CO and NMVOC emissions as well as indirect $N_2O$ emissions resulting from $NO_x$ and $NH_3$ emissions are included in CRF Table6 as documented in chp. 9. Since the $CO_2$ emissions from the cracker reported in source category 2B8b Ethylene, from 2C1 Secondary steel production, electric arc furnace and from 2C3 Primary aluminium production are based on carbon mass balances, their emissions of CO (from source categories 2C1 and 2C3) and NMVOC (from source categories 2B8b and 2C1) are not accounted for in the calculation of the indirect $CO_2$ emissions. Biogenic CO and

NMVOC emissions occur in source category 2H2 Food and beverages and 2G4 tobacco consumption and are not reported as indirect $CO_2$ emissions.

For several industrial processes within source categories 2A Mineral industry, 2B Chemical industry and 2C Metal industry, data and information on emission factors and activity data are classified as confidential (C), because they refer to a single enterprise. For reviewers, there is an additional version of chapter 4 Industrial processes and product use (IPPU) available, including all confidential data and information.

Figure 4-1 shows the evolution of greenhouse gas emissions in sector 2 between 1990 and 2020.

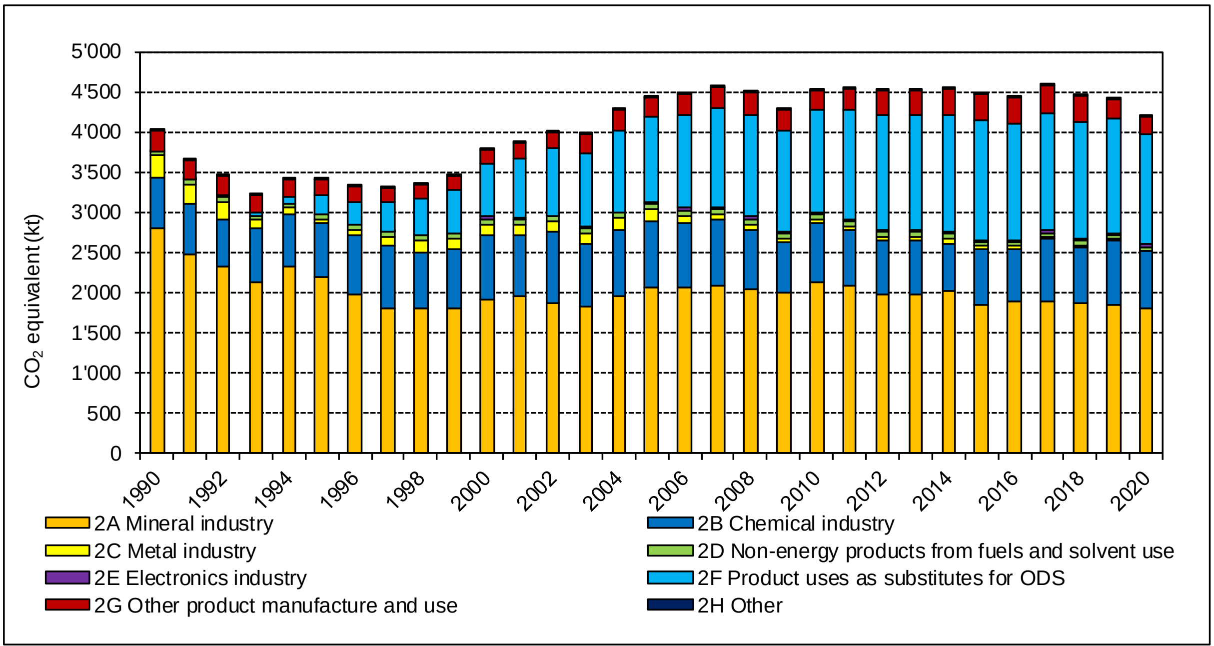


Figure 4-1 Switzerland's greenhouse gas emissions of sector 2 Industrial processes and product use.

2A Mineral industry remains the dominant source of sector 2, accounting for around 40% of the GHG emissions in 2020 although absolute emissions have decreased since 1990. 2B Chemical industry accounts for a share of around 20% and shows no clear trend since 1990. 2C Metal industry shows a strong decreasing trend and accounts only for a negligibly small share in 2020. 2D Non-energy products have also only a minor contribution in 2020.

2F Product uses as substitutes for ozone depleting substances (ODSs) is of considerable importance: The emissions have increased from 1990 to 2015 due to the replacement of CFCs and other ODSs by HFCs in many technical applications. However, the emissions are gradually decreasing over the past years due to restrictions of HFC use in mobile air-conditioning and stationary refrigeration. They account for almost one third of total GHG emissions in sector 2 in 2020. 2G Other product manufacture and use shows, after an increase between 2000 and 2017, a decrease in emissions since then. 2E Electronic industry and 2H Other are of little importance with regard to the overall GHG emissions of sector 2.

In Table 4-1, the development of GHG emissions in sector 2 Industrial processes and product use is given by gases. Dominant gases are $CO_2$, F-gases and $N_2O$ in 2020 whereas $CH_4$ has only a minor contribution. The relative trend of these gases referring to the base year 1990 is shown in Figure 4-2 and Figure 4-3.

Table 4-1 GHG emissions of sector 2 Industrial processes and product use by gases in $CO_2$ equivalent (kt).

| Gas | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | |
| $CO_2$ | 3'153 | 2'420 | 2'208 | 2'372 | 2'369 |
| $CH_4$ | 3.6 | 5.9 | 5.2 | 6.3 | 6.9 |
| $N_2O$ | 602 | 641 | 719 | 743 | 634 |
| F-gases | 254 | 354 | 849 | 1'311 | 1'520 |
| Sum | 4'012 | 3'421 | 3'781 | 4'432 | 4'530 |

| Gas | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | | | | | | |
| $CO_2$ | 2'324 | 2'201 | 2'203 | 2'256 | 2'087 | 2'152 | 2'128 | 2'114 | 2'099 | 2'026 |
| $CH_4$ | 6.6 | 6.8 | 5.3 | 5.7 | 5.6 | 7.0 | 7.1 | 7.5 | 6.9 | 6.4 |
| $N_2O$ | 609 | 588 | 580 | 493 | 574 | 528 | 681 | 588 | 686 | 605 |
| F-gases | 1'594 | 1'722 | 1'736 | 1'777 | 1'812 | 1'737 | 1'770 | 1'745 | 1'614 | 1'560 |
| Sum | 4'533 | 4'517 | 4'524 | 4'533 | 4'479 | 4'423 | 4'586 | 4'454 | 4'406 | 4'198 |

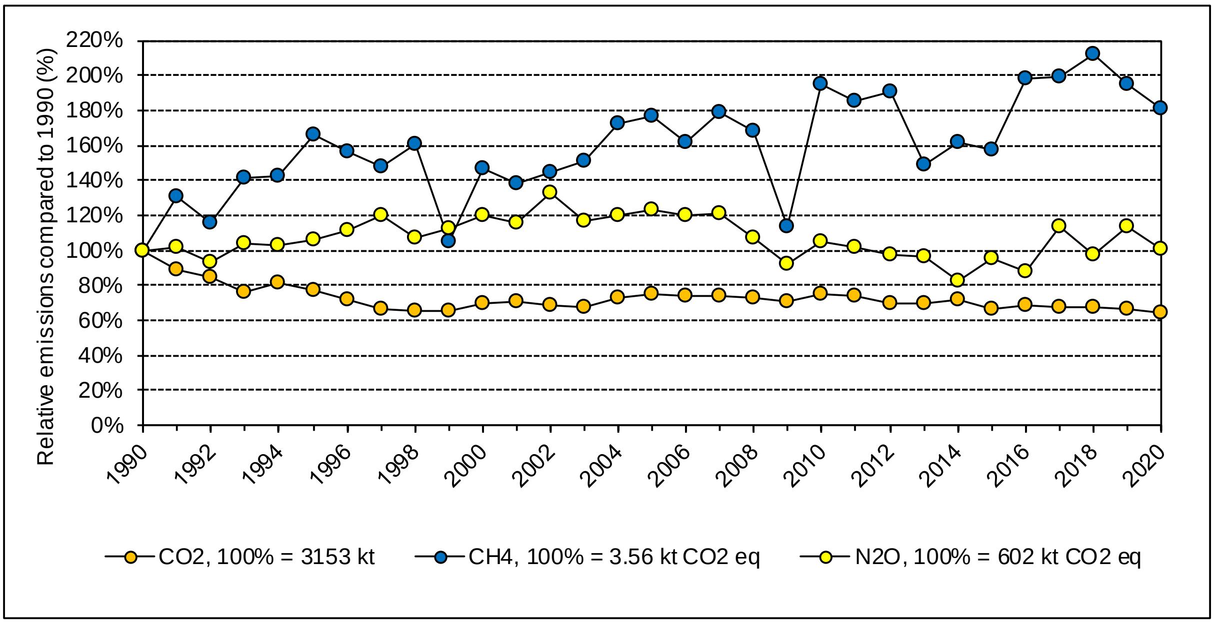


Figure 4-2 Relative trends of the greenhouse gas emissions (without F-gases, see Figure 4-3) of sector 2 Industrial processes and product use. The base year 1990 represents 100%.

Figure 4-2 shows that the emissions of $CO_2$ decreased between 1990 and 1998 and since then, they have remained at a constant level. Emissions of $N_2O$ from sector 2 Industrial processes and product use have increased slowly between 1990 and 2002 and decreased afterwards until 2014. However, since 2014 there has been an increasing trend again with even higher emissions in 2017, 2019 and 2020 than in 1990. Emissions of $CH_4$ have an increasing trend with considerable interannual fluctuations. However, absolute emissions are very small compared to $CO_2$ and $N_2O$.

Figure 4-3 shows a large increase in emissions of F-gases compared to the year 1990. Main contributions in the inventory 1990 result from the PFC emissions in the smeltering process of aluminium production (chp. 4.4.2.2) and from the use of $SF_6$ in electrical equipment and sound proof windows (chp. 4.8.2.1 and chp. 4.8.2.2). The increase between 1995 and 2012 is due to the increasing product uses of HFCs as substitutes for ODS (chp. 4.7) in refrigeration and air conditioning. Since 2012, total F-gas emissions have remained at a constant level with a visible drop after 2018. Most relevant and main source of F-gases emissions in 2020 is the use of HFC in refrigeration and air conditioning.

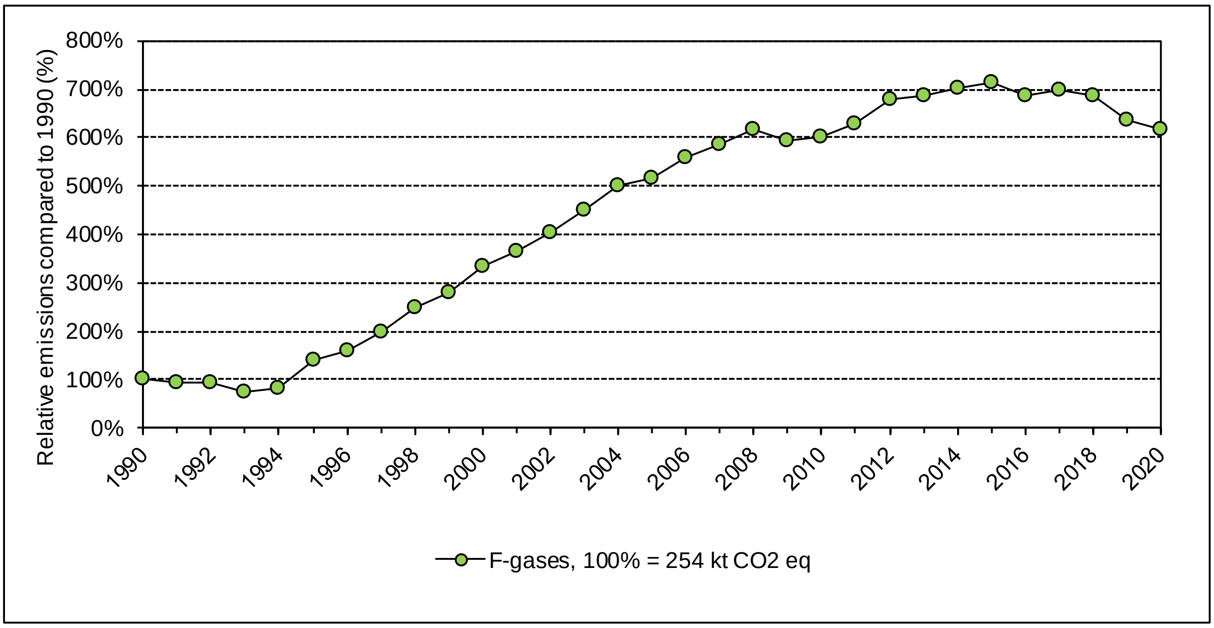


Figure 4-3 Relative trends in emissions of F-gases in sector 2 Industrial processes and product use. The base year 1990 represents 100%.

There are a total of seven key categories identified in sector 2 IPPU, five categories with direct greenhouse gas emissions and two categories with indirect $CO_2$ emissions (see Figure 4-4).

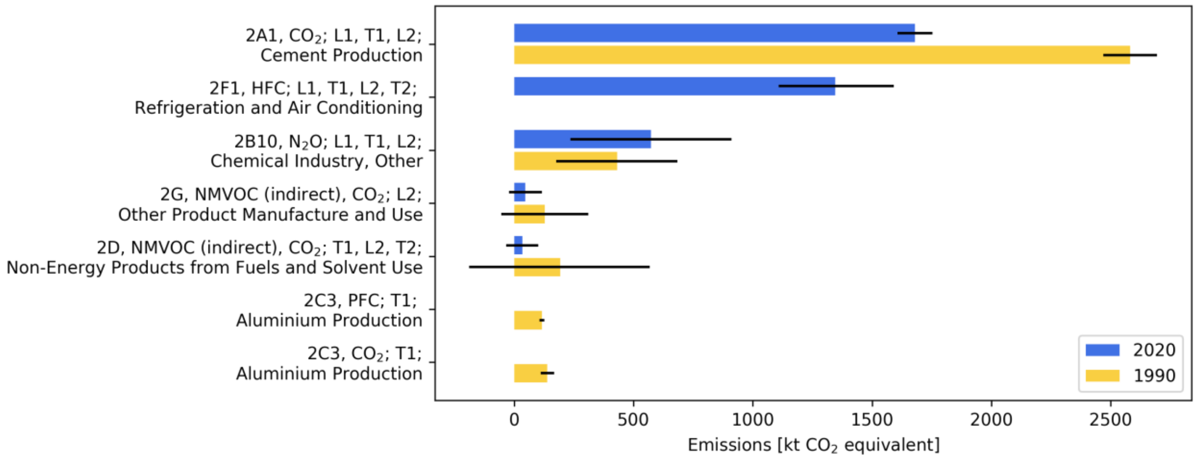


Figure 4-4 Key categories in the Swiss GHG inventory from sector 2 IPPU, including indirect $CO_2$ emissions, determined by the key category analyses, approaches 1 and 2. Categories are set out in order of decreasing emissions in 2020. L1: key category according to approach 1 level in 2020; L2: same for approach 2; T1: key category according to approach 1 trend 1990–2020; T2: same for approach 2. Black uncertainty bars represent the narrowest 95% confidence interval obtained by Monte Carlo simulations (see chp. 1.6 for details).

## 4.2. Source category 2A – Mineral industry

### 4.2.1. Source category description

Table 4-2 Key categories of 2A Mineral industries. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 2A1 | Cement Production | CO2 | L1, T1, L2 |

Table 4-3 Specification of source category 2A Mineral industry.

| 2A | Source category | Specification |
|---|---|---|
| 2A1 | Cement production | Geogenic $CO_2$ emissions from calcination process in cement production;<br>Emissions of $CO_2$, NOx, CO, NMVOC and $SO_2$ from blasting operations |
| 2A2 | Lime production | Geogenic $CO_2$ emissions from calcination process in lime production;<br>Emissions of $CO_2$, NOx, CO, NMVOC and $SO_2$ from blasting operations |
| 2A3 | Glass production | Geogenic $CO_2$ emissions from production of container and tableware glass, and glass wool |
| 2A4 | Other process uses of carbonates | Geogenic $CO_2$ emissions from production of fine ceramics, bricks and tiles and rockwool;<br>Geogenic $CO_2$ emissions from use of carbonates for sulphur oxide removal in municipal solid waste incineration plants and cellulose production (ceased in 2008);<br>Geogenic $CO_2$ emissions from use of sodium bicarbonate;<br>Emissions of $CO_2$, NOx, CO, NMVOC and $SO_2$ from blasting operations in plaster production |

## 4.2.2. Methodological issues

### 4.2.2.1. Cement production (2A1)

In Switzerland, there are six plants producing clinker and cement. The Swiss plants are rather small and do not exceed a capacity of 3'000 tonnes of clinker per day. All of them use modern dry process technology.

Emissions of geogenic $CO_2$ occur during the production of clinker, which is an intermediate component in the cement manufacturing process. During the production of clinker, limestone, which is mainly calcium carbonate ($CaCO_3$), is heated (calcined) to produce lime (CaO) and $CO_2$ as by-product. The CaO reacts subsequently with minerals in the raw materials and yields clinker. During this reaction step no further $CO_2$ is emitted. Clinker is then mixed with other components such as gypsum to make cement.

Blasting operations in the limestone quarries are another source of emissions for both $CO_2$ and precursor greenhouse gases such as $NO_x$, CO, NMVOC and $SO_2$.

Indirect $CO_2$ emissions resulting from CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

## Methodology

*Calcination process*

The geogenic $CO_2$ emissions from the calcination process in cement production are determined by a Tier 2 method according to the decision tree Fig. 2.1. of 2006 IPCC Guidelines (IPCC 2006, vol. 3, chp. 2.1 Cement production).

In Switzerland, no long wet or long dry kilns are used. Only modern preheater or precalciner kilns are used and also no so-called low-alkali cement is produced. Therefore, there is no land-filling of calcined cement dust (cement kiln dust, CKD) in Switzerland. In the cement plants all the filter dust is collected in high performance electrostatic precipitator or bag filters (having an efficiency of more than 99.999%) and being recycled to the kiln feed. In some cases, small portions of the CKD are added directly to the cement as filler. Due to the kiln technology used in Switzerland the degree of decarbonization of the CKD is almost equal to that of the kiln feed, meaning, that this CKD has not been decarbonised yet.

*Blasting operations*

Emissions resulting from blasting operations during the digging of limestone are calculated by a Tier 2 method according to the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2A1, Fig. 3.1) using country-specific emission factors. The $CO_2$ emissions from "blasting" are related only to the usage of explosives in the quarries and not to the fuel consumption of construction machinery such as bulldozers etc.

The $CO_2$ emission factor for the use of blasting agents amounts to 600 kg $CO_2$/t of blasting agent (EMIS 2022/2A1 Zementwerke übriger Betrieb).The amount of used explosives is reported to be 0.13 kg/t cement on average, based on measurement data of four Swiss cement plants in 2002. Since these covered more than 60% of the production, the value is considered representative for cement plants in Switzerland.

Total emissions reported for the production of cement are the sum of emissions from calcination process and blasting operations. The share of $CO_2$ emissions from blasting operations in limestone quarries is well below one tenth of a percent of the geogenic $CO_2$ emissions from the calcination process.

## Emission factors

*Calcination process*

The emission factor of $CO_2$ from calcination is provided per tonne of clinker. It accounts for geogenic emissions from the carbonate containing raw material, emissions from organic carbon content of the raw material and from cement kiln dust (CKD).

The base emission factor of 525 kg $CO_2$/t clinker used in the Swiss ETS corresponds to the value provided by the Cement Sustainability Initiative (CSI) in its report “$CO_2$ and Energy Accounting and Reporting Standard for the Cement Industry – The Cement $CO_2$ and Energy Protocol” (see method B1, p. 9 in CSI 2011). Data from the Swiss cement industry for the years 2008–2011 showed that CaO contents in clinker typically varied between 63% and 66%, while MgO contents were around 2%. This resulted in an emission factor that varied from 529 to 532 kg $CO_2$/t clinker for those years (weighted average from the values of the six cement plants). However, these contents already contained fractions deriving from non-carbonate sources. Therefore, it was decided in the ETS to define the base EF as described in the CSI Protocol and then add a share for non-carbonate C and CKD. In submission 2017, the EF was revised in order to establish a consistent time series from 1990 to 2015 and also to achieve consistency between the Swiss ETS and the greenhouse gas inventory (CSI 2011).

The emissions from the organic carbon content of the raw material are assumed to be a constant share of 0.2% of the raw material (i.e. 11.37 kg $CO_2$/t clinker). The emission factor of CKD is estimated based on plant-specific data available for 2013–2016 that were provided by the cement industry association (cemsuisse). From this data, an average emission factor of $CO_2$ from CKD is calculated (0.35 kg $CO_2$/t clinker). As the CKD represents only an insignificant proportion of the total EF, no annual update is provided.

Based on these three partial emission factors (base, non-carbonate C and CKD) a total emission factor per ton of clinker is calculated. This results in a country-specific emission factor of 536.7 kg $CO_2$/t clinker. It is assumed constant for the entire time period. Given that the cement plants have not changed the source of their raw material, it is justified to assume a constant emission factor over the entire time period.

Table 4-4 $CO_2$ emission factor for calcination in 2A1 Cement Production 1990 to 2020.

| **2A1 Cement production** | **Unit** | **1990–2020** |
|---|---|---|
| Calcination, $CO_2$ | kg/t clinker | 537 |

*Blasting operations*

The emission factors are country-specific based on emission factors of civil explosives and information on the specific consumption of explosives in the quarries as documented in the Handbook on emission factors for stationary sources (SAEFL 2000) as documented in the EMIS database (EMIS 2022/2A1 Zementwerke übriger Betrieb). They are assumed to be constant over the entire time period and are given per tonne of clinker.

Table 4-5 Emission factors for $CO_2$, $NO_x$, CO, NMVOC and $SO_2$ from blasting operations in g/t clinker from source category 2A1 Cement Production in 2020.

| **2A1 Cement production** | **Unit** | **$CO_2$** | **$NO_X$** | **CO** | **NMVOC** | **$SO_2$** |
|---|---|---|---|---|---|---|
| Blasting operations | g/t clinker | 34 | 3.3 | 3.3 | 8.6 | 0.14 |

**Activity data**

Since 1990, data on annual clinker production are provided by the industry association cemsuisse as documented in the EMIS database (EMIS 2022/2A1_Zementwerke Rohmaterial). From 2008 onwards they are based on plant-specific annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).

Table 4-6 Activity data of clinker production.

| 2A1 Cement production | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Clinker production | kt | 4'808 | 3'706 | 3'214 | 3'442 | 3'642 |

| 2A1 Cement production | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Clinker production | kt | 3'587 | 3'368 | 3'415 | 3'502 | 3'195 | 3'296 | 3'279 | 3'239 | 3'227 | 3'129 |

#### 4.2.2.2. Lime production (2A2)

During the production of lime, calcium carbonate ($CaCO_3$) is heated (calcined) yielding burnt lime (CaO) and $CO_2$ as by-product. In Switzerland, there is only one plant producing lime.

There is no industry in Switzerland producing lime for its own requirements, except for sugar production. A request to both sugar producing plants confirmed that indeed they produce lime from limestone in own shaft kilns. However, the $CO_2$ is re-captured in the sugar production process and thus no $CO_2$ emissions occur.

Blasting operations in quarries are another source of emissions for both $CO_2$ and precursor emissions such as $NO_x$, CO, NMVOC and $SO_2$.

Indirect $CO_2$ emissions resulting from CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

**Methodology**

*Calcination process*

Since 2013, the geogenic $CO_2$ emissions from the calcination process in lime production are determined by a Tier 3 method using plant-specific emission factors according to the decision tree Fig. 2.2. of the IPCC Guidelines (IPCC 2006, vol. 3, chp. 2.2 Lime production). Between 1990 and 2012, a Tier 2 method is applied.

*Blasting operations*

Emissions resulting from blasting operations during the digging of limestone are calculated by a Tier 2 method according to the EMEP/EEA Guidebook (EMEP/EEA 2019, chp. 2A2, Fig. 3.1) using country-specific emission factors. The $CO_2$ emissions from "blasting" are related only to the usage of explosives in the quarries and not to fuel consumption of e.g. bulldozers etc.

Total emissions reported for the production of lime are the sum of emissions from calcination process and blasting operations. $CO_2$ emissions from blasting operations in limestone quarries account only for a small share of the total emissions.

**Emission factors**

*Calcination process*

The emission factor for $CO_2$ from calcination of limestone depends both on the purity of the limestone and the degree of calcination (i.e. amount of $CO_2$ remaining in the lime produced).

A plant-specific value has been calculated based on industry declaration and it is assumed to be constant for the years 1990–2012 (EMIS 2022/2A2 Kalkproduktion, Rohmaterial). The value is confidential and is available to reviewers on request. Since 2013, emission factors are derived from annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).

Table 4-7 $CO_2$ emission factor for calcination process in lime production in kg/t lime for 1990–2020 are documented in the confidential NIR, which is available to reviewers on request.

*Blasting operations*

The emission factors are country-specific as documented in EMIS 2022/2A2 Kalkproduktion, übriger Betrieb. The values are confidential and they are available to reviewers on request.

Table 4-8 $CO_2$ emission factor for the calcination process in lime production in kg/t lime and emission factors for $CO_2$, $NO_X$, CO, NMVOC and $SO_2$ from blasting operations in g/t lime in 2020.

| 2A2 Lime production | Unit | $CO_2$ | $NO_X$ | CO | NMVOC | $SO_2$ |
|---|---|---|---|---|---|---|
| Calcination | kg/t | C | NA | NA | NA | NA |
| Blasting operations | g/t | C | C | C | C | C |

**Activity data**

Activity data on annual lime production are provided by the only existing plant in Switzerland, as documented in the EMIS database (EMIS 2022/2A2 Kalkproduktion, Rohmaterial and EMIS 2022/2A2 Kalkproduktion übriger Betrieb). Since 2009 they are based on plant-specific annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).

Detailed activity data are not reported since they are considered confidential.

Table 4-9 In the confidential NIR, the respective table with activity data on lime production are separately reported and available to reviewers.

#### 4.2.2.3. Glass production (2A3)

Source category 2A3 Glass production comprises geogenic $CO_2$ emissions from the carbonate containing raw materials, i.e. soda ash, limestone and dolomite. In Switzerland, the following three glass types are produced: container glass, tableware glass and glass wool. Today, there is only one production plant remaining for container glass and tableware glass after the other plants closed in 2002 and 2006, respectively. Glass wool is produced in two plants.

### Methodology

For determination of geogenic $CO_2$ emissions from glass production, a Tier 2 method according to the decision tree Fig. 2.3 of IPCC 2006 (vol. 3, chp. 2.4 Glass production) is used. For glass production in Switzerland this results in the following formula:

$$CO_2 \text{ Emissions} = M_{\text{Glass type}} \bullet EF_{\text{Glass type}} \bullet (1 - \text{cullet ratio})$$

The cullet ratio describes the share of recycled glass material which is used in the production. The melting of cullet causes no geogenic $CO_2$ emissions.

From 2005 onwards, the geogenic $CO_2$ emissions from 2A3 Container glass production is determined according to a Tier 3 method based on the amount of carbonate containing raw materials used, i.e. soda, dolomite and limestone and their effective carbonate content.

### Emission factors

The emission factors for glass production in Switzerland are taken from IPCC 2006 (vol.3, chp. 2.4 Glass production, Table 2.6). For the production of container glass (1990–2004), tableware glass and glass wool the values for glass type container, tableware and fibreglass are taken, respectively. As the emission factors are material properties, they remain constant over time.

From 2005 onwards, effective amounts of carbonate containing raw materials (soda ash, dolomite and limestone) are available from ETS monitoring reports for the container glass production and thus the corresponding default $CO_2$ emission factors are taken from IPCC 2006 (vol. 3, chp. 2.1, Table 2.1). As these emission factors are material properties, they remain constant over time.

Table 4-10 Geogenic $CO_2$ emission factor for glass production in g/t glass and g/t carbonate containing raw material (IPCC 2006).

| **2A3 Glass production** | **Unit** | **$CO_2$ geogenic** | |
|---|---|---|---|
| Glass wool (fibre glass insulation) | g/t | 250'000 | |
| Glass (speciality tableware) | g/t | 100'000 | |
| | | **1990–2004** | **2005–2020** |
| Container glass | g/t | 210'000 | |
| Soda use | g/t soda | | 414'920 |
| Dolomite use | g/t dolomite | | 477'320 |
| Limestone use | g/t limestone | | 439'710 |

Table 4-11 In the confidential NIR, a comparison of implied $CO_2$ emission factors based on Tier 2 and Tier 3 approaches is provided for container glass production in g/t glass for the time period 2005–2011.

Figure 4-5 In the confidential NIR, a comparison of Tier 2 and Tier 3 methods for deriving emission factors of geogenic $CO_2$ from 2A3 Container glass production is provided for the years between 2005 and 2011.

**Activity data and cullet ratios**

Source category 2A3 Glass production is dominated by the emissions from the production of container glass and glass wool.

For glass wool production, activity data are based on data from the two glass wool production plants in Switzerland. Since 2008, activity data are based on plant-specific annual monitoring reports.

Activity data of tableware and container glass production are based on data from Swiss glass producers. For container glass, they are based on ETS monitoring reports from 2005 onward.

Detailed information on activity data for container glass production and tableware production is confidential as there is only one production plant for container glass and tableware glass, respectively. Data are available to the reviewers on request (EMIS 2022/2A3 Hohlglas Produktion, EMIS 2022/2A3 Glas übrige Produktion and EMIS 2022/2A3 Glaswolle Produktion Rohprodukt).

Table 4-12 Activity data of glass production in Switzerland and cullet ratio in % as well as consumption of carbonate containing raw materials in container glass production

| 2A3 Glass production | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Container glass | | | | | | |
| Production | kt | C | C | C | C | C |
| Cullet ratio | % | C | C | C | NA | NA |
| Soda use | kt | NA | NA | NA | C | C |
| Dolomite use | kt | NA | NA | NA | C | C |
| Limestone use | kt | NA | NA | NA | C | C |
| Glass (speciality tableware) | | | | | | |
| Production | kt | C | C | C | C | C |
| Cullet ratio | % | C | C | C | C | C |
| Glass wool | | | | | | |
| Production | kt | 24 | 24 | 31 | 37 | 36 |
| Cullet ratio | % | 21 | 45 | 69 | 65 | 71 |

| 2A3 Glass production | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Container glass | | | | | | | | | | | |
| Production | kt | C | C | C | C | C | C | C | C | C | C |
| Cullet ratio | % | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Soda use | kt | C | C | C | C | C | C | C | C | C | C |
| Dolomite use | kt | C | C | C | C | C | C | C | C | C | C |
| Limestone use | kt | C | C | C | C | C | C | C | C | C | C |
| Glass (speciality tableware) | | | | | | | | | | | |
| Production | kt | C | C | C | C | C | C | C | C | C | C |
| Cullet ratio | % | C | C | C | C | C | C | C | C | C | C |
| Glass wool | | | | | | | | | | | |
| Production | kt | 41 | 39 | 33 | 32 | 31 | 32 | 36 | 40 | 47 | 40 |
| Cullet ratio | % | 72 | 61 | 67 | 67 | 67 | 67 | 69 | 70 | 71 | 71 |

### 4.2.2.4. Other process uses of carbonates (2A4)

Source category 2A4 Other process uses of carbonates comprises geogenic $CO_2$ emissions from production of fine ceramics (2A4a), bricks and tiles (2A4a) and rock wool (2A4d), from use of carbonates for sulphur oxide removal in municipal solid waste incineration plants (2A4d) and cellulose production (ceased in 2008) (2A4d), and from use of sodium bicarbonate (2A4d) as well as emissions of $CO_2$, $NO_x$, CO, NMVOC and $SO_2$ from blasting operations in plaster production (2A4d). The limestone use in cupola furnaces of iron foundries has been reallocated from source category 2A4d to 2C1.

Indirect $CO_2$ emissions resulting from CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

### Ceramics (2A4a)

Source category 2A4a Ceramics consists of the production of fine ceramics and brick and tile.

### Fine ceramics (2A4a)

In Switzerland, the main production of fine ceramics is sanitary ware. The carbonate containing raw materials limestone and dolomite as well as small amounts of soda ash are used in product glazes only. All information on the fine ceramics production is documented in EMIS 2022/2A4a Feinkeramik Produktion.

*Methodology*

The geogenic $CO_2$ emissions from fine ceramics production are determined by a Tier 2 method according to the decision tree Fig. 2.4 of IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates).

For fine ceramics production in Switzerland, this results in the following formula:

$$CO_2 \text{ Emissions} = (M_{Limestone} \bullet EF_{Limestone}) + (M_{Dolomite} \bullet EF_{Dolomite}) + (M_{Soda\ Ash} \bullet EF_{Soda\ Ash})$$

*Emission factors*

The $CO_2$ emission factors of limestone, dolomite and soda ash are taken from IPCC 2006 (vol. 3, chp. 2.1, Table 2.1). As these emission factors are material properties, they remain constant over time.

Table 4-13 Geogenic $CO_2$ emission factors used for fine ceramics and the production of brick and tile in g/t carbonate containing raw material and g/t product, respectively.

| **2A4a Ceramics** | **Unit** | **$CO_2$ geogenic** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Fine ceramics | | **1990–2020** | | | | | | | | |
| Limestone use | g/t limestone | 439'710 | | | | | | | | |
| Dolomite use | g/t dolomite | 477'320 | | | | | | | | |
| Soda use | g/t soda | 414'920 | | | | | | | | |
| | | **1990–2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
| Brick and tile production | g/t | 117'000 | 100'000 | 110'000 | 103'000 | 112'000 | 113'000 | 107'000 | 107'000 | 103'000 |

*Activity data*

Activity data for carbonate containing raw materials (i.e. limestone, dolomite and soda ash) used in the glazes of the fine ceramics production are extrapolated values based on industry data from the largest production plant in Switzerland. Detailed activity data are considered confidential. They are available to the reviewers on request.

**Brick and tile production (2A4a)**

In Switzerland, there are about 20 plants producing bricks and tiles. The manufacturing process uses limestone containing clay as main raw material.

*Methodology*

The brickearth used in Switzerland for the production of bricks and tiles does not consist of pure and defined contents of clay minerals but its clay content is varying depending on the individual pit, comprising other minerals such as calcite, dolomite and quartz. Compared to other countries, the fraction of carbonate containing raw material is relatively high. Detailed data on the composition of carbonate containing raw materials from the Swiss brick and tile industry were not available before 2013. Therefore, for the period 1990 until 2012 data from a comparison of geogenic $CO_2$ emissions based on representative analyses of the carbonate content of the clay used for brick and tile production in a number of plants in Switzerland and the European Union are applied. This study was carried out by the Swiss association of brick and tile industry (Verband Schweizerische Ziegelindustrie, VSZ) in 2012 (see EMIS 2022/2A4a Ziegeleien).

Since 2013, the Swiss brick and tile production plants are legally obliged to report geogenic emissions from carbonate containing raw materials annually (Federal Act on the Reduction of $CO_2$ Emissions, Swiss Confederation 2011 and Ordinance for the Reduction of $CO_2$ Emissions, Swiss Confederation 2012). The emissions are estimated from analyses of the carbonate content of the raw materials and an assumed calcination factor of 100%. This procedure corresponds to a Tier 3 method according to the decision tree Fig. 2.4 of IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates). Between 1990 and 2012 a Tier 2 method is applied.

*Emission factors*

According to the above mentioned study, bricks emit a weighted average of 13.2% of geogenic $CO_2$ (variation range 5.4%–24%) and roof tiles have a weighted average of 8.6% (variation range 5.6%–13%). Based on the production shares of the largest Swiss brick producer, a production ratio for bricks to tiles of 2:1 was assumed for the whole period from 1990 to 2012. This resulted in an average geogenic $CO_2$ emission factor of 117 kg $CO_2$/t brick and tile, which was assumed constant for the time period 1990 to 2012.

Since 2013, a production weighted emission factor is derived based on the plant-specific monitoring data of the geogenic $CO_2$ emissions from the carbonate containing raw materials. For emission factors see Table 4-13.

*Activity data*

Activity data are based on production data from the Swiss association of brick and tile industry (VSZ) (EMIS 2022/2A4). Since 2011 they are based on plant-specific annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).

Table 4-14 Activity data for the production of fine ceramics including the use of limestone, soda and dolomite in the glazes, brick and tile, rock wool and plaster as well as other use of carbonates (sodium bicarbonate).

| 2A4a Ceramics | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Fine ceramics production | kt | C | C | C | C | C |
| Limestone use | kt | C | C | C | C | C |
| Dolomite use | kt | C | C | C | C | C |
| Soda use | kt | C | C | C | C | C |
| Brick and tile production | kt | 1'271 | 1'115 | 959 | 1'086 | 879 |
| **2A4d Other** | | | | | | |
| Rock wool production | kt | C | C | C | C | C |
| Carbonate use in waste incineration plants | kt | 0.71 | 0.76 | 0.82 | 0.61 | NO |
| Limestone use in cellulose production | kt | 8.5 | 9.4 | 9.3 | 8.3 | NO |
| Other use of carbonates | kt | 5.9 | 5.4 | 7.0 | 7.3 | 6.9 |
| Plaster production | kt | 1'271 | 1'115 | 959 | 1'086 | 879 |

| 2A4a Ceramics | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fine ceramics production | kt | C | C | C | C | C | C | C | C | C | C |
| Limestone use | kt | C | C | C | C | C | C | C | C | C | C |
| Dolomite use | kt | C | C | C | C | C | C | C | C | C | C |
| Soda use | kt | C | C | C | C | C | C | C | C | C | C |
| Brick and tile production | kt | 800 | 792 | 785 | 765 | 726 | 660 | 622 | 581 | 554 | 531 |
| **2A4d Other** | | | | | | | | | | | |
| Rock wool production | kt | C | C | C | C | C | C | C | C | C | C |
| Carbonate use in waste incineration plants | kt | NO | NO | 2.7 | 1.9 | 6.5 | 6.6 | 6.8 | 7.2 | 7.0 | 7.0 |
| Limestone use in cellulose production | kt | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Other use of carbonates | kt | 6.4 | 7.6 | 6.1 | 7.5 | 6.7 | 6.8 | 6.5 | 7.4 | 7.8 | 7.9 |
| Plaster production | kt | 293 | 271 | 213 | 166 | 140 | 148 | 146 | 152 | 149 | 122 |

**Other uses of soda ash (2A4b)**

Soda ash is mainly used in the glass production, which is reported separately in source category 2A3 Glass production. A very small amount of soda ash is also applied in glazes of fine ceramics and is thus accounted for in source category 2A4a Ceramics (see Table 4-13). Based on a study investigating carbonate use in industry (INFRAS 2015), it is concluded that there are no known other uses of soda ash (2A4b) in Switzerland. No soda ash is used in flue gas or wastewater treatment. It was concluded that there is no other relevant emissive soda ash use and thus, reported as not occurring in the inventory so far.

During the in-depth review in 2019, the ERT raised the question about potential other uses of soda ash in Switzerland. Based on net imports of soda ash and the known uses in the production of glass (assuming for glass wool and speciality tableware glass the same soda ash content of carbonate raw materials as for container glass) and fine ceramics, an amount of about 11.6 kt resulted for 2017, of which it is not clear whether its use is emissive or not. In a conservative estimate, this would yield a maximum of about 4.8 kt of $CO_2$ emissions (default emission factor of 0.41492 t $CO_2$/t soda ash, IPCC 2006), which corresponds to 0.01% of the national total (excluding LULUCF) in 2017. Considering the entire time series, the share of the national total was largest in 1990 (0.02%) and has remained about constant (0.01%) since 2003. In accordance with decision 24/CP.19, annex I, paragraph 37(b), this is below the significance threshold and thus, the ERT recommended that Switzerland reports $CO_2$ emissions from source category 2A4b Other use of soda ash as not estimated (“NE”) in its inventory, which was implemented in the submission 2021.

### Other (2A4d)

### Rock wool production (2A4d)

In Switzerland, there is one single producer of rock wool. The plant uses carbonate containing raw materials like dolomite, basalt, cement and further additives as documented in the EMIS database (EMIS 2022/2A4d Steinwolle Produktion).

*Methodology*

Since 2013, rock wool manufacturers are legally obliged to report geogenic $CO_2$ emissions from carbonate containing raw material annually. For the years 2005–2011 and 2013 plant-specific data on raw material consumption and emission factors is available from monitoring reports of the Swiss ETS. From this information, data for the other years are interpolated for calculating an implied emission factor.

The geogenic $CO_2$ emissions from rock wool production are determined by a Tier 3 method according to IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates). Before 2004, a Tier 2 method was applied.

*Emission factors*

For rock wool production in Switzerland, the $CO_2$ emission factor is based on measurements of the oxides (CaO, MgO, $Na_2O$, $K_2O$, MnO) of the carbonate containing raw materials and the product for the years 2005 to 2011 as well as since 2013. Based on the difference in the oxide content in the raw material and the products, the total geogenic $CO_2$ emissions are determined. Consequently, the emission factor is specified as g/t rock wool. Since data on the carbonate content are missing for the years 1990 to 2004 and 2012 the mean value of the years 2005–2011 and 2013 is applied for these years.

The $CO_2$ emission factors are confidential. They are available to reviewers on request.

Table 4-15 Geogenic $CO_2$ emission factors used for rock wool production and other carbonate uses, $CO_2$ fossil, $NO_x$, CO, NMVOC and $SO_2$ emission factors for plaster production in g/t carbonate containing raw material and g/t product, respectively for 2020.

| 2A4d Other | Unit | $CO_2$ geogenic | $CO_2$ fossil | $NO_x$ | CO | NMVOC | $SO_2$ |
|---|---|---|---|---|---|---|---|
| Rock wool production | g/t | C | NA | NA | NA | NA | NA |
| Carbonate use in waste incineration plants | g/t | 523'880 | NA | NA | NA | NA | NA |
| Other carbonate uses | g/t | 523'880 | NA | NA | NA | NA | NA |
| Plaster production | g/t rocks | NA | 144 | 5.6 | 33 | 14 | 0.24 |

Table 4-16 In the confidential NIR, the respective table with geogenic $CO_2$ emission factors used for rock wool production is separately reported and available to reviewers.

*Activity data*

Activity data are based on industry data from the single rock wool production plant in Switzerland (monitoring reports of the Swiss ETS) and are therefore confidential. They are available to reviewers on request.

**Other carbonate uses (2A4d)**

In 2014, an assessment was carried out in order to identify sources of $CO_2$ emissions from carbonate use for sulphur oxide removal and acid neutralization, which were not considered in the Swiss greenhouse gas inventory so far (INFRAS 2015). The survey among selected potentially relevant industrial plants, industry associations, Swiss cantons and the Swiss customs administration (EZV) comprised the following substances: limestone ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), sodium bicarbonate ($NaHCO_3$) and soda ash ($Na_2CO_3$).

Besides applications of calcium hydroxide and sodium hydroxide in flue gas treatment also a few applications of limestone and sodium bicarbonate for sulphur oxide removal could be identified in Switzerland. Limestone had been used in the cellulose production up to 2008, when the plant was closed, and in one municipal solid waste incineration plant up to 2005. Since 2013, several waste incineration plants are using sodium bicarbonate.

In cupola furnaces of iron foundries limestone is also used as flux. The resulting geogenic $CO_2$ emissions are reported in 2C1 Iron and steel production. Limestone is also used to neutralize acid wastewater in one chemical production plant. These emissions are reported in source category 2B10 Limestone pit.

Additionally, it is assumed, that all other applications of sodium bicarbonate result in a complete conversion to $CO_2$. Since there is no production of sodium bicarbonate in Switzerland, the annual emissions can be estimated based on the net import.

*Methodology*

The method for calculating the geogenic $CO_2$ emissions from the use of limestone and sodium bicarbonate in all the source categories mentioned above – except in waste incineration plants from 1994 onwards – corresponds to a Tier 2 method according to the decision tree Fig. 2.4 of IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates).

The method for calculating the geogenic $CO_2$ emissions from the use of limestone and sodium bicarbonate in waste incineration plants from 1994 onwards corresponds to a Tier 3 method according to the decision tree Fig. 2.4 of IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates).

*Emission factors*

The emission factors of limestone and sodium bicarbonate are based on the stoichiometry of $CaCO_3$ (IPCC 2006, vol. 3 chp. 2.1, table 2.1, IPCC 2006) and $NaHCO_3$ (CRC 2004), respectively, see Table 4-15. A conversion factor of 100% is assumed for all applications of both carbonates.

*Activity data*

Activity data on limestone use in flue gas treatment in cellulose production are based on expert estimates on the specific consumption of limestone per tonne of cellulose as documented in the EMIS database (EMIS 2022/1A2d Zellulose Produktion).

The activity data of limestone and sodium bicarbonate use in waste incineration plants are provided by the industry as documented in the EMIS database (EMIS 2022/1A1a Kehrichtverbrennungsanlagen).

The activity data of sodium bicarbonate correspond to difference between the net import of sodium bicarbonate and the amount of sodium bicarbonate used in waste incineration plants. The net import data are provided by the Swiss customs administration as documented in the EMIS database (EMIS 2022/2A4d Karbonatanwendung weitere). For activity data see Table 4-14.

**Plaster production (2A4d)**

*Methodology*

There are two plaster production sites in Switzerland. The emissions stem mainly from blasting operations.

Emissions from blasting operations are determined by a country-specific method analogous to a Tier 2 method of the EMEP/EEA guidebook (EMEP/EEA 2019).

*Emission factors*

As there are no specific emission factors for gypsum mining, the emission factors for cement raw material mining are taken instead (with a rough estimate that 1.5 t of raw material are required for production of 1 t of cement). This method is documented in EMIS 2022/2A4d Gips-Produktion übriger Betrieb. For emission factors see Table 4-15.

*Activity data*

The activity data of the annual amount of raw material processed in the plaster production are based on industry data and expert estimates as documented in EMIS 2022/2A4d Gips-Produktion übriger Betrieb (see Table 4-14).

### 4.2.3. Uncertainties and time-series consistency

The uncertainty for $CO_2$ emissions in 2A1 Cement production, which is a key category regarding level and trend, amounts to 4.5% according to approach 1 (uncertainty propagation, Annex A2.2). This is in concordance with the value of 4.4% obtained by approach 2 (Monte Carlo simulations). An uncertainty of 2% is assumed for activity data and 4% for the emission factor, which consists of an average emission factor per tonne of clinker for calcination of the carbonate containing raw material (FOEN 2020k chp. G.7) and a correction for the content of organic carbon and cement kiln dust.

Combined uncertainty is estimated to be 3% for emissions from 2A2 Lime production and 4% for emissions from 2A3 Glass production (expert estimate).

For $CO_2$ emissions in source category 2A4 Other process uses of carbonates, an overall uncertainty of 3% is assumed. Most of the data stems from industrial plants participating in the Swiss ETS, which requires that the uncertainty in the emissions does not exceed a given limit (1.5%–7.5%, depending on the amount of emissions resulting from a given source) and from the Swiss Federal Customs Administration.

Consistency: Time series for 2A Mineral industry are all considered consistent.

### 4.2.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

For submission 2017, implied emission factors of 2A3 container glass production were assessed by both a Tier 2 and Tier 3 method for the years 2005–2011. This comparison provides an indication of the differences caused by the switch in the Tier level from Tier 2 (1990–2004) to Tier 3 (2005–2015).

### 4.2.5. Category-specific recalculations

The following recalculations were implemented in submission 2022. Major recalculations which contribute significantly to the total differences in GHG emissions of sector 2 IPPU between the latest and the previous submissions are also presented in chp. 10.1.2.2.

- 2A4a Fine ceramics: The carbonate containing raw materials (limestone, dolomite and soda ash) used in product glazes were updated from 2018 onwards based on industry data.

### 4.2.6. Category-specific planned improvements

There are no category-specific planned improvements.

# 4.3. Source category 2B – Chemical industry

## 4.3.1. Source category description

Table 4-17 Key categories of 2B Chemical industry. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 2B10 | Chemical Industry, Other | N2O | L1, T1, L2 |

Table 4-18 Specification of source category 2B Chemical industry.

| 2B | Source category | Specification |
|---|---|---|
| 2B1 | Ammonia production | Emissions of $CO_2$ and NMVOC are reported in 2B8b Ethylene production |
| 2B2 | Nitric acid production | Emissions of $N_2O$ and NOx from the production of nitric acid (ceased in 2018) |
| 2B5 | Carbide production | Emissions of $CO_2$, $CH_4$, CO and $SO_2$ from the production of silicon carbide and graphite |
| 2B8 | Petrochemical and carbon black production | Emissions of $CO_2$ and NMVOC from ethylene production. In Switzerland there is only ethylene production under this source category |
| 2B10 | Other | Emissions of $CO_2$, $CH_4$, CO and NMVOC from acetic acid production;<br>$CO_2$ emissions from limestone pit;<br>$CO_2$, $N_2O$, $NO_x$ and CO emissions from niacin production;<br>NMVOC emissions from PVC production (ceased in 1996);<br>$SO_2$ emissions from sulphuric acid production |

## 4.3.2. Methodological issues

### 4.3.2.1. Ammonia production (2B1)

Ammonia ($NH_3$) is produced in one single plant in Switzerland by catalytic reaction of nitrogen and synthetic hydrogen (see Figure 4-6). Ammonia is not produced in an isolated reaction plant but is part of an integrated production chain (see Figure 4-6).

The starting production process is the thermal cracking of liquefied petroleum gas and light virgin naphtha yielding ethylene (ethene, $C_2H_4$), and a series of by-products such as e.g. synthetic hydrogen and methane, which are used as educts for further production steps. According to the Swiss ammonia producer it is not possible to split and allocate the emissions of the cracking process ($CO_2$ and NMVOC) to every single product such as, e.g., ethylene, acetylene (ethyne, $C_2H_2$), cyanic acid or ammonia. Therefore, all $CO_2$ and NMVOC emissions of the cracking process are allocated to the ethylene production and are reported under the category 2B8b Ethylene production. Thus, for source category 2B1 Ammonia production, $CO_2$ and NMVOC emissions are reported as included elsewhere (IE). All information on the ammonia production and the cracking process is documented in EMIS 2022/2B1 Ammoniak-Produktion and EMIS 2022/2B8b Ethen-Produktion, respectively.

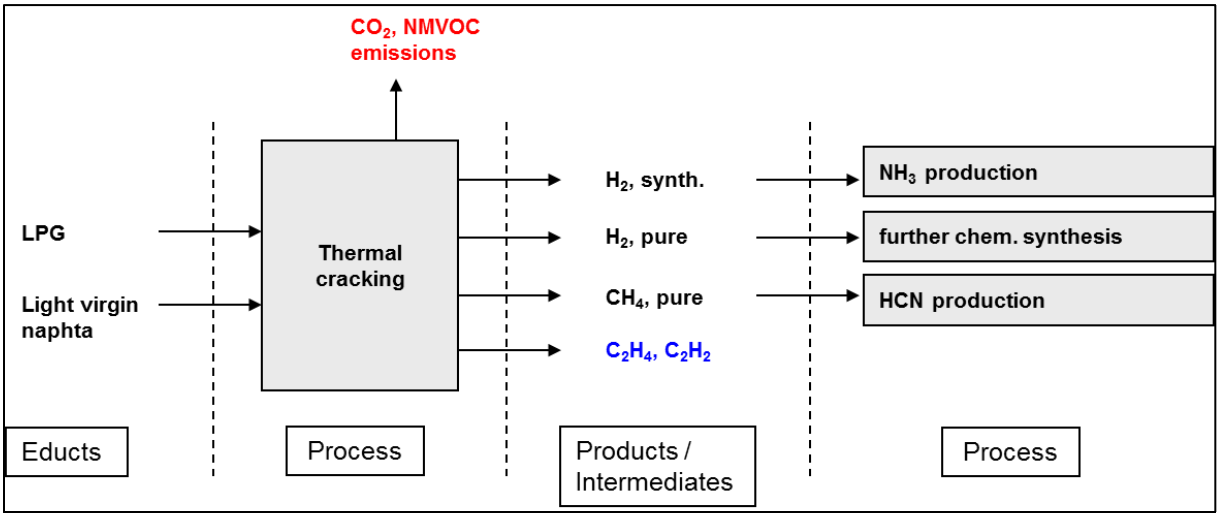


Figure 4-6 Process flow chart for the production of ethylene ($C_2H_4$) and acetylene ($C_2H_2$) by thermal cracking of liquefied petroleum gas (LPG) and light virgin naphtha. The intermediate product $H_2$, synth. is used as educt in the ammonia production in the same plant.

Table 4-19 Activity data for ammonia production in Switzerland are documented in the confidential NIR, which is available to reviewers on request.

#### 4.3.2.2. Nitric acid production (2B2)

In Switzerland, there was one single plant producing nitric acid ($HNO_3$) which stopped production in spring 2018. Nitric acid was produced by catalytic oxidation of ammonia ($NH_3$) with air. At temperatures of 800°C nitric monoxide (NO) is formed. During cooling, nitrogen monoxide reacted with excess oxygen to form nitrogen dioxide ($NO_2$). The nitrogen dioxide reacted with water to form 60% nitric acid ($HNO_3$). Today, two types of processes are used for nitric acid production: single pressure or dual pressure plants. In Switzerland a dual pressure plant was installed.

During this process, nitrous oxide ($N_2O$) can be formed as an unintentional by-product. In addition, also some nitrogen oxide ($NO_x$) is produced. In the Swiss production plant abatement of $NO_x$ was done by selective catalytic reduction (SCR, installed in 1988), which reduced $NO_x$ to $N_2$ and $O_2$ (the SCR in this plant was also used for treatment of other flue gases and was not installed for the $HNO_3$ production specially). In 1990, an automatic control system for the dosing of ammonia to the SCR process was installed. A new catalyst installed in 2013 reduced the $N_2O$ emissions.

No additional abatement technique is installed to destroy $N_2O$. A decomposition of $N_2O$ occurs, to some extent, simultaneously in the $NO_x$ reduction process.

**Methodology**

According to decision tree Fig. 3.2 of IPCC 2006 (vol. 3, chp. 3.3 Nitric acid production), the $N_2O$ emissions from nitric acid production are determined by a Tier 2 method during the time period 1990–2012 and by a Tier 3 method between 2013 and the end of production in 2018 based on direct measurements. The $NO_x$ emissions are calculated by a Tier 2 method according to the decision tree Fig. 3.1 in EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2B Chemical industry) using a plant-specific emission factor.

### Emission factors

The $N_2O$ and $NO_x$ emission factors for nitric acid production in Switzerland are based on measurements from the single nitric acid production plant.

The measurement of $N_2O$ was carried out in 2009 according to the guideline VDI-Richtlinie 2469/Blatt 1 (Messen gasförmiger Emissionen – Messen von Distickstoffmonoxid – Manuelles gaschromatographisches Verfahren) and is the only plant-specific measurement of $N_2O$ emissions. The test gas is sucked in via a heated titanium sensor and then treated with a solution of potassium permanganate and hydrogen peroxide in order to remove nitrogen oxides and further disturbing components. The $N_2O$ concentration is then measured using a gas chromatograph with an electron capture detector. The measurement uncertainty is ±20% (minimum ±0.5 mg/m$^3$). On repeated enquires the plant confirmed that since a denitrification system and an automatic control system for the ammonia addition were installed in 1988 and 1990, respectively, no modifications were made in the production line until 2012. Therefore, a constant $N_2O$-emission factor is assumed for this time period. A new catalyst installed in 2013 reduced the $N_2O$ emissions, which are measured online by NDIR photometry between 2013 and 2018.

The $NO_x$ emission factor is the mean value based on three plant-specific measurements in 2007, 2009 and 2012. Since no modifications were made in the production line between 1990 and 2012, a constant emission factor is assumed for this time period. In 2013, the volume of the SCR-plant was doubled. This modification together with the new catalyst in the production line slightly reduced the $NO_x$ emission factor. The values are documented in EMIS 2022/2B2 Salpetersäure Produktion.

Table 4-20 Emission factors for $N_2O$ for nitric acid production in Switzerland in kg/t nitric acid for 1990–2020 are provided in the confidential NIR, which is available to reviewers on request.

### Activity data

Activity data on annual production of nitric acid (100%) are provided annually by the Swiss production plant for the entire time period 1990–2018. Since 2013, activity data of the annual nitric acid production is taken from annual monitoring reports from the Swiss Emissions Trading Scheme (ETS). The data are confidential but available to reviewers (see EMIS 2022/2B2 Salpetersäure Produktion).

Table 4-21 Activity data for the production of nitric acid (100%) in Switzerland are documented in the confidential NIR, which is available to reviewers on request.

#### 4.3.2.3. Carbide production (2B5)

In Switzerland, there is one single plant producing carbide. The plant produces silicon carbide, which is used in abrasives, refractories, metallurgy and anti-skid flooring. Silicon carbide is produced together with graphite in a coupled process in an electric furnace at temperatures above 2000ºC using the Acheson process. The starting materials are quartz sand ($SiO_2$), petroleum coke and anthracite (C) which yield silicon carbide (SiC) and carbon monoxide (CO). The CO is converted to $CO_2$ in excess oxygen and released to the atmosphere. Petroleum coke and anthracite – although to a lower portion – may contain volatile organic compounds, which can form methane ($CH_4$) as an unintended by-product. There is no abatement techniques installed which could capture the $CO_2$ or $CH_4$ emissions.

Indirect $CO_2$ emissions resulting from $CH_4$ and CO emissions in this source category are included in CRF Table6 as documented in chp. 9.

**Methodology**

According to decision tree Fig. 3.5 of IPCC 2006 (vol. 3, chp. 3.6 Carbide production), the $CO_2$ and $CH_4$ emissions from silicon carbide production are determined by a Tier 2 method. The CO and $SO_2$ emissions are calculated by a Tier 2 method according to the decision tree Fig. 3.1 in EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2B Chemical industry) using plant-specific emission factors.

**Emission factors**

The $CO_2$, $CH_4$, CO and $SO_2$ emission factors are confidential and available to reviewers on request. The values are partly based on data from the single silicon carbide production plant and are documented in EMIS 2022/2B5 Graphit und Siliziumkarbid Produktion.

The $CO_2$, CO and $SO_2$ emission factors are based on data from the production plant. For $CO_2$ and CO, they are calculated based on the carbon mass balance of the production process and CO exhaust measurements from 2001 onwards. The $SO_2$ emission factor is derived from the sulphur content of the feedstocks, i.e. petroleum coke and anthracite. The $CO_2$ emission factors for the entire time series are listed in the following table.

Table 4-22 In the confidential NIR, a respective table with emission factors of fossil $CO_2$ in kg/t silicon carbide are provided. Data are available to reviewers on request.

Table 4-23 Emission factors for $CO_2$, $CH_4$, CO and $SO_2$ for carbide production in kg/t silicon carbide in Switzerland for 2020 are provided in the confidential NIR, which is available for reviewers upon request.

**Activity data**

Activity data on annual production of silicon carbide (and graphite) are provided annually from 1995 onwards by the production plant. For the time period 1990–1994 they are based on industry data.

The data are confidential but available to reviewers on request (see EMIS 2022/2B5 Graphit und Siliziumkarbid Produktion).

| |
|---|
| Table 4-24 In the confidential NIR, the respective table with activity data on silicon carbide production in Switzerland is separately reported and available to reviewers. |

#### 4.3.2.4. Petrochemical and carbon black production (2B8)

**Ethylene (2B8b)**

Ethylene (ethene, $C_2H_4$) is produced by a single plant in Switzerland by thermal cracking of liquefied petroleum gas and virgin naphtha. Ethylene is not produced in an isolated process but is co-processed together with several other products such as $H_2$, $CH_4$, and $C_2H_2$ (see flow chart in Figure 4-6 in chp. 4.3.2.1). From the thermal cracking process, emissions of $CO_2$ and NMVOC are released. They are both allocated entirely to the production of ethylene, which is the first product within the integrated production chain. $CH_4$ emissions to the atmosphere do not occur since $CH_4$ is completely used as an educt in the downstream production of cyanic acid (HCN) in the same facility (again, see Figure 4-6 and for further information see EMIS 2022/2B8b Ethen-Produktion). Therefore, $CH_4$ emissions are reported as NA for ethylene production and only $CO_2$ and NMVOC emissions are reported.

The $CO_2$ emissions from the cracker reported in source category 2B8b Ethylene production are based on a mass balance considering all feedstocks, products and by-products. Therefore, the NMVOC emissions are not included in the calculation of the indirect $CO_2$ emissions from sector 2 IPPU in order to avoid double counting.

**Methodology**

According to decision trees Fig. 3.8 of IPCC 2006 (vol. 3, chp. 3.9 Petrochemical and carbon black production) and Fig. 3.1 of the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2B Chemical industry), the $CO_2$ and NMVOC emissions, respectively, from ethylene production are determined by a Tier 2 method using plant-specific emission factors (EMIS 2022/2B8b Ethylene production).

**Emission factors**

The $CO_2$ and NMVOC emission factors for ethylene production are based on industry data from the single ethylene production plant in Switzerland. Annual emission data were only available from the year 2000 onwards. For the period 1990–1999 constant emission factors, i.e. the mean emission factors of the years 2000–2009 were assumed.

The emission factors for ethylene production are considered confidential; however, they are available to reviewers on request.

Table 4-25 Emission factors for $CO_2$ and NMVOC in ethylene production, NMVOC in acetic acid production, $CO_2$ in limestone pit, $CO_2$, $N_2O$, $NO_x$ and CO in niacin production and $SO_2$ in sulphuric acid production for 2020 in kg/t product.

| 2B8 Petrochemical and carbon black | Unit | $CO_2$ | $N_2O$ | $NO_x$ | CO | NMVOC | $SO_2$ |
|---|---|---|---|---|---|---|---|
| 2B8b Ethylene | kg/t | C | NA | NA | NA | C | NA |
| **2B10 Other** | | | | | | | |
| Acetic acid production | kg/t | NA | NA | NA | NA | C | NA |
| Limestone pit | kg/t | C | NA | NA | NA | NA | NA |
| Niacin production | kg/t | C | C | C | C | NA | NA |
| Sulphuric acid production | kg/t | NA | NA | NA | NA | NA | C |

Table 4-26 $CO_2$ fossil emission factors in 2B8b Ethylene are documented in the confidential NIR, which is available to reviewers on request.

### Activity data

Activity data on the annual production of ethylene are provided annually by the single ethylene production plant in Switzerland. Since 2013, activity data are taken from annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).The data are considered confidential but available to reviewers on request.

Table 4-27 Activity data for the production of ethylene, acetic acid, niacin, PVC and sulphuric acid as well as for limestone pit in Switzerland in kt.

| | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| **2B8 Petrochemical and carbon black production** | | | | | | |
| 2B8b Ethylene | kt | C | C | C | C | C |
| **2B10 Other** | | | | | | |
| Acetic acid production | kt | 30 | 27 | 24 | 8.4 | 20 |
| Limestone pit | kt | C | C | C | C | C |
| Niacin production | kt | C | C | C | C | C |
| PVC production | kt | 43 | 43 | NO | NO | NO |
| Sulphuric acid production | kt | C | C | C | C | C |

| | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2B8 Petrochemical and carbon black production** | | | | | | | | | | | |
| 2B8b Ethylene | kt | C | C | C | C | C | C | C | C | C | C |
| **2B10 Other** | | | | | | | | | | | |
| Acetic acid production | kt | 18 | 12 | C | C | C | C | C | C | C | C |
| Limestone pit | kt | C | C | C | C | C | C | C | C | C | C |
| Niacin production | kt | C | C | C | C | C | C | C | C | C | C |
| PVC production | kt | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Sulphuric acid production | kt | C | C | C | C | C | C | C | C | C | C |

### 4.3.2.5. Other (2B10)

Source category 2B10 Other comprises emissions from production of acetic acid, sulphuric acid, niacin and PVC (ceased in 1996) as well as from limestone pits.

**Acetic acid production (2B10)**

In Switzerland, there is only one plant producing acetic acid ($CH_3COOH$) remaining after the other one stopped its production by the end of 2012. The still existing plant emits NMVOC only whereas from the latter one also emissions of $CO_2$, $CH_4$ and CO occurred.

Indirect $CO_2$ emissions resulting from $CH_4$, CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

*Methodology*

In order to determine emissions of $CO_2$ and $CH_4$ from acetic acid a country-specific method analogous to a Tier 2 method according to IPCC 2006 (vol. 3) is used. The CO and NMVOC emissions are calculated by a Tier 2 method according to the decision tree Fig. 3.1 in the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2B Chemical industry).

*Emission factors*

The emission factors for $CO_2$, $CH_4$, CO and NMVOC from acetic acid production in Switzerland are plant-specific and based on data from industry and expert estimates documented in EMIS 2022/2B10 Essigsäure-Produktion.

In the plant which ceased production by the end of 2012 process emissions had been treated in a flue gas incineration. Thus, the reported emissions of $CH_4$, CO and NMVOC only occurred in case of malfunction, which resulted in strongly fluctuating plant-specific emission factors. In addition, the resulting implied emission factors based on the emissions of both plants are modulated by considerable production fluctuations of one of the plants from 2000 onwards.

The emission factors for acetic acid production are confidential but available to reviewers on request.

Table 4-28 In the confidential NIR, the respective table with emission factors for $CO_2$ and $CH_4$ in acetic acid production are separately reported and available to reviewers.

*Activity data*

The annual amount of produced acetic acid is based on data from industry and from the Swiss industry association for the chemical, pharmaceutical and biotech industry (scienceindustries) documented in EMIS 2022/2B10 Essigsäure-Produktion (see Table 4-27).

The data for acetic acid production since 2013 are confidential, since there is only one manufacturer remaining. The data are available for reviewers on request.

**Limestone pit (2B10)**
In one chemical plant acids are neutralized in a so-called limestone pit yielding geogenic $CO_2$ emissions.

*Methodology*

According to decision tree Fig. 2.4 of IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates), the $CO_2$ emissions from the limestone pit are determined by Tier 2 method using plant-specific emission factors.

*Emission factors*

The $CO_2$ emission factor is considered confidential but available to reviewers on request.

*Activity data*

Activity data of annual consumption of calcium carbonate are provided by the chemical plant from 1999 onwards as documented in EMIS 2022/2B10 Kalksteingrube. For the years 2005–2011 and since 2013 they are based on monitoring reports of the Swiss ETS. Since no data are available of the limestone pit for the time period 1990–1998, the annual activity is derived from the average annual consumption between 1999 and 2015.

Activity data is considered confidential but available to reviewers on request.

**Niacin production (2B10)**
In Switzerland, there is one plant producing niacin that emits $CO_2$, $N_2O$, $NO_x$ and CO. In the production process nitric acid is used as oxidizing agent. Since the nitric acid production plant was closed in spring 2018 the required nitric acid is directly produced within the niacin production plant using a so-called ammonia burner.

*Methodology*

In order to determine emissions of $CO_2$ and $N_2O$ from niacin production, a country-specific method analogous to a Tier 2 method according to IPCC 2006 (vol. 3) is used. The $NO_x$ and CO emissions are calculated by a Tier 2 method based on the decision tree Fig. 3.1 in the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2B Chemical industry) using plant-specific emission factors.

*Emission factors*

The emission factors of $CO_2$, $N_2O$, $NO_x$ and CO are plant-specific based on measurement data from industry. For $CO_2$ and CO, they are based on measurements in 2018 before and after the production process was modified (i.e. including the ammonia burner). For $N_2O$, the emission factor is derived from measurements in 2018 after the modification of the production process but with and without operating the ammonia burner. For $NO_x$, the emission factor is based on measurements in 2017 and 2018 (after process modification).

Due to lack of emission measurements in previous years, constant emission factors are assumed between 1990 and 2017 as documented in the EMIS database (EMIS 2022/2B10 Niacin-Produktion. The emission factor is considered confidential but available to reviewers on request.

| Table 4-29 In the confidential NIR, the respective table with emission factors for $CO_2$ and $N_2O$ emission factors for 2B10 Niacin production are separately reported and available to reviewers. |
| --- |

*Activity data*

Activity data of annual niacin production were provided by the Swiss production plant for the entire time period as documented in EMIS 2022/2B10 Niacin-Produktion. For the years 2005–2011 and since 2013 they are based on monitoring reports of the Swiss ETS.

Activity data are considered confidential but available to reviewers on request.

### PVC and sulphuric acid production (2B10)

Sulphuric acid ($H_2SO_4$) is produced by one plant only in Switzerland. From this production process $SO_2$ is emitted. Until 1996, also PVC was produced in Switzerland releasing NMVOC emissions.

Indirect $CO_2$ emissions resulting from NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

*Methodology*

In order to determine NMVOC and $SO_2$ emissions from sulphuric acid and PVC production, respectively, a Tier 2 method according to the decision tree Fig. 3.1 in the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2B Chemical industry) with plant-specific emission factors is used.

*Emission factors*

The emission factor for $SO_2$ from sulphuric acid production in Switzerland is plant-specific and based on measurement data from industry and expert estimates documented in the EMIS database (EMIS 2022/2B10 Schwefelsäure-Produktion).

The $SO_2$ emission factor is confidential but available to reviewers on request.

For PVC production the NMVOC emission factor was based on industry information and expert estimates (EMIS 2022/2B10 PVC-Produktion).

*Activity data*

The annual amount of sulphuric acid and PVC produced is based on data from industry and expert estimates documented in EMIS 2022/2B10 Schwefelsäure-Produktion and EMIS 2022/2B10 PVC-Produktion (see Table 4-27). The activity data for sulphuric acid production are confidential but available to reviewers on request.

### 4.3.3. Uncertainties and time-series consistency

For $N_2O$ emissions from 2B2 Nitric acid production, the uncertainty is assumed to be 7.5% (from 2013 onwards) since the Swiss ETS requires that an uncertainty of 7.5% is not exceeded for continuous $N_2O$ measurements. For 1990 an uncertainty of 60% is assumed based on the uncertainty rating given in the EMEP/EEA guidebook (EMEP/EEA 2019, part A, chp. 5, Table 2-2, rating B) since the calculated emissions are based on a single $N_2O$ emission measurement in 2009.

The uncertainties for $CO_2$ in source categories 2B5 Silicon carbide production, 2B8b Ethylene and 2B10 Acetic acid production (up to 2012) are estimated to be medium, (see Table 1-10 Semi-quantitative uncertainties for non-key categories) resulting in a relative uncertainty of 10%. For $CH_4$ from 2B5 Silicon carbide production a combined uncertainty of 20% is estimated.

The uncertainties for $CO_2$ and $N_2O$ emissions from 2B10 Niacin production are assumed to be 60% according to the uncertainty rating given in the EMEP/EEA guidebook (EMEP/EEA 2019, part A, chp. 5, Table 2-2, rating B) since the calculated emissions are based on (spot) measurement data from industry in 2018 only.

Consistency: Time series for 2B Chemical industry are all considered consistent.

### 4.3.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

### 4.3.5. Category-specific recalculations

The following recalculations were implemented in submission 2022. Major recalculations which contribute significantly to the total differences in GHG emissions of sector 2 IPPU between the latest and the previous submissions are also presented in chp. 10.1.2.2.

- 2B5: Source category 2B5 Silicon carbide production was updated based on new detailed industry data and information yielding revised activity data and emission factors ($CO_2$ and $CH_4$) for the years 1990–2012 and 1990–2019, respectively. $CO_2$ emissions are now based on a carbon mass balance taking into account CO emissions as well. The $CH_4$ emissions are now derived from the raw material consumption of petroleum coke.

### 4.3.6. Category-specific planned improvements

No category-specific improvements are planned.

## 4.4. Source category 2C – Metal industry

### 4.4.1. Source category description

Table 4-30 Key categories of 2C Metal industry. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 2C3 | Aluminium Production | CO2 | T1 |
| 2C3 | Aluminium Production | PFC | T1 |

Table 4-31 Specification of source category 2C Metal industry.

| 2C | Source category | Specification |
|---|---|---|
| 2C1 | Iron and steel production | Emissions of $CO_2$, NOx, CO, NMVOC and $SO_2$ from the production of iron and steel;<br>Geogenic $CO_2$ emissions from use of limestone in iron-foundries (cupola furnaces) |
| 2C2 | Ferroalloys production | Production is not occuring in Switzerland |
| 2C3 | Aluminium production | Emissions of PFC, $CO_2$, NOx, CO, NMVOC, and $SO_2$ from the production of primary aluminium (ceased in 2006); Emissions from use of $SF_6$ in aluminium foundries |
| 2C4 | Magnesium production | Emissions from use of $SF_6$ in magnesium foundries |
| 2C7 | Other | Emissions of CO and NMVOC from non-ferrous metal foundries;<br>Emissions of $CO_2$, NOx, CO and $SO_2$ from battery recycling |

### 4.4.2. Methodological issues

#### 4.4.2.1. Iron and steel production (2C1)

There is no primary iron and steel production in Switzerland. Only secondary steel production occurs, which is steel production from recycled steel scrap. After closing down of two steel plants in 1994, there remain two plants in Switzerland. Both plants use electric arc furnaces (EAF) with a carbon electrode for melting the steel scrap. During the melting process $CO_2$ emissions occur mainly from scrap, electrodes and carburization coal whereas the produced steel, filter dust and slag act as carbon sinks. Emissions of precursors such as $NO_x$, CO, NMVOC and $SO_2$ occur as well.

In Switzerland, no production of pig iron occurs but iron is processed in foundries only. Today, there exist about 14 iron foundries in Switzerland. About 75% of the iron is processed in induction furnaces and 25% in cupola furnaces. From induction furnaces only precursors are emitted. In cupola furnaces also $CO_2$ emissions from other bituminous coal and limestone occur. Other bituminous coal acts first of all as fuel but also as carburization material and reductant. Therefore it was decided to report those $CO_2$ emissions in source category 1A2a. This ensures consistency with the reported use of other bituminous coal as fuel in the Swiss overall energy statistics (SFOE 2021). In cupola furnaces of iron foundries, limestone is also used as flux as documented in the EMIS database (EMIS 2022/1A2a 2C1 Eisengiessereien Kupolöfen). The resulting geogenic $CO_2$ emissions are reported in 2C1.

The $CO_2$ emissions from 2C1 Secondary steel production, electric arc furnace are based on a carbon mass balance considering all carbon sources and sinks of the process. Therefore, the emissions of CO and NMVOC are not included in the calculation of the indirect $CO_2$ emissions from sector 2 IPPU in order to avoid a double counting.

**Methodology**

For determination of $CO_2$ emission from EAF in secondary steel production a mixture of a Tier 2 (before 2005 and for 2012) and a Tier 3 method (2005–2011 and since 2013) according to decision tree Fig. 4.7 of IPCC 2006 (vol. 3, chp. 4.2 Iron & steel and metallurgical coke production) is used. For the years 2005–2011 and from 2013 onwards plant-specific data on the carbon mass balance is available from monitoring reports of the Swiss ETS, since under the Ordinance for the Reduction of $CO_2$ Emissions (Swiss Confederation 2012) the plants are required to report their emissions annually (Tier 3). From this information, data for the other years are interpolated for calculating an implied emission factor. In Switzerland, no $CH_4$ emissions occur in the EAF process.

The method for calculating geogenic $CO_2$ emissions from limestone use in cupola furnaces of iron foundries corresponds to a Tier 2 method according to the decision tree Fig. 2.4 of IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates).

Emissions of all precursors are determined by a Tier 2 method based on the decision tree Fig. 3.1 in chapter 2C1 in the EMEP/EEA guidebook (EMEP/EEA 2019) using country-specific emission factors (EMIS 2022/2C1).

**Emission factors**

The emission factors for EAF in secondary steel production in Switzerland are country-specific and are based on measurements from industry and expert estimates documented in the EMIS database (EMIS 2022/2C1 Eisengiessereien Elektroschmelzofen/übriger Betrieb, EMIS 2022/2C1 Stahl-Produktion Elektroschmelzöfen and EMIS 2022/2C1 Stahlwerke Walzwerke).

The electrode consumption in the two Swiss plants differs. For the calculations all carbon sources (graphite electrodes, steel scrap, alloy coal, etc.) and carbon sinks (steel, filter dust and slag) for the years 2005–2011 and from 2013 onwards were taken into account. Based on these carbon mass balances, a mean plant-specific $CO_2$ emission factor results. The reported $CO_2$ emission factor for Swiss steel industry is the production-weighted average. Therefore, from this source category no indirect emissions are included in CRF Table6 as documented in chp. 9.

The plant-specific data are confidential but available to reviewers on request.

Table 4-32 $CO_2$ emission factor of electric arc furnaces in 2C1 Steel production in kg/t.

| 2C1 Steel production | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| $CO_2$ | kg/t | 8.3 | 8.0 | 7.7 | 8.8 | 7.6 |

| 2C1 Steel production | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $CO_2$ | kg/t | 7.1 | 7.9 | 8.5 | 8.2 | 8.6 | 8.8 | 9.2 | 9.1 | 8.5 | 8.5 |

Emission factors for all precursors emitted from steel production are based on air pollution control measurements of the steel plants. For submission 2016, emission factors of $NO_x$, CO, NMVOC, and $SO_2$ have been revised based on air pollution control measurements at the electric arc furnaces of the two plants in 1999, 2005 and 2010 and in 1998, 2009 and 2014, respectively.

The emission factor of geogenic $CO_2$ from limestone use in cupola furnaces of iron foundries is based on the stoichiometry of $CaCO_3$ (IPCC 2006, vol. 3 chp. 2.1, table 2.1), see Table 4-33. A conversion factor of 100% is assumed. The emission factors of the precursors from induction furnaces of iron foundries are provided by the Swiss foundry association (GVS).

Table 4-33 Emission factors for $CO_2$, $NO_x$, CO and NMVOC in iron production, for $CO_2$, $NO_x$, CO, NMVOC and $SO_2$ in steel production, for CO and NMVOC in non-ferrous metal production and for $CO_2$, $NO_x$, CO and $SO_2$ in battery recycling for 2020.

| 2C Metal industry | Unit | $CO_2$ | $NO_x$ | CO | NMVOC | $SO_2$ |
|---|---|---|---|---|---|---|
| 2C1 Iron production | kg/t | NA | 0.01 | 4.1 | 4.0 | NA |
| 2C1 Limestone use in iron foundries (cupola furnaces) | kg/t | 439.71 | NA | NA | NA | NA |
| 2C1 Steel production | kg/t | 8.5 | 0.14 | 0.7 | 0.11 | 0.014 |
| 2C7a Non-ferrous metals | kg/t | NA | NA | 0.24 | 0.05 | NA |
| 2C7c Battery recycling | kg/t | C | C | C | C | C |

**Activity data**

Activity data on annual production of iron and steel are provided annually by the Swiss foundry association (Giesserei-Verband Schweiz, GVS) and the steel plants, respectively. Since 2009, activity data of the annual steel production is taken from annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).

The amount of limestone used as flux in iron foundries (cupola furnaces) is estimated by GVS to be in the range of 30–50% of the coal consumed. Therefore, an average share of 40% is assumed to calculate the activity data of limestone use (EMIS 2022/1A2a_2C1 Eisengiessereien Kupolöfen).

Table 4-34 Production of iron, steel, aluminium and non-ferrous metals as well as amount of batteries recycled in Switzerland in kt.

| 2C Metal industry | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| 2C1 Iron production | kt | 170 | 130 | 120 | 67 | 53 |
| 2C1 Limestone use in iron foundries (cupola furnaces) | kt | 6.2 | 4.1 | 3.8 | 2.3 | 1.0 |
| 2C1 Steel production | kt | 1'108 | 716 | 1'022 | 1'159 | 1'218 |
| 2C3 Aluminium production | kt | 87 | 21 | 36 | 45 | NO |
| 2C7a Non-ferrous metals | kt | 60 | 56 | 53 | 33 | 20 |
| 2C7c Battery recycling | kt | NO | C | C | C | C |

| 2C Metal industry | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2C1 Iron production | kt | 61 | 46 | 45 | 43 | 37 | 34 | 35 | 34 | 24 | 20 |
| 2C1 Limestone use in iron foundries (cupola furnaces) | kt | 1.1 | 0.86 | 0.86 | 0.82 | 0.70 | 0.65 | 0.67 | 0.65 | 0.45 | 0.38 |
| 2C1 Steel production | kt | 1'322 | 1'252 | 1'231 | 1'315 | 1'296 | 1'238 | 1'270 | 1'291 | 1'130 | 1'125 |
| 2C3 Aluminium production | kt | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 2C7a Non-ferrous metals | kt | 12 | 6.6 | 6.4 | 9.5 | 8.9 | 9.0 | 8.0 | 6.8 | 6.4 | 5.1 |
| 2C7c Battery recycling | kt | C | C | C | C | C | C | C | C | C | C |

### 4.4.2.2. Aluminium production (2C3)

#### Methodology

The last production site for primary aluminium in Switzerland closed down in April 2006. According to IPCC 2006 (vol. 3, chp. 4.4, fig. 4.11), $CO_2$ emissions are calculated by a Tier 2 method using a country-specific emission factor. For PFC emissions, a more specific Tier 3 method with facility-specific data according to the Guidelines (IPCC 2006) was used. Operating smelter emissions have been monitored periodically by the industry for selected years.

FOEN import statistics indicate in the year 2003 part of the $SF_6$ imports to be related to the aluminium industry, referring to cleaning processes in foundries. The 2006 IPCC Guidelines mention use of $SF_6$ in aluminium production for magnesium alloys on a low scale but do not provide further information for evaluation. Accordingly, the same evaluation methodology as for magnesium foundries with an emission factor based on a Tier 2 method is applied.

#### Emission factors

The emission factor for $CO_2$ of 1.6 tonnes per tonne of aluminium is country-specific. It is based on measurements and data from industry and expert estimates, as documented in the EMIS database (EMIS 2022/2C3 Aluminium Produktion). $CO_2$ emissions from aluminium production stem from the oxidation of the anode in the electrolysis process. In Switzerland, only prebake anode technology was used. For the anode consumption, a constant mean value of 0.43 tonnes per tonne of aluminium was applied. It is assumed that the anode consisted completely of carbon and that it was fully oxidized during the process. Therefore, no indirect $CO_2$ emissions resulting from CO emissions from primary aluminium production are included in CRF Table6 as documented in chp. 9. However, the NMVOC emissions solely originate from the production of the electrodes at the plants. Accordingly, the respective indirect $CO_2$ emissions resulting from NMVOC in this source category are included in CRF Table6 as documented in chp. 9.

Before the close down of the only Swiss primary aluminium factory in 2006, PFC emission factors of operating smelters have been monitored periodically. Measurements made in 1990, 1999 and 2000 reported emission factors of 0.17, 0.06 and 0.04 kg per tonne, respectively, for those three years (Alcan 2003). This was reported to be lower than the European averages, by factors of 4.0, 4.7 and 4.0, respectively. For other years no measurements have been made in Switzerland; thus, European Union (EU) average emission factors have been used, multiplied by a factor of 0.25 (Alcan 2002).

Figure 4-7 shows the resulting development of the emission factor for PFC over time. The European average has decreased by over 75% from 0.68 kg PFC per tonne of aluminium to 0.16 kg PFC per tonne of aluminium between 1990 and 2000 (European Aluminium 2019).

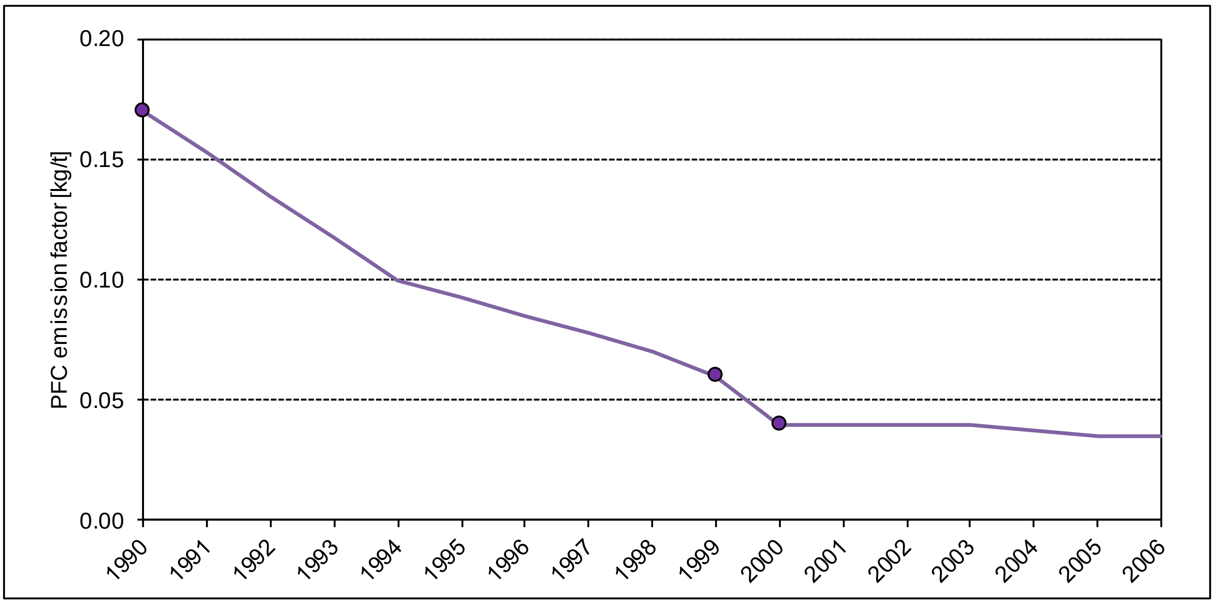


Figure 4-7 Extrapolation of PFC emission factor based on measurements in 1990, 1999 and 2000. The path for the reduction between measurements and the stagnation after the last measurements reflects the observed development of average emission factors in the European Union.

There is no documentation of the measurements. Due to the close down in 2006 it is not possible to redo any measurements or to collect any information about the process details retroactively. Measurement results and development of emission factors are assumed to be plausible because the factory used point feed prebake (PFPB) technology which is known for the lowest emissions per tonne of aluminium. The resulting emission factors for Switzerland are within the uncertainty range according to the 2006 IPCC Guidelines (variations by a factor of 10 using same technologies). The comparison with data from IAI (2005) on global PFC emissions from aluminium production showed that the monitored emissions from the smelter in Switzerland were lower by a factor of about 4.

Table 4-35 PFC emission factors for aluminium production in Switzerland. Aluminium production in Switzerland ceased in 2006.

| Gas | Unit | 1990 | 1995 | 2000 | 2005 | 2006 | 2007-2020 |
|---|---|---|---|---|---|---|---|
| $CF_4$ | kg/t | 0.15 | 0.083 | 0.036 | 0.032 | 0.032 | NO |
| $C_2F_6$ | kg/t | 0.017 | 0.0093 | 0.0040 | 0.0035 | 0.0035 | NO |

There are no measurements of $SF_6$ emissions available from aluminium foundries to identify the fraction of $SF_6$ destroyed or transformed in the cleaning process. For $SF_6$ used in aluminium foundries (2C3) it is therefore assumed that the total imported amount is emitted, in accordance with the default emission factor (1000 kg per tonne of imported substance) of the IPCC Guidelines (IPCC 2006).

**Activity data**

In 2006, the last primary aluminium production site in Switzerland was closed. Activity data on aluminium production from 1997 to 2006 are based on annual data published by the Swiss Aluminium Association. For earlier years, data were provided directly by the aluminium industry. Activity data for aluminium production in Switzerland are given in Table 4-34.

Activity data on $SF_6$ used in aluminium foundries (2C3) is derived from import data from FOEN statistics. Import companies indicated in the year 2003 a portion of $SF_6$ imports for foundries to be used for aluminium cleaning. For the activity data of any particular year, the mean value of the imports in the present and the previous year is used to account for possible time lag between import and consumption (e.g. for 2004 the mean value of 2003 and 2004 import data are used). In 2011, a study was carried out among members of the Swiss Foundry Association (GVS), confirming that $SF_6$ is not used any more in aluminium foundries. As no details on the imported amount are available for the time period 2003–2011, a steady decrease of the import amount of $SF_6$ is assumed from 2003 until the final elimination of $SF_6$ for aluminium cleaning in 2011. This assumption is based on the above-mentioned survey and on information obtained on applications within the category ‘others’ from FOEN import statistics.

### 4.4.2.3. Magnesium production (2C4)

**Use of $SF_6$ in magnesium foundries (2C4)**

$SF_6$ was used in Swiss magnesium foundries in the time period 1997 to 2016. There have been two magnesium foundries known to be using $SF_6$. In 2007 one of them closed down. A survey carried out 2011 among members of the Swiss Foundry Association (GVS) confirmed that only one company was using $SF_6$.

The import of $SF_6$ for magnesium foundries has been prohibited in Switzerland since 2017.

**Methodology**

$SF_6$ was used in magnesium foundries in the cleaning process as inert gas to fill casting forms. The Swiss Foundry Association (GVS) has not provided information on emission factors and hence a Tier 2 method is used.

**Emission factors**

There are no measurements of $SF_6$ emissions available to identify the fraction of $SF_6$ destroyed or transformed in the process. For $SF_6$ used in magnesium foundries (2C4) it is therefore assumed that the total imported amount is emitted, in accordance with the default emission factor (1000 kg per tonne of imported substance) of the 2006 IPCC Guidelines (IPCC 2006).

**Activity data**

Activity data on $SF_6$ used in magnesium foundries (2C4) are based on import data from FOEN statistics. For the activity data of any particular year, the mean value of the imports in the present and the previous year is used to account for possible time lag between import and consumption (e.g. for 2016 the mean value of 2015 and 2016 import data are used). The import of $SF_6$ ceased in 2016. Part of the import of the preceding year were considered for the phase-out 2016.

One of the magnesium foundries reported on the $SF_6$ consumption between 2008 to 2015 to the SWISSMEM statistics. The information is in accordance with import data obtained for FOEN statistics.

#### 4.4.2.4. Other (2C7)

**Battery recycling and non-ferrous metal foundries (2C7)**

There is one battery recycling plant in Switzerland which started operation in 1992. The recycling is done by applying the Sumitomo process. The batteries are first pyrolised at temperatures of 700°C in a reducing atmosphere in a shaft kiln. The gas with the carbonised components then goes to a post-combustion step where it is completely oxidised at temperatures of 1000°C. The flue gas is then directed to a flue gas treatment installation. The metal fraction from the pyrolysis goes to a melting furnace where it is reduced by addition of coal and magnesium oxide. As reducing agent coke and Carburit is used.

In Switzerland, there are one large company and several small plants operating non-ferrous metal foundries producing mainly copper alloys. During the melting process emissions of CO and NMVOC occur.

Indirect $CO_2$ emissions resulting from CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

**Methodology**

To determine emissions of $CO_2$, $NO_x$, CO and $SO_2$ from battery recycling and of CO and NMVOC from non-ferrous metal foundries, Tier 2 methods according to the EMEP/EEA Guidebook (EMEP/EEA 2019, chp. 2C7c and 2C7a) with country-specific emission factors are used.

**Emission factors**

The emission factors of $CO_2$, $NO_x$, $SO_2$, CO from battery recycling between 1992 and 2002 are based on measurements in 2003 as well as mass balances of the single recycling site and are assumed constant. Since 2003 they are based on air pollution control measurements from 2003 and 2012 and are assumed constant during this time period. Emission factors of NMVOC are also based on air pollution control measurements from 2003 and 2012 and are assumed constant for the entire time period (EMIS 2022/2C7 Batterie-Recycling).

Emission factors of CO and NMVOC from non-ferrous metal foundries in Switzerland are country-specific and based on measurements from industry and expert estimates documented in the EMIS database (EMIS 2022/2C7 Buntmetallgiessereien Elektroöfen) (see Table 4-33). Emission factors are confidential. They are available to reviewers on request.

**Activity data**

The annual amount of recycled batteries and produced non-ferrous metals in Switzerland is reported from industry (including monitoring reports of the Swiss ETS from 2006 onwards for the large non-ferrous metal company) and the foundry association as documented in the EMIS database (EMIS 2022/2C7 Batterie-Recycling and EMIS 2022/2C7 Buntmetallgiessereien Elektroöfen). Activity data are confidential. They are available to reviewers on request.

### 4.4.3. Uncertainties and time-series consistency

The combined uncertainty of $CO_2$ emissions in 2C1 Iron and steel production amounts to 5.4% according to approach 1 (uncertainty propagation, Annex A2.2); this value is in concordance with approach 2 (Monte Carlo simulations, Annex A2.3). Production data of the steel industry have a high confidence and its uncertainty is estimated at 2%. The uncertainty for the $CO_2$ emission factor is estimated at 5%. Since the geogenic $CO_2$ emissions from the limestone use in cupola furnaces (iron foundries) are comparatively small their contribution to the uncertainty calculation was neglected.

For the emission of $CO_2$ and PFC from 2C3 Aluminium production, which is a key category for both gases, combined uncertainties of 20.6% and 9%, respectively, are determined. The emission factor uncertainty for $CO_2$ is estimated to be 20%. The uncertainty in the activity data is estimated to be 5% for $CO_2$ emissions.

For the emissions of $SF_6$ from the use in 2C4 Magnesium production, the combined uncertainty is estimated at 27.7%.

The uncertainty of $CO_2$ emissions from source category 2C7 Other is estimated to be 20% (expert estimate).

Consistency: Time series for 2C Metal industry are all considered consistent.

### 4.4.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

### 4.4.5. Category-specific recalculations

There were no recalculations implemented in submission 2022.

### 4.4.6. Category-specific planned improvements

No category-specific improvements are planned.

## 4.5. Source category 2D – Non-energy products from fuels and solvent use

### 4.5.1. Source category description

Table 4-36 Direct emissions of 2D Non-energy products from fuels and solvent use are not a key category. Indirect emissions are documented in chp. 9.

Table 4-37 Specification of source category 2D Non-energy products from fuels and solvent use in Switzerland.

| 2D | Source category | Specification |
|---|---|---|
| 2D1 | Lubricant use | Emissions of $CO_2$ from primary usage of lubricants in machinery and vehicles and from fully oxidised lubricants blended into gasoline for 2-stroke engines |
| 2D2 | Paraffin wax use | Emissions of $CO_2$ from primary usage of paraffin waxes |
| 2D3a | Solvent use | Emissions of NMVOC from coating applications, degreasing, dry cleaning and chemical products as well as emissions of $CO_2$ resulting from post-combustion of NMVOC in exhaust gases of these sources |
| 2D3b | Road paving with asphalt | Emissions of NMVOC from road paving with asphalt |
| 2D3c | Asphalt roofing | Emissions of CO and NMVOC from asphalt roofing |
| 2D3d | Urea use in SCR catalysts of diesel engines | Emissions of $CO_2$ from urea use in SCR catalysts of diesel engines |

### 4.5.2. Methodological issues

#### 4.5.2.1. Lubricant use (2D1) and Paraffin wax use (2D2)

Lubricants are mostly used in industrial and transportation applications. They can be subdivided into motor oils, industrial oils and greases, which differ in terms of physical characteristics, commercial applications and environmental fate. Lubricants in engines of road and non-road vehicles are primarily used for their lubricating properties and associated GHG emissions are therefore considered as non-combustion emissions reported in 2D1 Lubricant use. Only lubricants blended into gasoline for 2-stroke engines are assumed to be fully oxidised.

The source category 2D2 Paraffin wax use includes products such as petroleum jelly, paraffin waxes and other waxes, including mixtures of saturated hydrocarbons, solid at ambient temperature. Paraffin waxes are separated from crude oil during the production of light (distillate) lubricating oils. Emissions from the use of waxes occur primarily when the waxes or derivatives of paraffins are combusted during use (e.g. candles).

**Methodology**

$CO_2$ emissions from the use of lubricants in 2-stroke engines (road and non-road vehicles) are calculated by a Tier 1 method and default emission factor according to the decision trees in IPCC 2006, vol. 2, chp. 3, Figure 3.2.2 and Figure 3.2.3) assuming that the lubricants are fully oxidised (as described in chp. 3.2.9.2.2). Please note that $CH_4$ and $N_2O$ emissions from lubricant use in 2-stroke engines are reported in sector 1 Energy since these emissions are included in the $CH_4$ and $N_2O$ emission factors of the respective 2-stroke engines (1A2gvii, 1A3biv, 1A3dii, 1A4aii, 1A4bii, 1A4cii and 1A5b).

$CO_2$ emissions from oxidation of all other lubricants and paraffin wax are calculated by a Tier 1 method according to the 2006 IPCC Guidelines applying the IPCC default oxidation fraction of 0.2 (IPCC 2006, vol. 3, chp. 5.2 and 5.3).

**Emission factors**

The $CO_2$ emission factor for lubricants used in 2-stroke vehicles is based on the default emission factor and the net calorific value from IPCC 2006 (vol. 2, chp. 2 Stationary combustion, Table 2.2 and chp.1, Table 1.2, respectively), see Table 4-38 and EMIS 2022/2 D 1_Schmiermittel-Verbrauch B2T. Non-$CO_2$ emissions from lubricant use in 2-stroke engines are included in the road and the non-road transportation model, since the emission factors are deduced from measurements on motorcycles including 2-stroke engines (see chp. 3.2.9.2.2).

The emission factors of $CO_2$ from all other lubricant and paraffin wax use in Switzerland are based on default IPCC values for NCV, carbon content and oxidation fraction documented in vol. 2, chp.1 and vol. 3, chp. 5.2 and 5.3, respectively, of IPCC 2006, see also EMIS 2022/2D1 Lubricant use and EMIS 2022/2D2 Paraffin wax use.

Table 4-38 $CO_2$ emission factor of 2D1 Lubricant use and 2D2 Paraffin wax use for 2020.

| | Unit | $CO_2$ |
|---|---|---|
| **2D1 Lubricant use** | | |
| in two-stroke engines | kg/t | 2'947 |
| unspecified | kg/t | 590 |
| **2D2 Paraffin wax use** | kg/t | 590 |

**Activity data**

The annual amount of lubricant and paraffin wax used in Switzerland is derived from Avenergy Suisse (formerly Swiss petroleum association) (Avenergy 2021). The consumption of lubricants of Liechtenstein, which forms a customs union with Switzerland, is subtracted from the consumption reported by Avenergy Suisse. The resulting amount is further differentiated between application in 2-stroke engines and unspecified use. The amount of lubricants corresponds to 2% of total gasoline consumption of all 2-stroke engines based on the road and non-road transportation models (INFRAS 2019b, INFRAS 2015a).

Table 4-39 Use of lubricants and paraffin waxes.

| | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| **2D1 Lubricant use** | | | | | | |
| in two-stroke engines | kt | 0.61 | 0.42 | 0.49 | 0.36 | 0.29 |
| unspecified | kt | 79 | 61 | 62 | 72 | 55 |
| **2D2 Paraffin wax use** | kt | 11 | 10 | 12 | 10 | 5.0 |

| | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2D1 Lubricant use** | | | | | | | | | | | |
| in two-stroke engines | kt | 0.28 | 0.27 | 0.26 | 0.23 | 0.21 | 0.23 | 0.23 | 0.23 | 0.22 | 0.19 |
| unspecified | kt | 53 | 51 | 53 | 53 | 51 | 51 | 50 | 45 | 44 | 41 |
| **2D2 Paraffin wax use** | kt | 4.6 | 3.3 | 3.8 | 4.5 | 3.8 | 3.4 | 4.0 | 4.2 | 3.4 | 3.3 |

### 4.5.2.2. Other (2D3)

**Solvent use (2D3a)**

Since the 2006 IPCC Guidelines (IPCC 2006, vol. 3, chp. 5.5) refer to the EMEP/EEA guidebook regarding methodologies for estimating NMVOC emissions from solvent use, the respective NFR codes are indicated as reference as well. Within 2D3a Solvent use, the NMVOC emissions from coating applications (2D3d NFR), degreasing (2D3e NFR), dry cleaning (2D3f NFR) as well as production and processing of chemical products (2D3g NFR) are reported. Paint application on wood, paint application in construction, industrial and non-industrial paint application, production of fine chemicals and other industrial cleaning account for the largest share of NMVOC emissions from 2D3a in 2020. Indirect $CO_2$ emissions resulting from NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

*Methodology*

For the determination of NMVOC emissions from solvent use in coating applications (2D3d NFR), degreasing (2D3e NFR), dry cleaning (2D3f NFR) as well as production and processing of chemical products (2D3g NFR) a Tier 2 method according to the EMEP/EEA guidebook (EMEP/EEA 2019) is used. For coating applications the emissions are based on the consumption of paints, lacquers, glazes, thinners etc. and their solvent content, for degreasing and dry cleaning on the solvent consumption and for production and processing of chemical products on the products manufactured or processed. Switzerland's Informative Inventory Report (FOEN 2022b, chps. 4.5.2.4–4.5.2.7) contains a detailed description of the country-specific emission factors and activity data of these four NFR source categories.

**Post-combustion of NMVOC from solvent use (2D3a)**

Due to the obligations of the Ordinance on Air Pollution Control (Swiss Confederation 1985) and Ordinance on the Incentive Tax on Volatile Organic Compounds (Swiss Confederation 1997) several industrial plants use facilities and equipment to reduce NMVOC in exhaust gases and room ventilation output. Often this implies the feeding of air with high NMVOC content into the burning chamber of boilers or other facilities to incinerate NMVOC. These $CO_2$ emissions from post-combustion of NMVOC are estimated based on industry data and expert estimates (Carbotech 2022a).

*Methodology*

The $CO_2$ emissions from post-combustion of NMVOC are calculated by a Tier 2 method using country-specific emission factors. Emissions are calculated based on the amount of NMVOC (and their carbon content) destroyed in the respective combustion facility of industrial plants (Carbotech 2022a). Post-combustion facilities are applied in source categories 2D3a Solvent use (industrial paint applications (2D3d NFR), metal degreasing (2D3e NFR) and chemical products, manufacture and processing (2D3g NFR)) and 2G4 Other. In 2018, the source category allocation of all post-combustion plants has been verified. For the ten largest facilities (within 2D3a and 2G4), which are responsible for about 70% of the emissions, the NMVOC quantities and respective carbon contents based on the composition of the solvents are updated annually whereas all the others every five years. For the latest submission, a complete update of all facilities was carried out by means of a survey of all cantonal air pollution control authorities, in addition, with VOC balances. If no information of the solvent composition is available, mean source category-specific values are applied for the carbon content.

Source categories coating applications (2D3d NFR) and degreasing (2D3e NFR) comprise nine facilities each, whereas chemical products, manufacture and processing (2D3g NFR) comprise about 80 facilities. Not all facilities have been in use for the entire period 1990–2020. There was a significant increase in total number of facilities from 32 in the year 1990 to 115 in 2002. Since then, the number fluctuates around 120.

The amounts of NMVOC eliminated by post-combustion are also declared in the respective VOC balances of the industrial plants and are thus not included as NMVOC emissions. When deriving the NMVOC emission factors for these source categories, the amount of NMVOC destroyed in post-combustion facilities is taken into account, i.e. the NMVOC emission factor is reduced accordingly.

*Emission factors*

$CO_2$ emission factors are derived based on the composition of the solvents (carbon content) destroyed in each post-combustion installation. For the ten most important installations (within 2D3a and 2G4), amount and composition of solvents destroyed are updated annually whereas for all others at least every five years. In between, the values are kept constant (see Table 4-40). For installations with no information on the solvent composition, mean industry-specific values are applied. The emission factors given in Table 4-40 are (source category specific) implied emission factors that depend both on carbon content and respective amount of the destroyed NMVOC. Thus, the implied emission factors of source categories with large post-combustion facilities may vary significantly over the years, due to changes in solvent compositions and amounts, starting-up or shutting down of facilities, etc.

Table 4-40 $CO_2$ emission factors for post-combustion of NMVOC in 2D3a Solvent use.

| 2D3a Solvent use | Unit | $CO_2$ | | | | |
|---|---|---|---|---|---|---|
| Post-combustion of NMVOC | | 1990 | 1995 | 2000 | 2005 | 2010 |
| Coating applications (2D3d NFR) | t/t NMVOC | 2.78 | 2.75 | 2.72 | 2.78 | 2.78 |
| Degreasing (2D3e NFR) | t/t NMVOC | NO | 2.63 | 2.63 | 2.64 | 2.65 |
| Chemical products, manufacture and processing (2D3g NFR) | t/t NMVOC | 2.02 | 1.71 | 1.96 | 1.97 | 2.23 |

| 2D3a Solvent use | Unit | $CO_2$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Post-combustion of NMVOC | | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
| Coating applications (2D3d NFR) | t/t NMVOC | 2.78 | 2.79 | 2.79 | 2.78 | 2.27 | 2.25 | 2.24 | 2.25 | 2.25 | 2.05 |
| Degreasing (2D3e NFR) | t/t NMVOC | 2.65 | 2.65 | 2.64 | 2.40 | 2.37 | 2.35 | 2.35 | 2.34 | 2.34 | 2.34 |
| Chemical products, manufacture and processing (2D3g NFR) | t/t NMVOC | 2.24 | 2.33 | 2.33 | 2.36 | 2.33 | 2.31 | 2.26 | 2.20 | 2.14 | 2.09 |

*Activity data*

Activity data are the amounts of NMVOC destroyed in post-combustion installations and are provided by the industry, VOC balances and cantonal air pollution control authorities. For the ten most important installations (within 2D3a and 2G4), they are updated annually whereas for all others at least every five years.

Table 4-41 Activity data of NMVOC post-combustion in 2D3a Solvent use.

| | | | | | | |
|---|---|---|---|---|---|---|
| Post-combustion of NMVOC | | | | | | |
| Coating applications (2D3d NFR) | t NMVOC | 443 | 662 | 756 | 986 | 1'104 |
| Degreasing (2D3e NFR) | t NMVOC | NO | 749 | 749 | 576 | 898 |
| Chemical products, manufacture and processing (2D3g NFR) | t NMVOC | 1'199 | 4'501 | 5'677 | 8'237 | 5'490 |

| 2D3a Solvent use | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Post-combustion of NMVOC | | | | | | | | | | | |
| Coating applications (2D3d NFR) | t NMVOC | 1'107 | 1'102 | 1'076 | 1'048 | 1'083 | 1'113 | 1'126 | 1'076 | 1'064 | 1'061 |
| Degreasing (2D3e NFR) | t NMVOC | 996 | 974 | 972 | 665 | 663 | 855 | 817 | 976 | 922 | 882 |
| Chemical products, manufacture and processing (2D3g NFR) | t NMVOC | 5'425 | 4'920 | 5'038 | 5'078 | 4'574 | 5'232 | 5'345 | 5'406 | 5'267 | 5'587 |

**Road paving with asphalt (2D3b)**

*Methodology*

Asphalt road surfaces are composed of compacted aggregate and asphalt binder. From road surfacing operations only NMVOC emissions occur. Based on the decision tree Fig. 3.1 in chapter 2D3b in the EMEP/EEA guidebook (EMEP/EEA 2019), the NMVOC emissions from 2D3b Road paving with asphalt are determined by a Tier 2 method based on country-specific emission factors as documented in EMIS 2022/2D3b NFR.

*Emission factors*

The emission factor for NMVOC emissions from 2D3b Road paving with asphalt comprises NMVOC emissions from the use of prime coatings and from the bitumen content in asphalt products (about 5%). The NMVOC content in the bitumen has decreased considerably between 1990 and 2010. The values are based on industry data from 1990, 1998, 2007, 2010 and 2013. All other years are interpolated and complemented with expert estimates documented in the EMIS database.

Table 4-42 Emission factors of 2D3b Road paving with asphalt, 2D3c Asphalt roofing and 2D3d Urea use in SCR catalysts (AdBlue) for 2020.

| | Unit | $CO_2$ | CO | NMVOC |
|---|---|---|---|---|
| **2D3b Road paving** | kg/t asphalt concrete | NA | NA | 0.54 |
| **2D3c Asphalt roofing** | kg/t asphalt sealing sheeting | NA | 0.0059 | 5.1 |
| **2D3d Urea use in SCR catalysts** | kg/kg urea solution | 0.238 | NA | NA |

*Activity data*

Activity data on the amount of asphalt products (so-called mixed goods) used for road paving is based on annual data from the association of asphalt production industry (SMI) for 1990 and from 1998 onwards and expert estimates for the years between.

Table 4-43 Activity data for road paving with asphalt, asphalt roofing and urea use in SCR catalysts.

| | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| **2D3b Road paving with asphalt** | | | | | | |
| Asphalt concrete | kt | 5'500 | 4'800 | 5'170 | 4'780 | 5'250 |
| **2D3c Asphalt roofing** | | | | | | |
| Asphalt sealing sheeting | kt | 54 | 56 | 58 | 51 | 68 |
| **2D3d Urea use in SCR catalysts** | | | | | | |
| AdBlue | kt | NO | NO | NO | 0.014 | 18 |

| | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2D3b Road paving with asphalt** | | | | | | | | | | | |
| Asphalt concrete | kt | 5'300 | 4'770 | 4'770 | 5'260 | 4'850 | 4'710 | 5'260 | 5'180 | 5'210 | 4'910 |
| **2D3c Asphalt roofing** | | | | | | | | | | | |
| Asphalt sealing sheeting | kt | 74 | 74 | 74 | 75 | 75 | 75 | 75 | 76 | 76 | 76 |
| **2D3d Urea use in SCR catalysts** | | | | | | | | | | | |
| AdBlue | kt | 21 | 22 | 24 | 25 | 26 | 29 | 31 | 34 | 36 | 33 |

**Asphalt roofing (2D3c)**

*Methodology*

This source category comprises emissions from production and use of asphalt roofing materials (saturated felt, roofing and siding shingles, roll roofing and sidings). These products are used in roofing and other building applications. From 2D3c Asphalt roofing only precursors such as CO and NMVOC arise. CO is emitted during the production process of asphalt roofing materials whereas NMVOC emissions are released during the entire production and laying processes (primers included). Based on the decision tree Fig. 3.1 in chapter 2D3c in the EMEP/EEA guidebook (EMEP/EEA 2019), the emissions of NMVOC from Asphalt roofing are determined by a Tier 2 method based on country-specific emission factors as documented in the EMIS database (EMIS 2022/2D3c Dachpappen Produktion und Verlegung). Emissions of CO are determined based on a Tier 1 method using the default emission factor for the production process from the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2D3c, Table 3.1).

Indirect $CO_2$ emissions resulting from CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

*Emission factors*

The NMVOC emission factors from asphalt roofing are based on information from the industry association, literature and expert estimates as documented in the EMIS database. Tier 1 emission factor of CO for the production process is taken from the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2D3c, Table 3.1) (see Table 4-42).

*Activity data*

Activity data is based on data from industry and expert estimates as documented in the EMIS database (see Table 4-43).

**Urea use in SCR catalysts of diesel engines (2D3d)**

This source category encompasses $CO_2$ emissions from the use of urea containing AdBlue in diesel engines with SCR-catalysts in road transportation (Euro V/VI and Euro 5/6).

*Methodology*

In accordance with the 2006 IPCC Guidelines, the consumption of Ad Blue is reported following a methodology suggested in the EMEP/EEA guidebook (EMEP/EEA 2016; part B, chp. 1.A.3.b.i-iv, page 48). A specific percentage of the fuel consumption of SCR-vehicles in road transportation according to their Euro class is applied for AdBlue consumption estimates. Emissions are calculated according to following formula:

$CO_2$ Emissions = EF • FC • Share of SCR vehicles mileage • Specific urea share

“FC” relates to the fuel consumption in tonnes of the entire vehicle category. “Share of SCR vehicles mileage” implies the mileage share of SCR-vehicles in the entire vehicle category and “Specific urea share” comprises the percentage of fuel consumption, which relates to AdBlue (urea solution) consumption.

*Emission factors*

The emission factor for $CO_2$ emissions from urea use in SCR-catalysts in vehicles is a default value from the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 1.A.3.b.i-iv, page 46) considering the molecular mass conversion of urea into $CO_2$ during the reaction with water and the content of 32.5% of the aqueous AdBlue urea solution (see Table 4-42).

*Activity data*

Activity data on AdBlue consumption as well as annual mileage are provided by INFRAS (INFRAS 2017, INFRAS 2019b) on a yearly basis as documented in EMIS 2022/2D3d NFR Urea (AdBlue) Einsatz Strassenverkehr. For activity data see Table 4-43.

### 4.5.3. Uncertainties and time-series consistency

The uncertainty of total $CO_2$ emissions from the entire source category 2D – Non-energy products from fuels and solvent use is estimated to be 14% (expert estimate). This is the combined uncertainty according to uncertainty propagation assuming 10% uncertainty for activity data and 10% uncertainty for emission factors.

Consistency: Time series for 2D Non-energy products from fuels and solvent use are all considered consistent.

### 4.5.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

### 4.5.5. Category-specific recalculations

The following recalculations were implemented in submission 2022. Major recalculations which contribute significantly to the total differences in direct and indirect $CO_2$ emissions of sector 2 IPPU between the latest and the previous submissions are presented also in chp. 10.1.2.2.

- 2D1: The activity data of source category 2D1 Lubricant use, unspecified was updated for 2019 due to a recalculation in the annual report of the Swiss petroleum association (Avenergy 2021).
- 2D1: The activity data of 2D1 Lubricant use in two-stroke engines changed for 2001–2019 due to recalculations in the gasoline consumption of two-stroke motorcycles (1A3biv) for the entire time series. Consequently, the activity data of 2D1 Lubricant use unspecified has also changed.
- 2D2: The activity data of paraffin wax use was updated for 2019 due to a recalculation in the annual report of the Swiss petroleum association (Avenergy 2021).
- 2D3a: The activity data and $CO_2$ emission factors of 2D3a Post combustion of NMVOC in coating applications (2D3d NFR), chemical products, manufacture and processing (2D3g NFR) and degreasing (2D3e NFR) were revised for 1990–2019 based on a comprehensive survey of all cantonal air pollution control authorities and VOC balances.
- 2D3d: Due to recalculations in activity data in sector 1A3b Road transportation, the use of AdBlue reported in sector 2D3d Other non-energy products from fuels and solvent use changed. Therefore, $CO_2$ fossil emissions changed in this sector for the years 2005–2019. The difference is up to 1.6 kt $CO_2$ in 2019.

### 4.5.6. Category-specific planned improvements

There are no planned improvements.

# 4.6. Source category 2E – Electronics industry

## 4.6.1. Source category description

Source category 2E Electronics industry is not a key category.

Source category 2E Electronics industry comprises HFC, PFC, $NF_3$ and $SF_6$ emissions from consumption of the applications listed in Table 4-44.

Table 4-44 Specification of source category 2E Electronics industry in Switzerland.

| 2E | Source category | Specification |
|---|---|---|
| 2E1 | Integrated Circuit or Semiconductur | Etching and cleaning processes in the production of IC and semiconductors (similar cleaning services for printed wiring boards included in the evaluation) |
| 2E2 | TFT flat panel display | No production of TFT flat panel displays in Switzerland, activities contained in the production of displays for watches |
| 2E3 | Photovoltaics | Emissions from photovoltaic manufacturing |
| 2E4 | Heat transfer fluids | No application in Switzerland assumed* |
| 2E5 | Other | Test activities (for example related to printed wiring boards), research activities |

* Heat transfer fluids subject of research, for example ORC systems. Alternative products available with low GWP as for example Novec 649 and 7000

## 4.6.2. Methodological issues

Emission calculations are based on import data from FOEN statistics for etching and cleaning processes of the electronics industry, covering different source categories as listed in Table 4-44 (until 2010 import declarations for electronic industry under solvents). Process-specific transformation and emission rates are used. A survey within the electronics industry was carried out for the submission in 2015 to distribute the imported substances to the different source categories of electronic industry and to obtain information on waste air treatment. Information was obtained on the type of substance used in different source categories, but no information on emission factors and type of efficiency of exhaust treatment. More information are available from Carbotech (2022).

**Methodology**

A Tier 2a approach with specific parameters for each gas is used for emission calculations. IPCC default values for the gas-specific transformation rate of different processes and general values for the exhaust treatment efficiency are applied according to the 2019 refinement of the 2006 IPCC Guidelines (IPCC 2019). The Tier 2a method is for semiconductor sub-sector with revised emission factors, also accounting for additional precursors and by-products.

For the inventory report 2011 (FOEN 2011) interviews were conducted with the industry to get in-depth information on allocation of imported PFC volumes to different applications and to obtain process-specific information from consumers. Until 2010, most PFC imports declared as 2F5 Solvents or 2F6 Other were related to the electronics industry (2E). Since 2011, PFC import declarations have been improved and information is provided for the source category 2E separately. A survey was carried out for the submission in 2015 to determine contributions of different source categories 2E1–2E5 in Table 4-44 (Carbotech 2022). As a result, the peak of $NF_3$ imports (and corresponding emissions) between 2009 and 2011 was found to be related to photovoltaic manufacture.

**Emission factors**

Default emission factors according to the 2019 refinement of the 2006 IPCC Guidelines are used for production and waste-air treatment (IPCC 2019). An exhaust treatment is assumed probable for most applications due to the Chemical Risk Reduction Ordinance (Swiss Confederation 2005) and given limit of 5% for the emission factor in semiconductor use. For some large users the presence of exhaust treatment was confirmed in a survey.

**Activity data**

Activity data are based on FOEN import statistics and industry information.

### 4.6.3. Uncertainties and time-series consistency

The uncertainty for the emissions from the use of HFC, PFC, $SF_6$, and $NF_3$ in 2E Electronics industry was estimated based on a Monte Carlo simulation. The obtained distribution types and numeric values for the emission uncertainties are reported in Annex A2.1. More information is available from Carbotech (2022).

Consistency: Time series for 2E Electronics industry are all considered consistent.

### 4.6.4. Category-specific QA/QC and verification

The entire time series are compared between the latest and the previous submissions. The general QA/QC measures are described in chp. 1.2.3.

### 4.6.5. Category-specific recalculations

The following recalculations were implemented in submission 2022. Major recalculations which contribute significantly to the total differences in direct and indirect $CO_2$ emissions of sector 2 IPPU between the latest and the previous submissions are presented also in chp. 10.1.2.2.

- 2E: Additional consumption of $C_5F_8$ added for 2019, transformation of $C_5F_8$ leading to emission of $CF_4$.

### 4.6.6. Category-specific planned improvements

No category-specific improvements are planned.

## 4.7. Source category 2F – Product uses as substitutes for ozone depleting substances

### 4.7.1. Source Category Description

Table 4-45 Key categories of 2F Product uses as substitutes for ozone depleting substances. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 2F1 | Refrigeration and Air Conditioning | HFC | L1, T1, L2, T2 |

Source category 2F Product uses as substitutes for ozone depleting substances comprises HFC and PFC emissions from consumption of the applications listed in Table 4-46.

Table 4-46 Specification of source category 2F Product uses as substitutes for ozone depleting substances in Switzerland.

| 2F | Source category | Specification |
|---|---|---|
| 2F1 | Refrigeration and air conditioning | Emissions from refrigeration and air conditioning (inclusive heat pumps and tumble dryers) |
| 2F2 | Foam blowing agents | Emissions from foam blowing, incl. polyurethan spray; |
| 2F4 | Aerosols | Emissions from use as aerosols, incl. metered dose inhalers |
| 2F5 | Solvents | Emissions from use as solvents |

The following graph shows HFC and PFC emissions from different applications in source category 2F. In 2020, stationary and mobile refrigeration and air conditioning equipment accounted by far for the highest emissions with a share of 98% of the total emissions in source category 2F. Further, emissions are dominated by HFCs and only a minor contribution comes from PFCs (less than 1%).

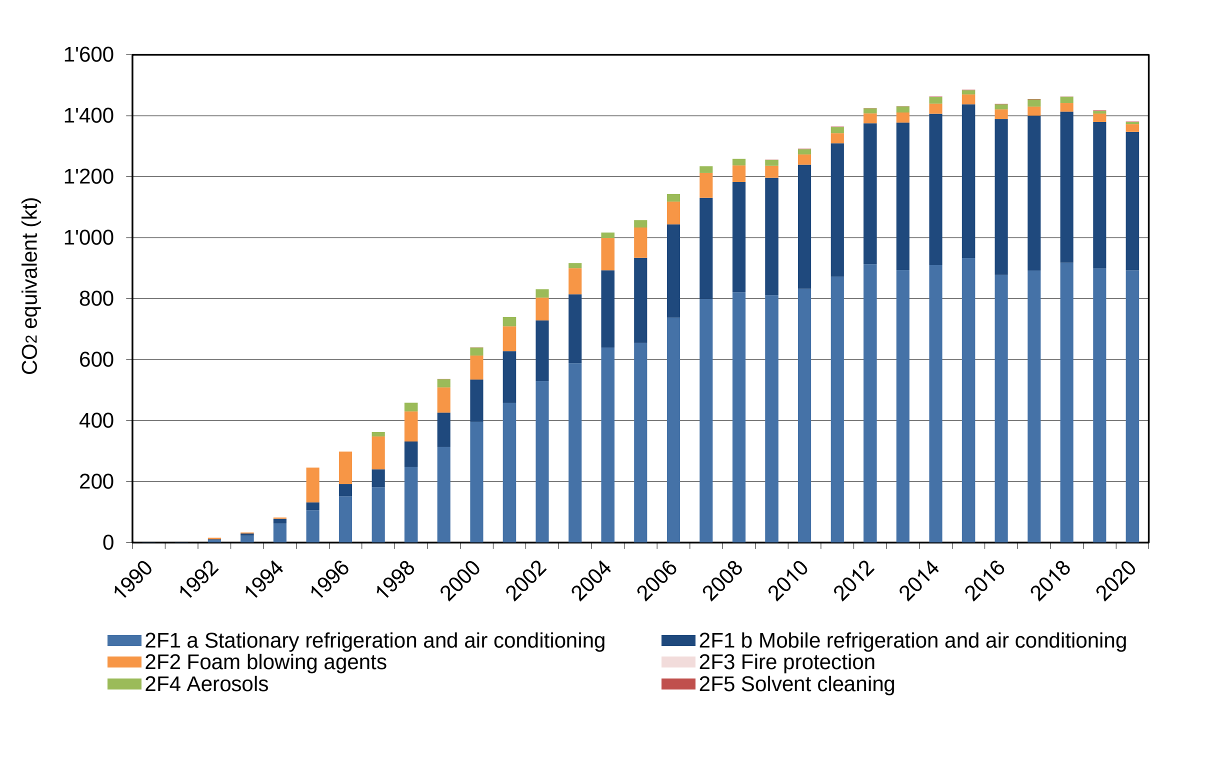


Figure 4-8 Development of emissions under source category 2F Product uses as substitutes for ozone depleting substances. HFC and small amounts of PFC are used as substitutes for ozone depleting substances. Most relevant today are emissions from the refrigerant stock in refrigeration and air conditioning equipment (2F1).

## 4.7.2. Methodological issues

The data models used for source category 2F are complex and therefore a comprehensive documentation of all relevant model parameters is not possible within the NIR. Most relevant is the contribution of 2F1 refrigeration and air conditioning. Calculations are carried out for different applications separately.

2F1a Stationary refrigeration and air conditioning

- Domestic refrigeration
- Commercial refrigeration
- Industrial refrigeration
- Stationary air conditioning, heat pumps and tumble dryers

2F1b Mobile refrigeration and air conditioning

- Mobile air conditioning in different vehicle types
- Transport refrigeration for different vehicle types

Annex A3.2 shows an illustrative example of the model structure and parameters used for calculating emissions from mobile air conditioning in cars. The most important assumptions for the data model are documented in Table 4-47. More information of the individual data and models is available from Carbotech (2022) as well as related background documents. This information is considered confidential, but it will be made available for consultation by reviewers on request.

#### 4.7.2.1. Refrigeration and air conditioning (2F1)

**Methodology**

The inventory under source category 2F1 includes different applications and equipment types. For each individual emission, models are used for calculating actual emissions as per the 2006 IPCC Guideline's Tier 2a approach (emission factor approach). In order to obtain the most reliable data for the calculations, two different approaches are applied to get the stock data needed for the model calculations. For the following applications a bottom-up approach is applied relying on statistics, product information and expert estimations:

- Domestic refrigeration
- Mobile air conditioning for different vehicle types
- Transport refrigeration for different vehicles types
- Stationary air conditioning (direct and indirect systems)
- Heat pumps
- Tumble dryers

On the other hand, a top-down approach is applied for the calculation of the stock in commercial and industrial equipment starting with the total imported amount of refrigerant. To determine the portion used for commercial and industrial refrigeration, the refrigerant consumption of other applications is subtracted from the import amount (consumption for the production and maintenance based on the bottom-up calculations of stock as given in the example of mobile air conditioning in Annex A3.2).

The total bulk refrigerant for commercial and industrial application is split considering the typical use of refrigerant blends and information on commercial and industrial equipment provided to FOEN (Carbotech 2022). Parameters for commercial and industrial applications are given in Table 4-47. Furthermore, HFC-245fa, included under commercial and industrial refrigeration, was found to be used for organic rankine cycles (ORC).

The combination of bottom-up with top-down calculations leads to more comprehensive results than using just a single approach. Noteworthy, in the hypothetical but possible case of incomplete bottom-up evaluations, the remaining imported refrigerant would be attributed to the production and maintenance of industrial and commercial refrigeration equipment. This might be the reason why the resulting refrigerant stock of commercial and industrial refrigeration, which serves as the residual, tends to be higher than in neighbouring countries.

The import data as reported to FOEN are adjusted for imported substances to be used in Liechtenstein. This is to eliminate double counting with the inventory data of Liechtenstein.

The split factor is based on the proportion of employees in the industrial and service sector (share of import for Liechtenstein <1%). The adjustment does not affect the bottom-up calculations and leads to an adjustment of commercial and industrial refrigeration mainly.

Figure 4-9 shows the required data for the model calculation of refrigeration and air conditioning.

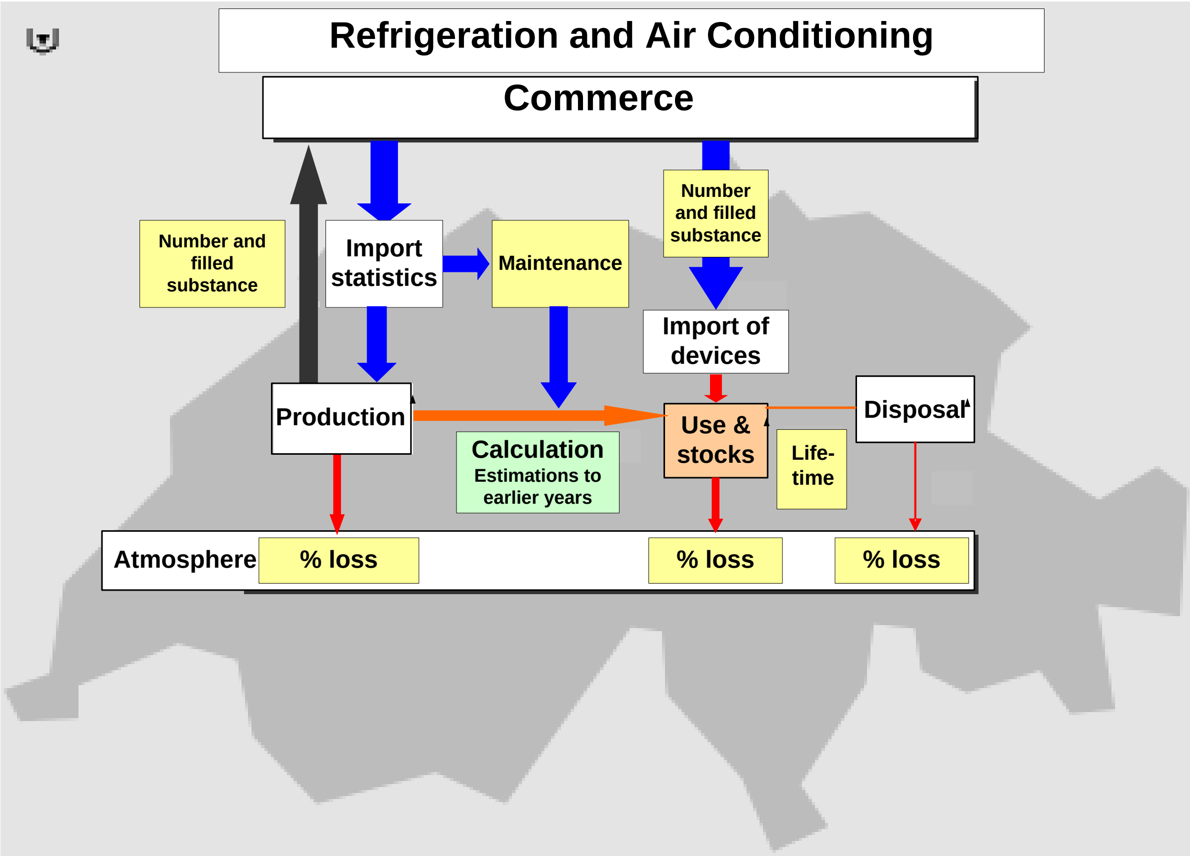


Figure 4-9 Required data for the model to calculate emissions from refrigeration and air conditioning in Switzerland.

Since 2008, there is an obligation for operators handling equipment containing more than 3 kg of HFCs to provide information to FOEN on the date of operation start, type of equipment, type and amount of refrigerant and date of disposal. This data source provides valuable information and has been applied to improve the estimates used for modelling emissions under source category 2F and for the split of commercial and industrial equipment. However, it does not allow to directly draw the stock data or emission factors for the national inventory.

### Emission factors

Emission factors related to manufacturing, product life and disposal as well as average product lifetime are established on the basis of expert judgement and literature. Direct monitoring of the product life emission factors is only done at the company level for internal use and has been used partly for the verification of the quality (confidential data from retailers and other industries). The product life factors and further parameters (i.e. re-filling frequency, handling losses and reuse of refrigerant) are used to allocate imported F-gases to new products and maintenance activities.

Table 4-47 displays the detailed model parameters used for the present submission. Changes of model parameters within the period 1990 to 2020 are indicated with values in brackets. The parameters in brackets are applied for the inventory 2020. For product life emission factors of some equipment types, a dynamic model is applied, which implies that emissions decreased linearly between 1995 and 2015 due to improved production technologies and the continuous sensitisation of service technicians. The start/end values are based on expert statements (UBA 2005, UBA 2007, Schwarz 2001, Schwarz and Wartmann 2005). The charge at the end of life for different applications has been analysed considering the technical minimal charge of the equipment and the expected frequency of the maintenance (UBA/Ökorecherche 2012). Disposal losses are calculated based on expert assumptions on the portion of broken equipment (100% loss) and on assumptions on disposal losses for professional recovery on site or waste treatment by specialized companies.

Table 4-47 Typical values of lifetime, charge and emission factors used in the model calculations for 1990 to 2020 for refrigeration and air conditioning equipment. Changes of model parameters within this time period are indicated with the new value in brackets (for example a charge of 4.7–7.5 kg was applied for heat pumps until 2000 and a lower charge of 2.8–4.5 kg from 2000 onwards). A linear interpolation is applied for the product life emission factor of commercial and industrial refrigeration, stationary air conditioning and for the emission factor of mobile air conditioning within the given time period.

| Equipment type | Product life time | Initial charge of new product | Manufacturing emission factor | Product life emission factor | Charge at end of life *) | Export of retiring equipment **) | Disposal loss emission factor ***) |
|---|---|---|---|---|---|---|---|
| | [a] | [kg] | [% of initial charge] | [% per annum] | [% of initial charge of new product] | [% of retiring equipment] | [% of remaining charge] |
| Domestic refrigeration | 16 | 0.1 | NO | 0.5 | 92 | 0-5 | 19 ****) |
| Commercial refrigeration | 8 | NR | 0.5 | Sinking from 12.5 in 1990 to 7.8 in 2015 | 80-90 | NE | 21 |
| Industrial refrigeration | 15 | NR | 0.5 | Sinking from 10 in 1990 to 5 in 2015 | 75-90 | NE | 15 |
| Transport refrigeration: trucks/vans | 10 | 1.8-7.8 | 1.5 | 15 | 86 | 90 | 28 |
| Transport refrigeration: wagons | 16 | NR | NO | 10 | 100 | NE | 28 |
| Stationary air conditioning: direct cooling systems | 15 | NR | 3 (2005: 1) | Sinking from 10 in 1995 to 4 in 2010 | 74-89 | NE | 28 |
| Stationary air conditioning: indirect cooling systems | 15 | NR | 1 | Sinking from 6 in 1995 to 4 in 2010 | 85-89 | NE | 19 |
| Stationary air conditioning: heat pumps | 15 | 4.7-7.5 (2000: 2.8-4.5) | 3 (2005: 1) | 2 | 86 | NE | 19 |
| Stationary air conditioning: tumble dryers | 15 | 0.4 | 0.5 | 2 | 74 | NE | 19 |
| Mobile air conditioning: cars | 15 | Sinking from 0.84 1990 to 0.55 in 2014 | NO | 8.5 | 58 | 31-72 (2016: 48) | 50 |
| Mobile air conditioning: truck/van cabins | 12 | 1.1 | NO | 10 (2010: 8.5) | 69-73 | 90 trucks 50 vans | 50 |
| Mobile air conditioning: buses | 12 | 7.5 | NO | 20 (2001: 15) | 100 | 50 | 50 |
| Mobile air conditioning: trains | 16 | 20 | NO | 5.5 | 100 | 50 | 20 |

*) Calculated value taking into account annual loss and portion refilled over the whole product life where applicable.

**) Allocation of disposal losses to export country (export for reselling and secondhand use)

***) Calculated value taking into account share of total refrigerant loss and emission factor of professional disposal. Disposal losses of HFC and PFC occur from 2000 onwards (introduction of HFCs and PFCs starting 1991 and 8 to 16 years lifetime of equipment). The value of 50% for mobile air conditioning is based on UBA 2005 and expert assumptions on share of total refrigerant loss, e.g. due to road accident.

****) Takes into account HFC-134a content in foams, based on information from the recycling organisation SENS.

NR = Not relevant as only aggregate data is used

NO = Not occurring (only import of charged units)

NE = Not estimated

**Activity data**

Activity data are taken from industry information and national statistics such as for admission of new cars, buses, vans and trucks. Stock data is modelled dynamically. Due to the large number of sub-models used for modelling the total emissions for source category 2F1, no table on time series of activity data is provided here. For illustration, Annex A3.2 shows the detailed calculation model for car air conditioning including the time series for the activity data for this particular sub-model. Mobile air conditioning accounts for approx. 33% of the total emissions ($CO_2$ eq) of source category 2F1 Refrigeration and air conditioning in the inventory 2020.

For the NIR 2012 (FOEN 2012) a cross check has been performed for results from model calculation and FOEN statistics on disposal and recycling of HFCs. This has indicated a significant gap with higher disposal values in model calculations compared to the FOEN disposal statistics. Some of the gap is explained by the onsite reuse and recycling of refrigerants, which is not reflected in the FOEN statistics and by other factors as e.g. the not accounted export of refrigeration equipment for second-hand use. Export rates used in model calculations are given in Table 4-47.

The registered refrigerant import is assumed to cover the consumption of Switzerland and Liechtenstein. To avoid double counting with the inventory data of Liechtenstein, the activity data for the equipment type commercial and industrial refrigeration is reduced by 0.9%, based on the share of imports of substances to be used in Liechtenstein. The reduction factor is based on the proportion of employees in the industrial and service sector in these two countries. For other equipment types no scope for double counting with the inventory of Liechtenstein was identified and therefore no correction factor is applied.

### 4.7.2.2. Foam blowing agents (2F2)

**Methodology**

In Switzerland no production of open cell foam based on HFCs is reported by the industry. Therefore, only closed cell PU and XPS foams, PU spray applications and further closed cell applications as sandwich elements are relevant under source category 2F2.

The emission model (Tier 2a) for foam blowing has been developed top down based on import statistics for products, industry information and expert assumptions for market volumes and emission factors. Emissions from further not specified applications of foam production have been calculated (Tier 1a) as residual balance between FOEN import statistics and consumption in PU spray, PU and XPS foams.

A desktop research on HFC-245fa use in neighbouring countries was carried out for the inventory 2019 to identify the relevance of HFC-245fa emissions from the import of foam products. HFC-245fa has not been used for foam blowing in Switzerland, but measurements at the Jungfraujoch site by Empa (see chp. 4.7.4 and Annex A5.1) indicate emissions probably related to the import of foam products. Due to the low relevance, lacking data and the decreasing use in neighbouring countries since 2005 (partly through bans) the model calculations were not extended with HFC-245fa (Carbotech 2022).

### Emission factors

For the emission factors and the lifetimes of XPS and PU foams, expert estimates and default values according to the 2006 IPCC Guidelines (IPCC 2006, Volume 3, p. 7.37) are used. For PU sprays, expert estimates and specific default values according to the 2006 IPCC Guidelines (IPCC 2006, Volume 3, p. 7.37) are used. Unknown applications are evaluated following the Gamlen model recommended in the 2006 IPCC Guidelines (IPCC 2006). First-year losses are allocated to the country of production.

Table 4-48 Typical values on lifetime, charge and emission factors used in model calculations for foam blowing.

| **Product** | **Product lifetime** | **Charge of new product** | **Manufacturing emission factor** | **Product life emission factor** | **Charge at end of life** |
|---|---|---|---|---|---|
| Foam type | years | % of product weight | % of initial charge | % per annum | % charge of new product |
| PU foam | 50 | 4.5 | NR | NR | Calculated charge minus emissions over lifetime (so far not relevant, products still in use) |
| XPS foam HFC-134a | 50 | 6.5 | NR | NR / 0.7** | |
| XPS foam HFC-152a | | | | 100 / 0** | |
| PU spray all HFC | 50 | 13.6 / 0 * | <1% | 95 / 2.5 ** | |
| Unknown use: | | | | | |
| HFC 134a, HFC 227ea, HFC 365 mfc | 20 | NR | 10 | 10 / 4.5 ** | |
| HFC 152a | | | 100 | 100 / 0 ** | |

* The first value represents the charge of HFC 1995 (start of HFC use as substitutes for ozone depleting substances). The HFC amount was reduced continuously between 1995 and 2008. Since 2009 the production of PU spray is HFC free in Switzerland.

** Data for 1st year / following years (HFC-152a all emissions allocated to production)

NR Not relevant (PU foam: no substances according to this protocol have been used; XPS foam: emissions occur outside Switzerland; unknown use: calculations are based on the remaining propellant import amount).

### Activity data

HFCs have been used until 2008 in the Swiss production of PU spray. The export rate of PU spray from Swiss production was about 96.5% of the total production volume in the time period of the HFC use. About one third of the PU spray sold in Switzerland originates from local production, the rest is imported. For PU rigid foams no HFCs are used as foam blowing agent (only pentane and $CO_2$). There has been no production of XPS in Switzerland with HFCs. XPS foams were 100% imported until 2010. In 2011 a new production facility was started which, however, does not use HFCs. The HFC import not related to the main applications above has been allocated to further unknown applications (possible use in the production of sandwich elements mentioned by an import company of foam blowing agents has not been confirmed).

Detailed activity data for this source category are considered confidential, but are available to reviewers on request.

### 4.7.2.3. Fire protection (2F3)

No emissions occur in source category 2F3 within Switzerland. The application of HFCs, PFCs and $SF_6$ in fire extinguishers is prohibited by law.

### 4.7.2.4. Aerosols (2F4)

**Methodology**

The Tier 2a emission model for Aerosol / metered dose inhalers is based on a top-down approach using import statistics for HFCs.

**Emission factors**

A manufacturing emission factor of 1% is applied. The model then assumes prompt emissions, i.e. 50% of the remaining substance is emitted in the first year and the rest in the second year, in line with the 2006 IPCC Guidelines (IPCC 2006).

**Activity data**

In most aerosol applications, HFCs have been replaced already in the past years. According to the information of companies filling aerosol bottles for use in households, e.g. cosmetics, cloth care and paint, no HFC is being used. For special technical applications – especially metered dose inhalers (MDI) – HFC is still in use. Compared to the total amount of aerosol applied, the HFC use for MDI is considered to be irrelevant.

Activity data are based on import statistics. The export and import of filled products is unknown, but assumed to be in a similar range.

### 4.7.2.5. Solvents (2F5)

**Methodology**

HFCs and PFCs are used as solvents. Emissions are calculated according to a Tier 1a method according to the 2006 IPCC Guidelines on basis of a top-down approach using import statistics and industry information on allocation of the imported HFC and PFC amounts to different applications.

The import data as reported to FOEN cover imported substances to be used in Switzerland and Liechtenstein, and are therefore split in proportion of inhabitants of the two countries to avoid double counting.

**Emission factors**

In line with the 2006 IPCC Guidelines prompt emissions are assumed, i.e. half of the initial amount is emitted in the first year, the other half in the second year.

**Activity data**

Activity data are based on import statistics. Imports before 2011 were included under solvents. Therefore, the model for allocation of imported PFC volumes was adjusted accordingly for substances related to the electronics industry. Since 2011 imports for semiconductors manufacturing and further etching processes of electronics industry are registered as separate category in FOEN import statistics.

To avoid double counting with the inventory data of Liechtenstein, the import data reported to FOEN which is assigned to source category 2F5 in the inventory of Switzerland is reduced by 0.5%. The reduction factor is based on the proportion of inhabitants in these two countries.

#### 4.7.2.6. Other applications (2F6)

There are no further applications of substitutes for ozone depleting substances in Switzerland.

### 4.7.3. Uncertainties and time-series consistency

For refrigeration equipment, air conditioning equipment as well as for foam blowing, a Monte Carlo analysis according to IPCC Good Practice Guidance (IPCC 2000) for the evaluation of uncertainties of model calculations according to Tier 1 and 2 has been carried out. The Monte Carlo analysis was performed on the inventory data of the latest GHG inventory (submission 2022). For the purpose of the Monte Carlo analysis, the uncertainty of all relevant parameters (e.g. initial appliance charge, product life emission factor, import and export volumes, etc.) used in the emission models for the applications as per Table 4-49 below has been characterised using the following statistical distributions:

- Triangular distribution (defined by the three parameters minimum, maximum and most likely value)
- Uniform distribution (same probability for the whole spectrum)
- Normal or lognormal distribution

The analysis was carried out with 5’000 cycles. Details on the distributions of parameters used (i.e. type of distribution, minimum, maximum, most likely value) are available from background documents at FOEN (Carbotech 2022).

For the submission 2006 the uncertainty for the import statistic data had been estimated for the first time. Discussions with the persons responsible for data collection in the years 1997–2015 led to the estimations of standard deviation and minimal and maximal values given in Table 4-49. A normal distribution is used in the Monte Carlo analysis and the standard deviation, minimal and maximal values applied to define the probability ranges.

Table 4-49 Estimated uncertainty for the data of the imported substances.

| Year | Std. Dev. | Minimal | Maximal | Remarks |
|---|---|---|---|---|
| Up to 1999 | 20% | 15% | 50% | Assumed that the data is not complete |
| 2000 – 2003 | 20% | 20% | 20% | Data can be incomplete or possible double declaration |
| 2004 – 2020 | 10% | 20% | 20% | Data can be incomplete or possible double declaration |

The probability range of parameters applied in the model calculation is defined based on the variation given in expert interviews and the literature. Table 4-50 illustrate the definition of ranges for the example of commercial refrigeration.

Table 4-50 Assumptions on probability ranges for the example of commercial refrigeration.

| Parameter | appplied "likeliest" | Minimal | Maximal | Remarks |
|---|---|---|---|---|
| Initial charge of product | NR | NR | NR | Not relevant, calculated value |
| Manufacturing emission factor | 0.5% | 0.1% | 3% | Triangular distribution |
| Prefilled import | 25% | 10% | 40% | Normal distribution, StdDev5% |
| Product life emission factor 1990 | 12.5% | 5% | 20% | Normal distribution, StdDev5% |
| Product life emission factor 2020 | 7.2% | 5% | 15% | Lognormal distribution, StdDev2% |
| Recharge of product life emissions | 80% | 70% | 100% | Triangular distribution |
| Product lifetime | 8 | 7 | 15 | Triangular distribution |
| Charge at end of life | NR | NR | NR | Not relevant, calcualted value |
| Disposal loss emission factor (professional disposal) | 10% | 1% | 40% | Normal distribution, StdDev10% |
| Professional disposal | 85% | 45% | 95% | Normal distribution, StdDev5% |

Table 4-51 summarises the results for the application-specific emission models. The “value 2020” represents the reported emissions in kt $CO_2$ eq for the specific application for the year 2019. The uncertainty values stem from the Monte Carlo analysis. Detailed data are available from background documents at FOEN (Carbotech 2022).

The uncertainty of the resulting total emissions from source category 2F Product uses as substitutes for ODS is about 20%. Higher values result for the contributions of sub-categories and for single applications evaluated under 2F1. The calculated refrigerant amount for commercial and industrial refrigeration depends on the consumption of further refrigerant applications. Higher consumption for those applications lead to lower consumption in commercial and industrial applications and vice versa.

Relevant parameters for the building of stock in foam are the PU foam import and export rate of past years and the PU spray first year emission factor. The data base for PU sprays has been significantly improved with effect from the 2007 submission (FOEN 2007). This is attributed to improved models which have been elaborated by the main producer and its blowing agent import firm. However, the following three factors lead to a small amount remaining in the stock with a relative high uncertainty: high import and export rate of PU spray, lacking information on import of PU spray and on propellant used in import products and high uncertainty regarding the emission factor of the first year.

Table 4-51 Summary of results for model parameter “emissions” from Monte Carlo analysis for 2020 data on selected emission sources.

| Application | Model parameter | Value 2020<br>kt $CO_2$ eq. | Average<br>kt $CO_2$ eq. | Median<br>kt $CO_2$ eq. | min.<br>kt $CO_2$ eq. | max.<br>kt $CO_2$ eq. | Uncertainty<br>% |
|---|---|---|---|---|---|---|---|
| 2F1 Refrigeration and air conditioning | Emissions in kt $CO_2$ eq. | 1'341 | 1'411 | 1'403 | 1'030 | 1'983 | 19 |
| 2F2 Foam blowing agents | | 26 | 41 | 36 | 6 | 218 | 173 |
| 2F4 Aerosols | | 6 | 6 | 6 | 2 | 12 | 41 |
| 2F5 Solvents | | 0.7 | 0.6 | 0.6 | 0.2 | 0.9 | 59 |
| Total 2F Product use as substitutes for ODS | | 1'374 | 730 | 1'446 | 1'039 | 2'214 | 20 |

Consistency: Time series for 2F are all considered consistent.

### 4.7.4. Category-specific QA/QC and verification

The entire time series are compared between the latest and the previous submissions. Recalculations were identified and correspond to applied changes and improvements in model calculations.

The assumptions of decreasing emission factors for the different equipment types under source category 2F1 Refrigeration and air conditioning have been cross-checked with the inventories of Austria and Germany and have been found to be in line with the assumptions made for these inventories.

The FOEN supports a monitoring campaign at the high-altitude research station Jungfraujoch, where various greenhouse gases are measured continuously. The location of the research station normally provides analyses of tropospheric background concentrations. However, under special meteorological conditions, an estimate of Swiss emissions can be derived from the measurements. For five HFCs (HFC-134a, HFC-125, HFC-152a, HFC-143a, HFC-32) and for $SF_6$ a comparison of the inventory data with the inferred emissions is presented in Annex A5.1. Estimated emissions based on measurements at Jungfraujoch agree fairly well with the emission estimates of HFC-134a, HFC-125, HFC-143a, HFC-32 and of $SF_6$ of the Swiss greenhouse gas inventory. Larger differences result for less relevant contributions of HFC-152a. The allocations of first year emissions of foam blowing agents to the country of production might be the reason for the observed differences.

### 4.7.5. Category-specific recalculations

Recalculations reported in submission 2022:

- 2F2: A correction of roundings was made, using two decimal places as applied for other emission factors.

### 4.7.6. Category-specific planned improvements

Changes are expected and will be analysed in this area due to the revision of the Chemical Risk Reduction Ordinance and $CO_2$ compensation programmes (share of products with HFC, recycling of HFC, replacement of HFC).

## 4.8. Source category 2G – Other product manufacture and use

### 4.8.1. Source category description

Table 4-52 Direct emissions of 2G Other product manufacture and use are not a key category. Indirect emissions are documented in chp. 9.

Table 4-53 Specification of source category 2G Other product manufacture and use.

| 2G | Source category | Specification |
|---|---|---|
| 2G1 | Electrical equipment | Emissions of $SF_6$ from use in electrical equipment |
| 2G2 | $SF_6$ and PFCs from other product use | Emissions of $SF_6$ and PFC not accounted in other source categories (i.e. for particle accelerators, soundproof windows, leakage detection, medicinal products, research and laboratory use) |
| 2G3 | $N_2O$ from product uses | Emissions of $N_2O$ from the use of $N_2O$ in hospitals;<br>Emissions of $N_2O$ from the use of aerosol cans |
| 2G4 | Other | Emissions of NMVOC from domestic solvent use, printing, other solvent and product use as well as emissions of $CO_2$ resulting from post-combustion of NMVOC in exhaust gases of these sources;<br>Emissions of $CO_2$, $NO_x$, CO, NMVOC and $SO_2$ from use of fireworks;<br>Emissions of $NO_x$, CO and NMVOC from use of tobacco;<br>Emissions of HFC not accounted in other source categories |

### 4.8.2. Methodological issues

#### 4.8.2.1. Electrical equipment (2G1)

**Methodology**

Under an agreement with FOEN, the industry association SWISSMEM is reporting actual emissions of $SF_6$ on the basis of a mass-balance approach (Tier 3a). The mass balance includes mainly data for the production, installation, operation and disposal of electrical equipment, but included in past years also small amounts of $SF_6$ for other applications (i.e. research, magnesium foundry). SWISSMEM is collecting data from its members and is cross-checking the reported $SF_6$ consumption data with data from importers of $SF_6$. Installations in operation with electrical equipment containing $SF_6$ are periodically inspected for leakage, and losses are refilled (topping up). The refilled quantities and any $SF_6$ charge required during repair are reported as emissions at the time of filling. A product lifetime of 35 years is assumed.

**Emission factors**
Emission factors for source category 2G1 are based on industry information and are calculated values based on the mass-balance data. The discontinuity in emission factor from 2005 to 2006 data is due to the inspection intervals, optimised data collection and technical optimisation of equipment. The trend for reduced emission factors can be linked to the existing agreement of SWISSMEM and FOEN on the reduction of $SF_6$ emissions.

**Activity data**
Activity data are based on industry information. The wide annual fluctuation of $SF_6$ emissions from electrical equipment is related to the annual fluctuation of market volumes for such equipment as well as variations in inspection intervals and equipment break-down requiring topping up of $SF_6$ charge in the equipment. Import declarations obtained for FOEN import statistics are cross-checked regularly in order to eliminate double counting between SWISSMEM data and other import declarations.

### 4.8.2.2. $SF_6$ and PFCs from other product use (2G2)

**Methodology**
The emissions reported under 2G2 are related to the use of $SF_6$ for industrial particle accelerators (2G2b), the use of $SF_6$ for soundproof windows (2G2c) and other PFC and $SF_6$ use (2G2e). 2G2e summarizes medicinal products, research/analytics and further applications that are not specified (including the unallocated difference in $SF_6$ emissions based on the FOEN import statistics and the SWISSMEM mass balance).

Under an agreement with FOEN, the industry association SWISSMEM is reporting actual emissions of $SF_6$ from industrial particle accelerators on the basis of a mass-balance approach (Tier 3a).

For 2G2c soundproof windows and 2G2e Other a Tier 2 approach is applied for $SF_6$. Therefore, the unallocated amount of $SF_6$ under 2G2e has been modelled assuming applications similar to those in 2G1.

Further evaluations of applications under 2G2e are based on FOEN import statistics and industry data, including applications with direct emissions and applications with banks. No further details are provided due to confidentiality. They are available in the confidential NIR for reviewers on request.

**Emission factors**
For the unallocated amount of $SF_6$, the emission factor is assumed to be 4% for manufacturing and 1% per year during the product life. The remaining charge is completely emitted at the time of disposal after a lifetime of 40 years. Because of the long lifetime, the disposal emissions are not yet relevant for the results.

For soundproof windows an emission rate of 1% per year is assumed, including the portion of broken windows. For the manufacturing an emission factor of 33% is assumed. However, since 2008, there is no production of windows with $SF_6$ in Switzerland.

### Activity data

Activity data are based on import statistics and industry information. For the unallocated amount of $SF_6$ an export rate of 80% is assumed similar to electrical equipment 2G1. For the inventory report submitted in 2015 (FOEN 2015), the split factors for allocation of imported amounts to different applications was checked through industry interviews and in-depth analysis in order to eliminate double counting between SWISSMEM data and other import declarations. Interviews with industry were carried out for the present inventory to identify applications of substances related to research and analytics under source category 2G2e Other.

## 4.8.2.3. $N_2O$ from product uses (2G3)

### Methodology

Emissions of $N_2O$ from the source category 2G3 occur from the anaesthesia use in hospitals (2G3a Medical applications) and from the use of aerosol cans in households and restaurants (2G3b Other). For both categories a Tier 2 method based on country-specific emission factors for the production/consumption of $N_2O$ is used (IPCC 2006, vol. 3 chp. 8.4).

### Emission factors

For source category 2G3a Medical applications the emission factor is calculated based on the amount of $N_2O$ sold for anaesthesia purpose in Switzerland divided by the number of inhabitants. The amount of $N_2O$ sold is derived from annual sales data from the main suppliers from 2005 onwards (EMIS 2022/2G3a Lachgasanwendung Spitäler).

Source category 2G3b Other includes $N_2O$ emissions from whipped-cream makers using gas capsules for private households and restaurants. The emission factor is calculated based on sales data and $N_2O$ content of gas capsules sold in Switzerland divided by the number of inhabitants (EMIS 2022/2G3b Lachgasanwendung Haushalt).

Table 4-54 $N_2O$ emission factors for the source categories 2G3a Medical applications and 2G3b Other.

| 2G3a Use of $N_2O$ for anaesthesia | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| $N_2O$ | g/inhabitant | 43 | 30 | 16 | 13 | 6.8 |
| **2G3b $N_2O$ from aerosol cans** | | | | | | |
| $N_2O$ | g/inhabitant | 9.0 | 10 | 11 | 11 | 12 |

| 2G3a Use of $N_2O$ for anaesthesia | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_2O$ | g/inhabitant | 6.1 | 5.7 | 3.5 | 3.8 | 3.3 | 2.5 | 2.3 | 2.2 | 2.1 | 2.0 |
| **2G3b $N_2O$ from aerosol cans** | | | | | | | | | | | |
| $N_2O$ | g/inhabitant | 12 | 12 | 11 | 11 | 11 | 10 | 10 | 10 | 10 | 10 |

### Activity data

As the emission factors are expressed in g $N_2O$ per capita, the corresponding activity data for the source categories 2G3a Medical applications and 2G3b Other are the Swiss population (SFSO 2021c).

Table 4-55 Activity data for the source categories 2G3a Use of $N_2O$ for anaesthesia and 2G3b $N_2O$ from aerosol cans.

| 2G3 $N_2O$ from product uses | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| 2G3a, 2G3b | inhabitants | 6'712'000 | 7'041'000 | 7'184'000 | 7'437'000 | 7'825'000 |

| 2G3 $N_2O$ from product uses | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2G3a, 2G3b | inhabitants | 7'912'000 | 7'997'000 | 8'089'000 | 8'189'000 | 8'282'000 | 8'373'000 | 8'452'000 | 8'514'000 | 8'575'000 | 8'638'000 |

## 4.8.2.4. Other (2G4)

### Other solvent use (2G4)

Since the IPCC Guidelines (IPCC 2006, vol. 3, chp. 5.5) refer to the EMEP/EEA guidebook regarding methodologies for estimating NMVOC emissions from solvent use, the respective NFR codes are indicated as reference as well. Within 2G4 Other solvent use, the NMVOC emissions from domestic solvent use (2D3a NFR), printing (2D3h NFR), other solvent use (2D3i NFR) as well as other product use (2G NFR) are reported. Domestic solvent use comprises mainly the use of cleaning agents, detergents, cosmetics and toiletries in private households whereas the other three NFR source categories consist of solvent applications in various production processes and services and the use of solvent-based products in various industrial processes, services and commerce. Domestic solvent use is by far the largest NMVOC emission source of 2G4 Other solvent use. Indirect $CO_2$ emissions resulting from NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

*Methodology*

For the determination of NMVOC emissions from domestic solvent use (2D3a NFR), printing (2D3h NFR), other solvent use (2D3i NFR) and other product use (2G NFR) a Tier 2 method according to the EMEP/EEA guidebook (EMEP/EEA 2019) is used. For domestic solvent use, the emissions are based on the products consumed and their solvent content and are calculated in proportion to the Swiss population. For package printing and other printing industry the emissions are based on the ink consumption, for other solvent use mainly on the number of employees and for other product use on the number of employees and products applied or manufactured. Switzerland's Informative Inventory Report (FOEN 2022b, chp. 4.5.2.1, 4.5.2.8, 4.5.2.9 and 4.6.2.1) contains a detailed description of the country-specific emission factors and activity data of these four NFR source categories.

### Post-combustion of NMVOC from other solvent use (2G4)

Due to the obligations of the Ordinance on Air Pollution Control (Swiss Confederation 1985) and Ordinance on the Incentive Tax on Volatile Organic Compounds (Swiss Confederation

1997) several industrial plants use facilities and equipment to reduce NMVOC in exhaust gases and room ventilation output. Often this implies the feeding of air with high NMVOC content into the burning chamber of boilers or other facilities to incinerate NMVOC. These $CO_2$ emissions from post-combustion of NMVOC are estimated based on industry data and expert estimates (Carbotech 2022a).

*Methodology*

The $CO_2$ emissions from post-combustion of NMVOC are calculated by a Tier 2 method using country-specific emission factors. Emissions are calculated based on the amount of NMVOC (and their carbon content) destroyed in the respective combustion facility of more than 100 industrial plants (Carbotech 2022a).

Post-combustion facilities are applied in source categories 2D3a Solvent use (see chp. 4.5.2.2) and 2G4 Other solvent use comprising printing (2D3h NFR), other solvent use (2D3i NFR) and other product use (2G NFR). In 2018, the source category allocation of all post-combustion plants has been verified. For the ten largest facilities (within 2D3a and 2G4), which are responsible for about 70% of the emissions, the NMVOC quantities and respective carbon contents based on the composition of the solvents are updated annually whereas all the others every five years. For the latest submission, a complete update of all facilities was carried out by means of a survey of all cantonal air pollution control authorities, in addition, with VOC balances. If no information of the solvent composition is available, mean source category-specific values are applied for the carbon content.

Not all facilities have been in use for the entire period 1990–2020. There was a significant increase in total number of facilities from 32 in the year 1990 to 115 in 2002. Since then, the number fluctuates around 120.

These amounts of NMVOC eliminated by post-combustion are also declared in the respective VOC balances of the industrial plants and are thus not included as NMVOC emissions. When deriving the NMVOC emission factors for these source categories, the amount of NMVOC destroyed in post-combustion facilities is taken into account, i.e. the NMVOC emission factor is reduced accordingly.

*Emission factors*

$CO_2$ emission factors are derived based on the composition of the solvents (carbon content) destroyed in each post-combustion installation. For the ten most important installations (within 2D3a and 2G4), amount and composition of solvents destroyed are updated annually whereas for all others at least every five years. In between the values are kept constant (see Table 4-56). For installations with no information on the solvent composition, mean industry-specific values are applied. The emission factors given in Table 4-56 are (source category specific) implied emission factors that depend both on carbon content and respective amount of the destroyed NMVOC. Thus, the implied emission factors of source categories with large post-combustion facilities may vary significantly over the years, due to changes in solvent compositions and amounts, starting-up or shutting down of facilities, etc.

Table 4-56 $CO_2$ emission factors for post-combustion of NMVOC in 2G4 Other.

| 2G4 Other | Unit | $CO_2$ | | | | |
|---|---|---|---|---|---|---|
| **Post-combustion of NMVOC** | | **1990** | **1995** | **2000** | **2005** | **2010** |
| Printing (2D3h NFR) | t/t NMVOC | 2.25 | 2.20 | 2.17 | 2.14 | 2.14 |
| Other solvent use (2D3i NFR) | t/t NMVOC | 1.97 | 1.96 | 1.96 | 1.94 | 1.95 |
| Other product use (2G NFR) | t/t NMVOC | 1.30 | 1.60 | 1.64 | 1.71 | 1.90 |

| 2G4 Other | Unit | $CO_2$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Post-combustion of NMVOC** | | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
| Printing (2D3h NFR) | t/t NMVOC | 2.14 | 2.14 | 2.14 | 2.15 | 2.09 | 2.10 | 2.10 | 2.09 | 2.10 | 2.00 |
| Other solvent use (2D3i NFR) | t/t NMVOC | 1.97 | 1.98 | 2.00 | 2.05 | 2.27 | 2.27 | 2.27 | 2.27 | 2.27 | 2.49 |
| Other product use (2G NFR) | t/t NMVOC | 1.73 | 1.76 | 1.77 | 1.74 | 1.67 | 1.71 | 1.69 | 1.75 | 1.79 | 1.83 |

*Activity data*

Activity data are the amounts of NMVOC destroyed in post-combustion installations and are provided by the industry, VOC balances and cantonal air pollution control authorities. For the ten most important installations (within 2D3a and 2G4), they are updated annually whereas for all others at least every five years.

Table 4-57 Activity data of NMVOC post-combustion in 2G4 Other.

| 2G4 Other | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| **Post-combustion of NMVOC** | | | | | | |
| Printing (2D3h NFR) | t NMVOC | 2'188 | 9'357 | 11'276 | 13'036 | 13'414 |
| Other solvent use (2D3i NFR) | t NMVOC | 288 | 474 | 530 | 395 | 554 |
| Other product use (2G NFR) | t NMVOC | 412 | 1'034 | 1'217 | 939 | 688 |

| 2G4 Other | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Post-combustion of NMVOC** | | | | | | | | | | | |
| Printing (2D3h NFR) | t NMVOC | 14'831 | 14'091 | 14'424 | 13'752 | 14'112 | 14'477 | 15'661 | 15'292 | 15'423 | 14'732 |
| Other solvent use (2D3i NFR) | t NMVOC | 563 | 573 | 583 | 364 | 368 | 360 | 352 | 344 | 336 | 58 |
| Other product use (2G NFR) | t NMVOC | 964 | 964 | 996 | 1'046 | 1'086 | 1'097 | 1'255 | 1'224 | 1'237 | 1'154 |

**Other product use (2G4)**

In addition to NMVOC emissions from the use of solvent-based products in industrial processes, services and commerce, emissions of $CO_2$, $NO_x$, CO and $SO_2$ as well as of $NO_x$, CO and NMVOC from the use of fireworks and tobacco, respectively, are reported in source category 2G4 Other product use (2G NFR).

Since the emissions of CO and NMVOC from tobacco use are of biogenic origin, they are not considered for calculation of indirect $CO_2$ emissions. Thus indirect $CO_2$ emissions resulting from CO emissions from use of fireworks only are included in CRF Table6 as documented in chp. 9.

*Methodology*

The emissions are determined by a Tier 2 method according to the EMEP/EEA guidebook (EMEP/EEA 2019) using country-specific emission factors. For tobacco use a description of the country-specific emission factors and activity data is given in Switzerland's Informative Inventory Report (FOEN 2022b, chp. 4.6.2).

*Emission factors*

The emission factors for $CO_2$, $NO_x$, CO and $SO_2$ from the use of fireworks are documented in FOEN (2014p) and are displayed in Table 4-58.

Table 4-58 Emission factors for $CO_2$, $NO_x$, CO, $SO_2$ for source category 2G4 Use of fireworks in 2020.

| 2G4 Other | Unit | $CO_2$ | $NO_x$ | CO | $SO_2$ |
|---|---|---|---|---|---|
| **Other product use (2G NFR)** | | | | | |
| Fireworks | kg/t | 43 | 0.26 | 7.4 | 4.1 |

*Activity data*

Activity data for the use of fireworks are annual sales figures based on the statistics of the Swiss federal office for police (FEDPOL 2021).

Table 4-59 Activity data for source category 2G4 Use of Fireworks.

| 2G4 Other | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| **Other product use (2G NFR)** | | | | | | |
| Fireworks | kt | 0.8 | 1.0 | 1.5 | 1.4 | 1.7 |

| 2G4 Other | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Other product use (2G NFR)** | | | | | | | | | | | |
| Fireworks | kt | 2.0 | 1.9 | 2.3 | 1.8 | 1.6 | 1.2 | 1.7 | 1.8 | 1.0 | 1.0 |

**HFC not accounted in other source categories (2G4)**

Emissions of HFC not accounted for in any other source categories are reported under 2G4 Other. For confidentiality reasons, no further details are provided here. Information is documented in the confidential NIR.

*Methodology*

A Tier 2 approach is applied for HFCs with prompt emissive applications based on import statistics.

*Emission factors*

Prompt emissions of HFC are calculated following the IPCC Guidelines assuming a total loss of product within two years (50% loss in the first and 50% in the second year) (IPCC 2006).

*Activity data*

HFC activity data under 2G4 are based on FOEN import statistic and company data.

### 4.8.3. Uncertainties and time-series consistency

The uncertainty of total $CO_2$ emissions from the entire source category 2G4 is estimated at 14% (expert estimate). This value was obtained assuming 10% uncertainty for the activity data and 10% uncertainty for the emission factor.

The uncertainty of $N_2O$ emissions from source category 2G3 is estimated at 80% (expert estimate, see Table 1-10).

The uncertainty of $SF_6$, HFC and PFC emissions in source category 2G is estimated based on a Monte Carlo analysis and reported in Table A-2 of Annex A2.1. Further details are available from background documents, confidential/internal excel calculations and the respective report (Carbotech 2022).

Time series is consistent, with exception of the source category 2G2 Electrical equipment where from 2000 onwards the data are based on a Tier 3a approach instead of model calculations according to Tier 2 as applied for data before 2000. Due to lack of basic information it is not possible to provide a consistent time series for category 2G2 Electrical equipment retroactively.

### 4.8.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

For $SF_6$, measurements at Jungfraujoch are used to estimate Swiss emissions for verification purposes (see 4.7.4 and Annex 5). Estimated emissions based on measurements at Jungfraujoch agree within uncertainties with the emissions from the inventory.

### 4.8.5. Category-specific recalculations

The following recalculations were implemented in submission 2022. Major recalculations which contribute significantly to the total differences emissions of sector 2 IPPU between the latest and the previous submissions are presented also in chp. 10.1.2.2.

- 2G2: Company specific data 2020 obtained for part of the $SF_6$ were included under 2G2 other. Recalculations were made for the portion of $SF_6$ used in the same application 2004 to 2019 (see further details in the confidential NIR).
- 2G4: The activity data and $CO_2$ emission factor of 2G4 Post combustion of NMVOC in printing (2D3h NFR), other solvent (2D3i NFR) and product use (2G NFR) were revised for 1990–2019 based on a comprehensive survey of all cantonal air pollution control authorities and VOC balances.

### 4.8.6. Category-specific planned improvements

No category-specific improvements are planned.

# 4.9. Source category 2H – Other

## 4.9.1. Source category description

Source category 2H Other is not a key category.

Table 4-60 Specification of source category 2H Other in Switzerland.

| 2H | Source category | Specification |
|---|---|---|
| 2H1 | Pulp and paper | Emissions from NMVOC from pulp and paper including chipboard, fibreboard and cellulose production (ceased in 2008) |
| 2H2 | Food and beverages industry | Emissions of CO and NMVOC from production of food and drink |
| 2H3 | Other | Emissions of $CO_2$, NOx, CO, NMVOC and $SO_2$ from blasting and shooting |

## 4.9.2. Methodological Issues

### 4.9.2.1. Pulp and paper (2H1)

**Methodology**

In 2020, the production of chipboard and fibreboard are the relevant industrial processes in the source category 2H1 Pulp and paper. In Switzerland, chipboard and fibreboard were produced in one and two plants, respectively, until 2019. Since 2020 only one plant is left. The cellulose production was closed down in 2008 and is not occurring anymore in Switzerland. The NMVOC emissions are calculated by a Tier 2 method according to the EMEP/EEA guidebook (EMEP/EEA 2019) using country-specific emission factors.

Indirect $CO_2$ emissions resulting from NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

**Emission factors**

The emission factor for NMVOC emissions from pulp and paper production in Switzerland is country-specific and based on measurements and data from industry and expert estimates documented in EMIS 2022/2H1. The implied emission factor given in Table 4-61 is production-weighted and related to chipboard and fibreboard production. It is confidential but available to reviewers on request.

Table 4-61 Emission factors for CO and NMVOC in pulp and paper production and food and beverages industry, $CO_2$, $NO_x$, CO, NMVOC and $SO_2$ from blasting and shooting for 2020.

| 2H Other | Unit | $CO_2$ | $NO_x$ | CO | NMVOC | $SO_2$ |
|---|---|---|---|---|---|---|
| 2H1 Pulp and paper | g/t | NA | NA | NE | C | NE |
| 2H2 Food and beverage industry (exc. beer, wine, spirits) | g/t | NA | NA | 250 | 2'210 | NA |
| 2H2 Food and beverage industry (beer, wine, spirits) | g/m$^3$ | NA | NA | NA | 350 | NA |
| 2H3 Blasting and shooting | kg/t | 400 | 35 | 310 | 60 | 0.5 |

### Activity data

The annual amount of pulp and paper produced in Switzerland is based on data from industry and expert estimates documented in EMIS 2022/2H1. Due to the production structure in Switzerland, i.e. one production site for cellulose (ceased in 2008), one for chipboard and two for fibreboard (one ceased in 2019), only the sum of the production volume of 2H1 Pulp and paper industry is provided, and since 2020 activity data are confidential. Detailed data can be accessed by reviewers on request.

Table 4-62 Pulp and paper production, food and beverages production and amount of explosives used.

| 2H Other | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| 2H1 Pulp and paper | kt | 604 | 593 | 641 | 693 | 602 |
| 2H2 Food and beverage industry (exc. beer, wine, spirits) | kt | 2'249 | 2'114 | 2'300 | 2'134 | 2'397 |
| 2H2 Food and beverage industry (beer, wine, spirits) | m3 | 560'972 | 516'519 | 492'208 | 452'877 | 467'699 |
| 2H3 Blasting and shooting; blasting agent and powder | kt | 2.6 | 1.3 | 1.9 | 0.79 | 2.4 |

| 2H Other | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2H1 Pulp and paper | kt | 564 | 533 | 510 | 516 | 519 | 503 | 507 | 502 | 460 | C |
| 2H2 Food and beverage industry (exc. beer, wine, spirits) | kt | 2'525 | 2'491 | 2'413 | 2'533 | 2'473 | 2'471 | 2'492 | 2'455 | 2'479 | 2'392 |
| 2H2 Food and beverage industry (beer, wine, spirits) | m3 | 461'453 | 454'903 | 449'070 | 446'567 | 447'709 | 439'556 | 435'426 | 457'265 | 464'866 | 437'731 |
| 2H3 Blasting and shooting; blasting agent and powder | kt | 2.9 | 2.3 | 2.2 | 2.1 | 2.1 | 0.67 | 0.73 | 0.81 | 0.67 | 0.63 |

## 4.9.2.2. Food and beverages industry (2H2)

### Methodology

Production of beverages comprises wine, beer and spirits and food industry comprises production of bread, sugar, smoked meat, roasting of coffee and the milling industry. The CO and NMVOC emissions from food and beverages industry are calculated by a Tier 2 method according to the EMEP/EEA guidebook (EMEP/EEA 2019) using country-specific emission factors. Since these CO and NMVOC emissions are of biogenic origin, they are not considered for calculation of indirect $CO_2$ emissions.

### Emission factors

The emission factors for CO and NMVOC emissions from food and beverages industry are country-specific and based on measurements and data from industry and expert estimates as documented in the EMIS database (EMIS 2022/2H2). The implied emission factors are production-weighted (Table 4-61).

**Activity data**

The annual amount of food and beverages produced is based on data from industry and the farmers' association (SBV) and expert estimates as documented in EMIS 2022/2H2 (Table 4-62).

#### 4.9.2.3. Other (2H3)

**Methodology**

For determination of emissions of $CO_2$, $NO_x$, CO, NMVOC and $SO_2$ from blasting and shooting, an analogous Tier 2 method with country-specific emission factors is used as documented in the EMIS database (EMIS 2022/2H3 Sprengen und Schiessen).

Indirect $CO_2$ emissions resulting from CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

**Emission factors**

The emission factors for $CO_2$, $NO_x$, CO, NMVOC and $SO_2$ from blasting and shooting activities are country-specific and based on measurements and data from industry and expert estimates (see Table 4-61).

**Activity data**

The annual amount of used explosives is based on the Federal statistics on explosives (FEDPOL 2021) (Table 4-62).

### 4.9.3. Uncertainties and time-series consistency

The uncertainty for $CO_2$ emissions from 2H3 Other is estimated to be 8% (expert judgement) since activity data are taken from customs statistics.

Consistency: Time series for 2H Other are all considered consistent.

### 4.9.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

### 4.9.5. Category-specific recalculations

There were no recalculations implemented in submission 2022.

### 4.9.6. Category-specific planned improvements

No category-specific improvements are planned.

# 5. Agriculture

| Responsibilities for sector Agriculture | |
|---|---|
| Overall responsibility, author | Daniel Bretscher (Agroscope) |
| Sector experts (including QC) | Christoph Ammann (Agroscope), Thomas Kupper (HAFL), Chloé Wüst (Agroscope; QC) |
| EMIS database operation | Sabine Schenker (FOEN) |
| Technical contributors (including QC) | Dominik Eggli (Meteotest), Pascal Graf (Meteotest) |
| Annual updates (NIR text, tables, figures) | Daniel Bretscher (Agroscope) |
| Internal review | Michael Bock (FOEN) |

## 5.1. Overview

This chapter provides information on the estimation of the greenhouse gas emissions from the sector Agriculture. The following source categories are reported:

- 3A Enteric fermentation, $CH_4$ emissions from domestic livestock.
- 3B Manure management, emissions of $CH_4$, $N_2O$ and $NO_x$
- 3D Agricultural soils, emissions of $N_2O$, $NO_x$ and NMVOC
- 3G Liming, emissions of $CO_2$
- 3H Urea application; emissions of $CO_2$

No emissions are reported for 3C Rice cultivation as in Switzerland only a small area is cultivated with upland rice. The categories 3E Prescribed burning of savannahs and 3F Field burning of agricultural residues do not occur in Switzerland and are therefore not reported.

$CO_2$ emissions from soils are reported under 4 Land use, land-use change and forestry (LULUCF). $CO_2$ emissions from energy use in agriculture are reported under 1A4c Agriculture/forestry/fishing.

Because $CH_4$ and NMVOC emissions from the agriculture sector are of biogenic origin (CO emissions do not occur), from this sector no indirect $CO_2$ emissions are included in CRF Table 6 as documented in chp. 9.

Total greenhouse gas emissions from the agriculture sector in 2020 were 5'757 kt $CO_2$ equivalent which is a contribution of 13.3% to the total of Swiss greenhouse gas emissions (excluding indirect $CO_2$, excluding LULUCF, Table 2-5, Table 5-1). Main agricultural sources of greenhouse gases were 3A Enteric fermentation, emitting 57% of all agricultural greenhouse gases, followed by 3D Agricultural soils with 26% and 3B Manure management with 17% (Figure 5-1). 3G Liming and 3H Urea application contributed 0.6% and 0.2% respectively.

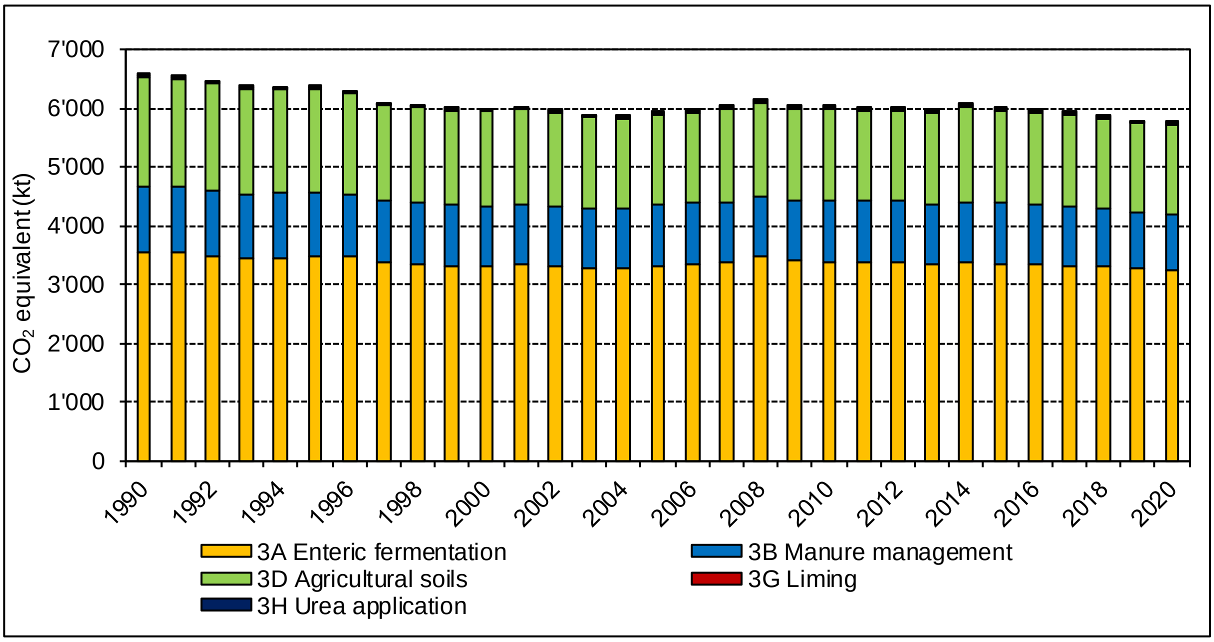


Figure 5-1 Greenhouse gas emissions of the agricultural sector in $CO_2$ equivalent (kt).

Table 5-1 Greenhouse gas emissions of the agricultural sector in $CO_2$ equivalent (kt).

| Gas | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | |
| $CO_2$ | 49 | 42 | 39 | 42 | 44 |
| $CH_4$ | 4'250 | 4'157 | 3'936 | 3'947 | 4'016 |
| $N_2O$ | 2'283 | 2'172 | 2'009 | 1'945 | 1'993 |
| Sum | 6'582 | 6'371 | 5'984 | 5'934 | 6'053 |

| Gas | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | | | | | | |
| $CO_2$ | 44 | 42 | 42 | 46 | 45 | 47 | 48 | 46 | 45 | 45 |
| $CH_4$ | 4'010 | 4'018 | 3'974 | 4'002 | 3'990 | 3'962 | 3'924 | 3'909 | 3'848 | 3'822 |
| $N_2O$ | 1'958 | 1'954 | 1'937 | 2'021 | 1'959 | 1'948 | 1'964 | 1'927 | 1'889 | 1'890 |
| Sum | 6'011 | 6'013 | 5'954 | 6'069 | 5'994 | 5'957 | 5'936 | 5'882 | 5'783 | 5'757 |

$CH_4$ and $N_2O$ emissions generally declined from 1990 until 2004 (Figure 5-2). Subsequently $CH_4$ emissions increased slightly until 2008 and decreased again afterwards. $N_2O$ emissions remained more or less on a constant level since 2004 with a decreasing trend in the last years. This general development can be explained by the development of the cattle population and the input of mineral fertilisers. Use of mineral fertiliser declined due to the introduction of the “Proof of Ecological Performance (PEP)” in the early 1990s (Agroscope 2019a, Leifeld and Fuhrer 2005), while the cattle population was influenced by the market situation, the milk quotation system (suspended in 2009) and the general agricultural policy- and subsidy-system (OECD 2013). Most emission factors did not change significantly over the inventory years. $CO_2$ emissions display high year to year variability due to variability of urea application, which depends among others on the relative price levels of different industrial fertilisers.

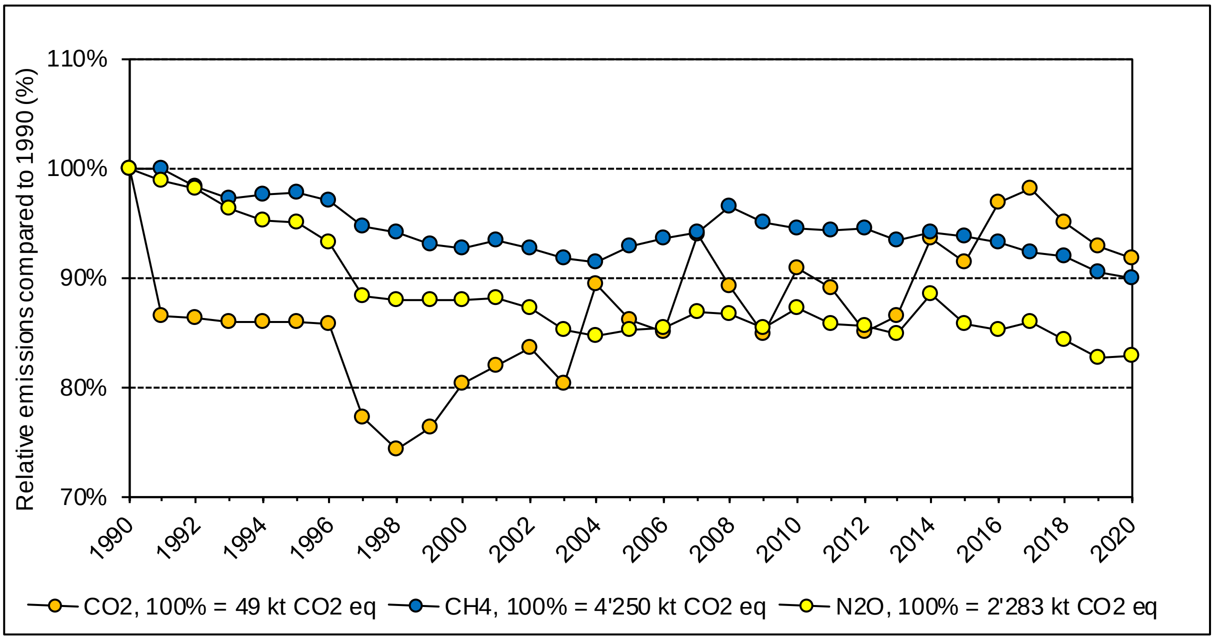


Figure 5-2 Relative trends of the greenhouse gas emissions of sector 5 Agriculture. The base year 1990 represents 100%.

Among the key categories of the Swiss inventory, six are from the agricultural sector (Figure 5-3).

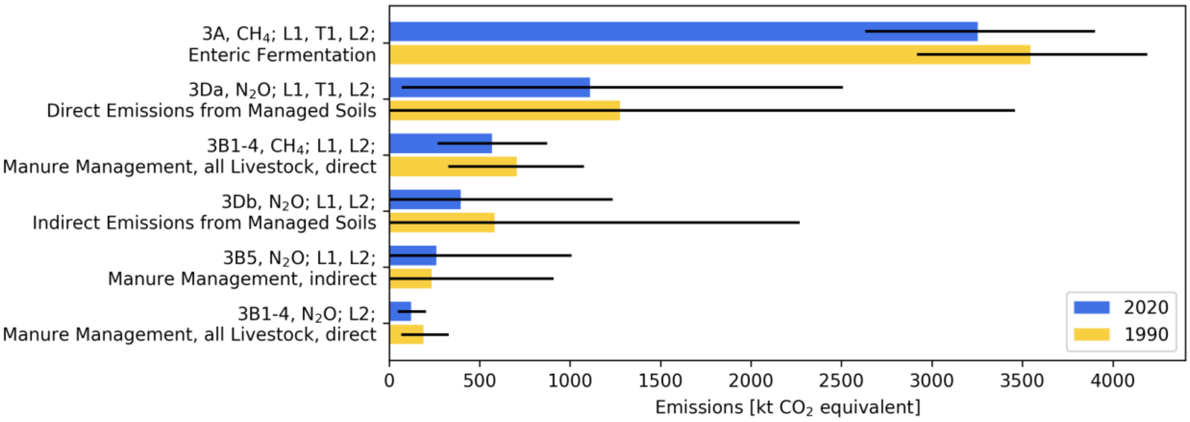


Figure 5-3. Key categories in the Swiss GHG inventory from sector 3 Agriculture determined by the key category analyses, approaches 1 and 2. Categories are set out in order of decreasing emissions in 2020. L1: key category according to approach 1 level in 2020; L2: same for approach 2; T1: key category according to approach 1 trend 1990–2020; T2: same for approach 2. Black uncertainty bars represent the narrowest 95% confidence interval obtained by Monte Carlo simulations (see chp. 1.6 for details).

## 5.2. Source category 3A – Enteric fermentation

### 5.2.1. Source category description

Table 5-2 Key categories of 3A Enteric fermentation. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 3A | Enteric Fermentation | CH4 | L1, T1, L2 |

This emission source comprises the domestic livestock population broken down into 3 cattle categories (mature dairy cattle, other mature cattle, growing cattle), sheep, swine, buffalo, camels, deer, goats, horses, mules and asses, poultry, rabbits and livestock not covered by the agricultural census (livestock NCAC) (Table 5-3).

Emissions from 3A Enteric fermentation declined from 1990 until 2004, mainly due to a reduction in the number of cattle. However, between 2004 and 2008 cattle livestock numbers and subsequently $CH_4$ emissions increased, whereas since 2008 they were decreasing again.

Cattle contribute over 90% to the overall emissions from 3A Enteric fermentation and the contribution of mature dairy cattle is almost 59%.

Emissions from fur-bearing animals are not occurring in Switzerland as provisions for the husbandry of wild animals are very strict according to the Swiss Animal Welfare Act (Swiss Confederation 2003). This is true for the whole inventory time period as the first version of the law dates back to 1978. Consequently, fur farming is not economically viable in Switzerland. In addition, fur animals (other than rabbits) are not included in national livestock data.

Table 5-3 Specification of source category 3A Enteric fermentation.

| 3A | Source | Specification |
|---|---|---|
| 3A1 | Cattle | Mature Dairy Cattle |
| | | Other Mature Cattle |
| | | Growing Cattle (Fattening Calves[1], Pre-Weaned Calves, Breeding Cattle 1st year (Breeding Calves + Breeding Cattle 4-12 months), Breeding Cattle > 1 year, Fattening Cattle (Fattening Calves 0-4 months[2], Fattening Cattle 4-12 months)) |
| 3A2 | Sheep | Lambs < 1 year |
| | | Mature Sheep |
| 3A3 | Swine | |
| 3A4a | Buffalo | Bisons < 3 years[3] |
| | | Bisons > 3 years[3] |
| 3A4b | Camels | Llamas < 2 years |
| | | Llamas > 2 years |
| | | Alpacas < 2 years |
| | | Alpacas > 2 years |
| 3A4c | Deer | Fallow Deer |
| | | Red Deer |
| 3A4d | Goats | |
| 3A4e | Horses | Horses < 3 years |
| | | Horses > 3 years |
| 3A4f | Mules and Asses | Mules |
| | | Asses |
| 3A4g | Poultry | |
| 3A4h i | Rabbits | |
| 3A4h ii | Livestock NCAC | Sheep |
| | | Goats |
| | | Horses < 3 years |
| | | Horses > 3 years |
| | | Mules |
| | | Asses |

1) Fattening for veal with a milk based diet (slaughtere at ap. 100 days). See chp. 5.2.2.3.
2) Fattening for beef meat (slaughtered at ap. 400 days). See chp. 5.2.2.3.
3) Bisons (Bos bison and/or Bos bonasus). Water buffalos (Bubalus bubalis) are included under cattle. See chp. 5.2.2.3.

## 5.2.2. Methodological issues

### 5.2.2.1. Methodology

For mature dairy cattle a detailed Tier 3 model approach is applied, predicting gross energy intake by the means of a feeding model that takes into account animal performance and diet bio-chemical composition. A country-specific methane conversion rate ($Y_m$) was derived from a series of studies representing Swiss specific feeding conditions.

Emission estimation for all other cattle categories follows a Tier 2 approach. This means that detailed country-specific data on nutrient requirements and feed intake were used. $CH_4$ conversion rates were taken from the 2006 IPCC Guidelines (IPCC 2006).

Methods for all other animal categories are based on a Tier 2 approach, estimating country-specific energy intake rates. Methane conversion rates were taken from the 2006 IPCC Guidelines or from published peer reviewed literature.

The calculation of $CH_4$ emissions is done by Agroscope, the Swiss centre of excellence for agricultural research (Agroscope 2022).

### 5.2.2.2. Emission factors

All emission factors for 3A Enteric fermentation are country-specific, based on IPCC equation 10.21 (IPCC 2006):

$$EF = \frac{GE * (Y_m \div 100) * 365\,days/y}{55.65\,MJ/kg\,CH_4}$$

EF = annual $CH_4$ emission factor (kg/head/year)

GE = gross energy intake (MJ/head/day)

$Y_m$ = methane conversion rate, which is the fraction of gross energy in feed converted to methane (%)

55.65 MJ/kg = energy content of methane.

#### *5.2.2.2.1. Gross energy intake (GE)*

For calculating the gross energy intake (GE), country-specific methods based on available data on requirements of net energy, digestible energy and metabolisable energy were used. The different energy levels used for energy conversion from energy required for maintenance and production to GE intake are illustrated in Figure 5-4. The respective conversion factors are given in Table 5-4.

For the **cattle categories** detailed estimations for energy requirements are necessary. As the Swiss Farmers Union (SBV) does not provide these estimates on a detailed cattle sub-category level, requirements for each cattle source category were calculated individually following the feeding recommendations for Switzerland provided in RAP (1999) and Morel et al. (2015). These RAP recommendations are also used by the Swiss farmers as the basis for their cattle feeding regimes and for filling in application forms for direct payments; they are therefore highly appropriate.

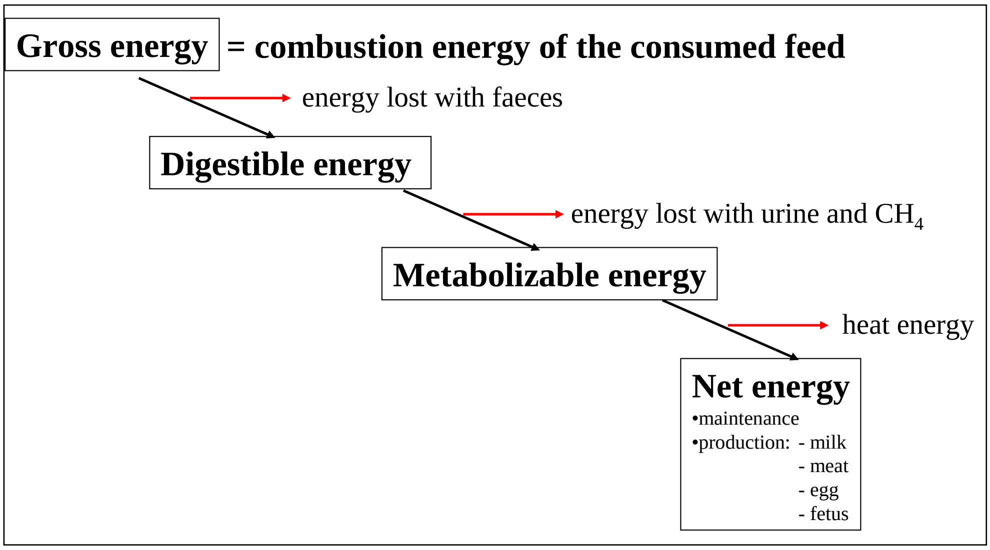


Figure 5-4 Levels of feed energy conversion (Soliva 2006).

Table 5-4 Conversion factors used for calculation of energy requirements of individual livestock categories (Soliva 2006). GE: Gross energy; DE: Digestible energy; ME: Metabolisable energy; NEL: Net energy for lactation; NEV: Net energy for growth. Blue: annually changing parameters, value for 2020.

| **Livestock Category** | | **Conversion Factors** | |
|---|---|---|---|
| Mature Dairy Cattle | | NEL to GE | 0.341 |
| Other Mature Cattle | | NEL to GE | 0.265 |
| Growing Cattle | *Fattening Calves* | *ME to GE* | *0.939* |
| | *Pre-Weaned Calves* | *NEL to GE* | *0.299* |
| | *Breeding Calves* | *NEL to GE* | *0.358* |
| | *Breeding Cattle (4-12 months)* | *NEL to GE* | *0.319* |
| | *Breeding Cattle (> 1 year)* | *NEL to GE* | *0.313* |
| | *Fattening Calves (0-4 months)* | *NEV to GE* | *0.355* |
| | *Fattening Cattle (4-12 months)* | *NEV to GE* | *0.397* |
| Sheep | *Fattening Sheep* | *NEV to GE* | *0.350* |
| | *Milksheep* | *NEL to GE* | *0.287* |
| Swine | | DE to GE | 0.682 |
| Buffalo | | NA | NA |
| Camels and Llamas | | NA | NA |
| Deer | | NA | NA |
| Goats | | NEL to GE | 0.283 |
| Horses | | DE to GE | 0.700 |
| Mules and Asses | | DE to GE | 0.700 |
| Poultry | | ME to GE | 0.700 |
| Rabbits | | NA | NA |
| Livestock NCAC | | NA | NA |

For **mature dairy cattle** a detailed feeding model from the Agroscope department for Livestock Sciences was used to predict gross energy intake (Agroscope 2014c).

Energy and protein requirements were estimated based on animal performance (body weight, milk production, pregnancy) following the standard feeding recommendations for Switzerland (RAP 1999). Live weight was estimated based on statistics of carcass weight according to Burren et al. (2021). Live weight increased more or less linearly from 637 kg in 1990 to 680 kg in 2020. Statistics of annual milk production are provided by the Swiss Farmers Union (SBV 2021, Table 5-5). Milk production includes marketed milk, milk consumed by calves on farms and milk sold outside the commercial industry (MISTA 2021). It should be noted that daily milk yield refers to milk production during lactation (305 days) and not during the whole year (365 days). Accordingly, milk production and energy requirement for lactation was zero during the two remaining months when the cows are dry. During the dry months additional energy requirements for pregnancy were accounted for.

To cover total animal energy and protein requirements, typical Swiss specific basic feed rations were defined as model inputs. The average basic feed ration in summer consisted of 92% fresh grass and 8% maize cubes. In winter the feed ration consisted of 10% maize silage, 13% grass silage, 72% hay and 5% fodder beet. Concentrates are automatically supplemented in the model according to additional energy and protein requirements not covered by the basic feed ration. Concentrates consisted of a varying mixture of barley grains, wheat grains, maize grains, maize gluten, soybean meal and rapeseed meal according to specific animal requirements. Subsequently, average bio-chemical composition and properties of the total feed ration (e.g. energy content, protein content, digestibility) were derived, weighing the respective values of the individual feed ingredients given in the Swiss Feed Database (Agroscope 2014b). Finally, gross energy intake was estimated based on the total feed intake and the gross energy content of the total ration that was 18.26 MJ/kg on average for the years 1990–2020.

In the year 2003 yearly milk yield surpassed 6000 kg per head. To achieve yearly milk yields higher than 6000 kg, cows have to be fed with an increasing share of feed concentrates that have a substantially higher net energy (NE) density than the basic feed ration. The model reproduces this behaviour. Due to the increasing ratio of net energy to gross energy the increase of gross energy intake is slower after the year 2003 although milk yield increases more or less at the same rate (Table 5-6).

A more exhaustive model description is contained in Agroscope (2019a).

Table 5-5 Average daily milk production during 305 days of lactation in Switzerland.

| Milk Production Cattle | | 1990 | 1995 | 2000 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Population Size Mature Dairy Cattle | head | 783'100 | 739'641 | 669'410 | 620'708 | 618'065 | 614'795 | 628'516 | 599'361 | 589'024 | 589'239 |
| Lactation Period | day | 305 | 305 | 305 | 305 | 305 | 305 | 305 | 305 | 305 | 305 |
| Milk Yield Mature Dairy Cattle | kg/head/day | 15.81 | 16.91 | 18.63 | 20.53 | 20.61 | 21.09 | 21.70 | 22.31 | 22.46 | 22.70 |
| Milk Yield Other Mature Cattle | kg/head/day | 8.20 | 8.20 | 8.20 | 8.20 | 8.20 | 8.20 | 8.20 | 8.20 | 8.20 | 8.20 |

| Milk Production Cattle | | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| Population Size Mature Dairy Cattle | head | 591'212 | 586'609 | 587'385 | 583'277 | 575'766 | 569'185 | 564'190 | 554'588 | 546'479 |
| Lactation Period | day | 305 | 305 | 305 | 305 | 305 | 305 | 305 | 305 | 305 |
| Milk Yield Mature Dairy Cattle | kg/head/day | 22.77 | 22.36 | 22.89 | 23.13 | 23.09 | 22.87 | 23.38 | 23.09 | 23.26 |
| Milk Yield Other Mature Cattle | kg/head/day | 8.20 | 8.20 | 8.20 | 8.20 | 8.20 | 8.20 | 8.20 | 8.20 | 8.20 |

For **other mature cattle** and **growing cattle,** data on energy intake were based on the feeding requirements according to RAP (1999) and Morel et al. (2015). In the calculation of the NE data, the animal’s weight, daily growth rate, daily feed intake (dry matter), daily feed energy intake, and energy required for milk production and pregnancy for the respective sub-categories were considered. The method is described in detail in Soliva (2006) but has been revised slightly here. A distinction is made between NE for lactation (NEL) and NE for growth (NEV) (Table 5-4). For some of the growing cattle categories NEL is used instead of NEV, even if NEV would seem appropriate. However, cattle-raising is often coupled with dairy cattle activities and therefore the same energy unit (NEL) is used in these cases. Exceptions are the fattening calves (milk-fed calves), whose requirement for energy is expressed as metabolisable energy (ME).

Table 5-6 Gross energy intake per head of different livestock groups. Sub-categories not contained in the reporting tables (CRF) are displayed in italic. The entire time series at a livestock sub-category level is provided in Annex A3.3.

| Gross Energy Intake | | 1990-2011 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1990 | 1995 | 2000 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
| | | MJ/head/day | | | | | | | | | |
| Cattle | | | | | | | | | | | |
| Mature Dairy Cattle | | 255.2 | 265.0 | 279.2 | 294.1 | 294.1 | 296.7 | 299.9 | 301.4 | 302.4 | 303.6 |
| Other Mature Cattle | | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 |
| Growing Cattle (weighted average) | | 103.3 | 103.9 | 103.6 | 101.0 | 101.1 | 100.9 | 101.0 | 100.3 | 99.8 | 99.9 |
| | *Fattening Calves* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* |
| | *Pre-Weaned Calves* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* |
| | *Breeding Calves* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* |
| | *Breeding Cattle (4-12 months)* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* |
| | *Breeding Cattle (> 1 year)* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* |
| | *Fattening Calves (0-4 months)* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* |
| | *Fattening Cattle (4-12 months)* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* |
| Sheep | | 21.2 | 24.0 | 22.4 | 22.8 | 22.6 | 22.2 | 22.0 | 22.7 | 22.6 | 22.6 |
| Swine | | 25.7 | 26.5 | 25.1 | 24.5 | 23.9 | 24.2 | 24.6 | 24.9 | 24.7 | 24.6 |
| Buffalo (weighted average) | | NA | 136.6 | 146.9 | 140.6 | 138.9 | 130.4 | 129.1 | 134.8 | 136.9 | 139.8 |
| Camels (weighted average) | | NA | NA | 34.8 | 31.7 | 31.7 | 31.7 | 31.6 | 31.5 | 31.0 | 31.4 |
| Deer (weighted average) [1)] | | 50.5 | 55.3 | 56.4 | 55.4 | 55.8 | 55.9 | 56.5 | 56.8 | 56.5 | 56.7 |
| Goats | | 25.0 | 27.9 | 25.7 | 25.4 | 25.3 | 25.0 | 25.0 | 25.3 | 25.1 | 25.6 |
| Horses (weighted average) | | 107.3 | 106.9 | 107.4 | 107.7 | 107.7 | 107.7 | 107.7 | 107.8 | 107.9 | 107.9 |
| Mules and Asses (weighted average) | | 39.2 | 39.7 | 39.5 | 39.4 | 39.5 | 39.3 | 39.2 | 40.0 | 40.2 | 39.9 |
| Poultry [2)] | | 1.2 | 1.2 | 1.3 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.0 | 1.0 |
| Rabbits | | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Livestock NCAC (weighted average) | | 90.2 | 72.0 | 32.9 | 34.3 | 34.5 | 35.4 | 35.3 | 36.2 | 37.8 | 37.8 |

| Gross Energy Intake | | 2012-2020 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
| | | MJ/head/day | | | | | | | | |
| Cattle | | | | | | | | | | |
| Mature Dairy Cattle | | 304.5 | 302.1 | 304.3 | 305.9 | 306.6 | 305.9 | 307.9 | 307.5 | 309.0 |
| Other Mature Cattle | | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 |
| Growing Cattle (weighted average) | | 100.2 | 100.1 | 99.9 | 99.7 | 99.2 | 99.0 | 98.6 | 98.4 | 98.0 |
| | *Fattening Calves* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* |
| | *Pre-Weaned Calves* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* |
| | *Breeding Calves* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* |
| | *Breeding Cattle (4-12 months)* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* |
| | *Breeding Cattle (> 1 year)* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* |
| | *Fattening Calves (0-4 months)* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* |
| | *Fattening Cattle (4-12 months)* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* |
| Sheep | | 22.5 | 22.4 | 22.6 | 22.5 | 22.9 | 23.0 | 23.3 | 23.4 | 24.0 |
| Swine | | 24.4 | 25.1 | 25.1 | 25.4 | 25.8 | 25.5 | 25.2 | 26.4 | 25.6 |
| Buffalo (weighted average) | | 135.9 | 136.0 | 134.6 | 134.5 | 134.4 | 133.1 | 162.8 | 159.8 | 159.1 |
| Camels (weighted average) | | 31.6 | 31.9 | 31.8 | 31.6 | 31.2 | 31.2 | 31.0 | 31.2 | 31.4 |
| Deer (weighted average) [1)] | | 57.0 | 58.1 | 58.0 | 58.0 | 58.5 | 58.8 | 59.3 | 59.6 | 59.6 |
| Goats | | 25.6 | 25.6 | 25.0 | 25.5 | 25.1 | 25.2 | 25.1 | 25.5 | 26.4 |
| Horses (weighted average) | | 107.9 | 108.0 | 108.1 | 108.3 | 108.4 | 108.4 | 108.5 | 108.5 | 108.5 |
| Mules and Asses (weighted average) | | 39.9 | 39.6 | 39.6 | 39.6 | 39.6 | 39.5 | 38.4 | 38.4 | 38.4 |
| Poultry [2)] | | 1.0 | 1.0 | 1.0 | 1.1 | 1.0 | 1.1 | 1.1 | 1.0 | 1.0 |
| Rabbits | | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Livestock NCAC (weighted average) | | 37.8 | 39.0 | 38.7 | 39.3 | 40.3 | 40.4 | 36.9 | 37.6 | 38.3 |

[1)] Deer: Gross energy intake per animal place (mother with offspring)

[2)] Poultry data is not gross energy intake (GE) but metabolizable energy intake (ME)

The gross energy intake for other mature cattle is significantly higher than IPCC (2006) default values, since the category “other mature cattle” in Switzerland only includes mature cows that produce offspring for meat (so-called “suckler cows” or “mother cows”). Milk production of other mature cattle is 2500 kg per head and year (305 days of lactation) and has not changed over the inventory time period (Morel et al. 2015).

The gross energy intake of growing cattle was calculated separately for all sub-categories displayed in Table 5-6 (in italics) and subsequently averaged (weighted average). No methane is generated from milk. Nevertheless, energy intake from milk or milk products is considered when estimating methane emission factors from enteric fermentation of calves. However, the methane conversion rate is adjusted accordingly as explained under chp. 5.2.2.2.2. The energy intake values for all 7 sub-categories are constant over time. Since the composition of the growing cattle category changed over time (e.g. more pre-weaned calves, fewer fattening calves, see Table 5-8), the average gross energy intake for growing cattle also changes slightly. To calculate an annual emission factor, the categories breeding calves and breeding cattle 4-12 months were combined in the category breeding cattle 1st year (not shown in Table 5-6 and Table 5-8). Accordingly, the respective animals have two separate gross energy intake values, i.e. 44.0 MJ/head/day for the first 4 months and 90.1 MJ/head/day for the last 8 months. The same procedure is applied for fattening calves 0–4 months (56.9 MJ/head/day) and fattening cattle 4–12 months (126.3 MJ/head/day) summing up to the category fattening cattle.

Energy requirements and gross energy intake of **sheep**, **swine**, **goats** and **poultry** were obtained from the respective estimates of the Swiss Farmers Union (SBV 2021, Giuliani 2021). These estimates are not officially published anymore in the statistical yearbooks (e.g. SBV 2017) but are still available from background data and are based on the same method as used for energy requirement statistics in earlier years (e.g. SBV 2007).

Gross energy intake for **horses**, **mules and asses** were estimated by Stricker (2012), mainly based on Meyer and Coenen (2002).

Table 5-7 Dry matter and gross energy requirements for buffalo, camels and deer according to Richner et al. (2017).

| | | DM Intake | GE Intake |
|---|---|---|---|
| | | kg DM/head/day | MJ/head/day |
| Buffalo | Bisons < 3 years | 4.93 | 90.99 |
| | Bisons > 3 years | 10.68 | 197.14 |
| Camels | Llamas < 2 years | 1.34 | 24.77 |
| | Llamas > 2 years | 2.33 | 42.97 |
| | Alpacas < 2 years | 0.82 | 15.16 |
| | Alpacas > 2 years | 1.51 | 27.80 |
| Deer 1) | Fallow Deer | 2.74 | 50.55 |
| | Red Deer | 5.48 | 101.10 |

1) Requirements for deer are assessed per animal place i.e. mother with offspring.

For **buffalo**, **camels** and **deer**, energy intake was derived from data on dry matter intake provided in Richner et al. (2017) (Table 5-7). According to the 2006 IPCC Guidelines an energy density of 18.45 MJ*kg$^{-1}$ was used to convert dry matter to gross energy (IPCC 2006).

Energy intake of **rabbits** was estimated by Menzi (2014) based on Schlegel and Menzi (2013).

Finally for **livestock NCAC** the same energy intakes as the respective animal categories in the official census were used.

Final compilation of livestock gross energy intake was conducted in Agroscope (2022). Resulting estimates are provided in Table 5-6 (main categories) and in Annex A3.3 (all years and all sub-categories).

##### *5.2.2.2.2. Methane conversion rate ($Y_m$)*

For the methane conversion rate ($Y_m$), few country-specific data exist. Accordingly, for most animal categories default or literature values were used. Due to its great importance a country-specific $Y_m$ was used for **mature dairy cattle**. A value of 6.9% was derived from a series of measurements conducted under Swiss specific feeding and husbandry conditions at the Federal Institute of Technology in Zurich (based on data compiled in Zeitz et al. (2012) and additional measurements described in Estermann et al. (2001), Külling et al. (2002) and Staerfl et al. (2012)).

For all **other cattle categories**, **sheep** and **buffalo** default values recommended by the IPCC for developed countries in Western Europe were used (IPCC 2006: Tables 10.12, 10.13, 10A.2, 10A.3). For all juvenile cattle consuming milk or milk products (i.e. calves) the methane conversion rate is weighted, assuming a $Y_m$ of zero for milk energy and a $Y_m$ of 6.5% for all other energy.

According to table 10.13 in IPCC (2006) two different $Y_m$ were used for **sheep**, namely 4.5% for lambs <1 year and 6.5% for mature sheep. Overall $Y_m$ was subsequently weighted according to the population structure. For **camels** and **deers** the same methane conversion rate as for sheep was applied, assuming the same relationship between adult and juvenile animals.

For **swine** a methane conversion rate of 0.6% was used. This value was suggested by Crutzen et al. (1986) and was confirmed by the compilation of references in Minonzio et al. (1998). Since the 2006 IPCC Guidelines do not provide a default value for **goats**, an $Y_m$ of 6% was adopted based on the work of Martínez-Fernández et al. (2014) and Fernández et al. (2013). For **Horses**, **mules and asses** an $Y_m$ of 2.45% was used, which corresponds to a methane energy loss of 3.5% of digestible energy (Vermorel et al. 1997, Minonzio et al. 1998) and a feed digestibility of 70% (Stricker 2012). For **poultry** a country-specific value (0.16% of metabolisable energy) was used. This value was evaluated in an in vivo trial with broilers (Hadorn and Wenk 1996). For **rabbits** an $Y_m$ of 0.6% was applied as suggested in the national GHG inventory of Italy (ISPRA 2020). Finally, as for gross energy intake, the same methane conversion rates as for the respective animals in the official census were used for **livestock NCAC**.

#### 5.2.2.3. Activity data

Livestock population data were obtained from statistics published by the Swiss Farmers Union (SBV 2021) and the Swiss Federal Statistical Office (SFSO 2021a) (Table 5-8). In 2011 activity data for the time series 1990–2010 were revised and harmonised during a joint effort of the Agroscope Reckenholz-Tänikon Research Station (ART) and the Swiss College of Agriculture (SHL) in 2011 (ART/SHL 2012).

The category other mature cattle only includes mature cows used to produce offspring for meat.

Emission estimation for growing cattle was conducted at a more disaggregated level than the one displayed in the reporting tables (CRF). The livestock category growing cattle in the reporting tables includes the sub-categories fattening calves, pre-weaned calves, breeding calves, breeding cattle 4–12 months, breeding cattle >1 year, fattening calves 0–4 months and fattening cattle 4–12 months. The two sub-categories of fattening calves are distinguished by their weight at slaughter and their feeding regime. The first sub-category (“fattening calves”) refers to animals raised for veal with a milk based diet (slaughtered at approximately 100 days) whereas the second sub-category (“fattening calves 0-4 months”) refers to animals fattened for beef meat (slaughtered at app. 400 days). Although not growing cattle in the proper sense, bulls are contained in the categories breeding cattle (>1 year) and fattening cattle (4–12 months) according to their purposes. This disaggregation of the category growing cattle enhances the accuracy of the emission estimation procedure from livestock activities (also refer to chp. 5.3.2.1).

Emission estimation for buffalo, camels, horses, mules and asses and deers was also conducted on a more disaggregated level than displayed in the reporting tables (CRF). Additional data on a livestock sub-category level are contained in Annex A3.3. The livestock category “buffalo” in the Swiss GHG Inventory contains only bisons (*Bos bison* and/or *Bos bonasus*). Water buffalos (*bubalus bubalis*) are included under cattle. The category “camels” contains only llamas and alpacas.

For the categories "Fattening Pigs over 25 kg" (subcategory of swine) and "Broilers" (subcategory of poultry) adjustments were made in order to correctly consider animal turnover rates (Kupper et al. 2022, SFSO 2021b). The values for these subcategories are thus higher here than in the official statistics.

Additionally to official statistical data, population data of livestock not covered by the agricultural census of the Swiss Federal Statistical Office were assessed. The respective category “Livestock NCAC” (livestock not covered by agricultural census) consists of sheep, goats, horses and mules and asses held for non-agricultural purposes (e.g. horses for sports and leisure) and/or livestock held by private persons or enterprises that do not fulfil the criteria of an agricultural enterprise. Data for the respective horses, mules and asses were derived from background data of the gross nutrient balance of the Swiss Federal Statistical Office (SFSO 2021b). For sheep and goats, data from individual cantons having full livestock census were used to estimate the relative share for the whole of Switzerland. The respective estimates were conducted in the course of the elaboration of the gross nutrient balance of the Swiss Federal Statistical Office (SFSO 2021b).

Table 5-8 Activity data for calculating methane emissions from 3A Enteric fermentation (ART/SHL 2012, SBV 2021, SFSO 2021a, SFSO 2021b). The complete time series on a livestock sub-category level are provided in Annex A3.3.

| **Population Size** | | **1990-2011** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **1990** | **1995** | **2000** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** |
| | | 1'000 head | | | | | | | | | |
| Cattle | | 1'855 | 1'748 | 1'588 | 1'555 | 1'567 | 1'572 | 1'604 | 1'597 | 1'591 | 1'577 |
| Mature Dairy Cattle | | 783 | 740 | 669 | 621 | 618 | 615 | 629 | 599 | 589 | 589 |
| Other Mature Cattle | | 12 | 23 | 45 | 78 | 87 | 94 | 98 | 108 | 111 | 111 |
| Growing Cattle | | 1'060 | 986 | 874 | 856 | 862 | 863 | 877 | 890 | 891 | 877 |
| | *Fattening Calves* | *112* | *102* | *103* | *106* | *101* | *100* | *95* | *107* | *114* | *111* |
| | *Pre-Weaned Calves* | *10* | *18* | *36* | *62* | *67* | *72* | *76* | *84* | *86* | *86* |
| | *Breeding Cattle 1st Year* | *346* | *295* | *236* | *222* | *223* | *223* | *232* | *224* | *222* | *216* |
| | *Breeding Calves* | *214* | *166* | *76* | *75* | *77* | *76* | *80* | *76* | *75* | *73* |
| | *Breeding Cattle (4-12 months)* | *132* | *129* | *161* | *147* | *147* | *147* | *152* | *148* | *146* | *142* |
| | *Breeding Cattle (> 1 year)* | *404* | *378* | *352* | *318* | *320* | *320* | *322* | *328* | *326* | *322* |
| | *Breeding Cattle 2nd Year* | *253* | *239* | *222* | *205* | *210* | *210* | *213* | *216* | *215* | *213* |
| | *Breeding Cattle 3rd Year* | *151* | *139* | *130* | *113* | *110* | *109* | *110* | *112* | *111* | *109* |
| | *Fattening Cattle* | *188* | *193* | *147* | *147* | *149* | *148* | *152* | *147* | *144* | *143* |
| | *Fattening Calves (0-4 months)* | *88* | *82* | *43* | *35* | *35* | *34* | *36* | *35* | *34* | *34* |
| | *Fattening Cattle (4-12 months)* | *100* | *110* | *105* | *112* | *114* | *114* | *116* | *112* | *110* | *109* |
| Sheep | | 395 | 387 | 421 | 446 | 448 | 444 | 446 | 432 | 434 | 424 |
| Swine | | 1'965 | 1'739 | 1'670 | 1'744 | 1'797 | 1'748 | 1'671 | 1'691 | 1'750 | 1'726 |
| Buffalo | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| Camels | | 0 | 0 | 1 | 3 | 3 | 4 | 4 | 5 | 6 | 6 |
| Deer [1)] | | 0 | 1 | 3 | 4 | 4 | 4 | 5 | 5 | 6 | 6 |
| Goats | | 68 | 53 | 62 | 74 | 76 | 79 | 81 | 81 | 83 | 83 |
| Horses | | 28 | 41 | 50 | 55 | 56 | 58 | 59 | 60 | 62 | 57 |
| Mules and Asses | | 6 | 8 | 12 | 16 | 16 | 17 | 18 | 19 | 20 | 19 |
| Poultry | | 7'310 | 6'656 | 7'160 | 8'911 | 8'107 | 9'303 | 9'813 | 10'099 | 10'629 | 10'904 |
| Rabbits | | 61 | 41 | 28 | 25 | 24 | 27 | 25 | 28 | 35 | 34 |
| Livestock NCAC | | 16 | 19 | 88 | 89 | 86 | 86 | 93 | 96 | 95 | 103 |

| **Population Size** | | **2012-2020** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
| | | 1'000 head | | | | | | | | |
| Cattle | | 1'565 | 1'557 | 1'563 | 1'554 | 1'555 | 1'545 | 1'543 | 1'525 | 1'515 |
| Mature Dairy Cattle | | 591 | 587 | 587 | 583 | 576 | 569 | 564 | 555 | 546 |
| Other Mature Cattle | | 114 | 117 | 118 | 118 | 121 | 123 | 125 | 128 | 131 |
| Growing Cattle | | 859 | 854 | 857 | 853 | 859 | 852 | 854 | 842 | 837 |
| | *Fattening Calves* | *103* | *102* | *102* | *103* | *107* | *108* | *111* | *110* | *110* |
| | *Pre-Weaned Calves* | *88* | *90* | *91* | *91* | *93* | *96* | *97* | *99* | *102* |
| | *Breeding Cattle 1st Year* | *210* | *208* | *210* | *210* | *211* | *209* | *208* | *201* | *199* |
| | *Breeding Calves* | *72* | *71* | *71* | *71* | *72* | *71* | *71* | *68* | *68* |
| | *Breeding Cattle (4-12 months)* | *139* | *137* | *138* | *139* | *139* | *138* | *137* | *133* | *131* |
| | *Breeding Cattle (> 1 year)* | *317* | *313* | *312* | *308* | *306* | *305* | *302* | *295* | *290* |
| | *Breeding Cattle 2nd Year* | *211* | *210* | *210* | *209* | *209* | *208* | *207* | *204* | *203* |
| | *Breeding Cattle 3rd Year* | *106* | *103* | *101* | *99* | *97* | *98* | *94* | *91* | *87* |
| | *Fattening Cattle* | *140* | *141* | *143* | *142* | *141* | *134* | *136* | *136* | *136* |
| | *Fattening Calves (0-4 months)* | *33* | *34* | *34* | *34* | *33* | *32* | *32* | *32* | *32* |
| | *Fattening Cattle (4-12 months)* | *107* | *108* | *109* | *108* | *107* | *102* | *104* | *104* | *104* |
| Sheep | | 417 | 409 | 403 | 395 | 397 | 398 | 403 | 400 | 398 |
| Swine | | 1'678 | 1'615 | 1'631 | 1'605 | 1'553 | 1'546 | 1'501 | 1'447 | 1'448 |
| Buffalo | | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 |
| Camels | | 6 | 6 | 6 | 6 | 6 | 7 | 7 | 7 | 6 |
| Deer [1)] | | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 7 | 7 |
| Goats | | 85 | 85 | 85 | 84 | 85 | 88 | 91 | 92 | 90 |
| Horses | | 58 | 57 | 57 | 55 | 56 | 56 | 46 | 47 | 47 |
| Mules and Asses | | 20 | 20 | 20 | 20 | 20 | 21 | 34 | 34 | 33 |
| Poultry | | 11'409 | 11'844 | 12'446 | 12'541 | 13'180 | 13'207 | 13'984 | 14'417 | 15'199 |
| Rabbits | | 28 | 28 | 27 | 25 | 25 | 22 | 22 | 21 | 19 |
| Livestock NCAC | | 114 | 111 | 109 | 120 | 113 | 110 | 108 | 103 | 102 |

[1)] Deer: numbers correspond to animal places i.e. mother with offspring.

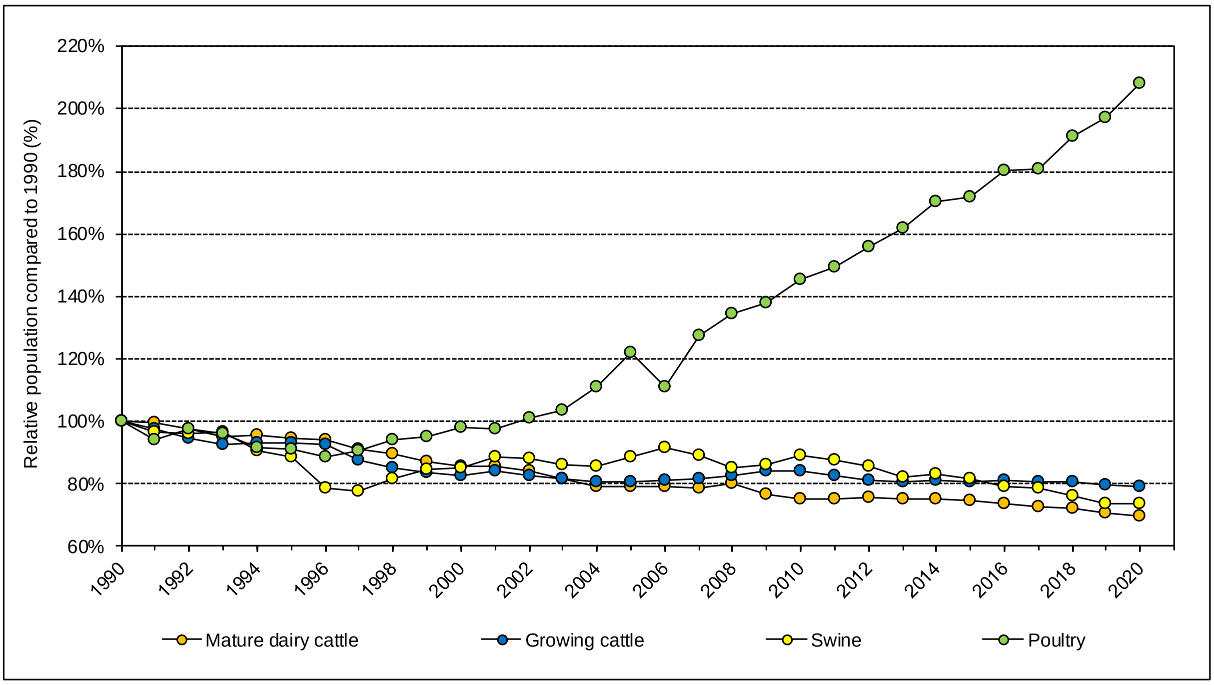


Figure 5-5 Relative development of the populations of main animal categories. The category with the strongest increase, i.e. other mature cattle, is not displayed, as it increases to over 1000% of the 1990 value by 2020.

Livestock populations in Switzerland are primarily influenced by the general agricultural policy, i.e. the subsidy system, the milk quotation system and the development of the economic framework conditions. The number of cattle declined slightly until the year 2004. However, cattle livestock numbers increased between 2004 and 2008, mainly due to an increase of the number of growing cattle. Since 2008 the cattle population was decreasing again, possibly due to the suspension of the milk quotation system in 2009.

After a decrease until 1996, the number of swine increased until 2006 – a process that has been observed in many other European countries (SBV 2004: p.69). Since then, the number of swine has fluctuated slightly below the level of 2006. During the most recent years a slight downward trend can be observed. The number of poultry shows a rapid increase between 1990 and 2018 with a distinct dip only between 2005 and 2006, a consequence of changed human consumption patterns as a result of the avian flu in 2006.

The number of sheep was more or less constant while the number of goats increased following a decline between 1990 and 1995.

### 5.2.3. Uncertainties and time-series consistency

For the uncertainty analysis the input data from ART (2008a) were used and were updated with the latest activity and emission data as well as with default uncertainties of the 2006 IPCC Guidelines. The detailed input uncertainty values for category 3A are reported in Annex A2.1. The resulting, combined uncertainty for emissions is [-19%; +20%] according to both approach 1 (uncertainty propagation, Annex A2.2) and approach 2 (Monte Carlo simulations, Annex A2.3).

For further results and discussion of the uncertainties see chp. 1.6 and Annex 2.

The time series 1990–2020 are all considered consistent, although the following issues should be considered:

- Between 1998 and 1999 the questionnaire for the collection of livestock data was modified. In some animal categories this led to minor ruptures in the time series. Consequences for overall emissions are, however, of minor importance. An analysis conducted in 2012 revealed, that while the average annual change for the years 1990–2011 over all animal categories (excluding other mature cattle) was 3.3% points, the annual change for the years 1998–1999 was 3.8% points (ART/SHL 2012).
- Since 2009 the population statistics of growing cattle are derived from the animal traffic database (ATD 2020). Aggregation was adapted to the format necessary for the AGRAMMON-model and the GHG inventory by the School of Agricultural, Forest and Food Science (HAFL, Kupper et al. 2022). Data in the animal traffic database are considered more complete than the data from the survey of the SFSO because the animal traffic database includes also animals held outside agricultural enterprises.
- Since 2015 the census date for sheep and goats is the 1st of January instead of May as before. This is especially relevant for juveniles as they are usually only born in spring. Accordingly, a rupture in the official time series can be observed. This has been corrected in the GHG Inventory based on background data of the gross nutrient balance of the Swiss Federal Statistical Office (SFSO 2021b).
- Since 2018 the population statistics of bisons is assessed in the animal traffic database. The age limit between young and adult bisons changed from 3 years (1095 days) to 900 days. This causes a rupture in the time series. This has been corrected in the GHG Inventory based on background data of the gross nutrient balance of the Swiss Federal Statistical Office (SFSO 2021b).
- Since 2018 the population statistics of horses, mules and asses are assessed in the animal traffic database (ATD 2020). The age limit between young and adult animals changed from 3 years (1095 days) to 900 days. Furthermore, allocation of different breeds to the categories horses, mules and asses changed. Additionally the animal traffic database comprises now all animals, i.e. equids covered by the official agricultural census of the Swiss Federal Statistical Office and equids held by private persons or enterprises that do not fulfil the criteria of an agricultural enterprise. To assure time series consistency population statistics of equids were reconditioned by the Swiss Federal Statistical Office (SFSO 2021b). Nevertheless, small ruptures may still occur particularly due to the assessment of equids not covered by agricultural census. However, influence on the overall emissions is small.
- Gross energy intake and implied emission factors of some of the aggregated animal categories reveal some fluctuations during the inventory period due to varying shares of the sub-categories.
- Gross energy intake as well as the implied emission factor for mature dairy cattle increase, mainly as a result of higher milk production and live weight (Table 5-5).

### 5.2.4. Category-specific QA/QC and verification

General QA/QC measures are described in NIR chp. 1.2.3.

All further category-specific QA/QC activities are described in a separate document (Agroscope 2019a). General information on agricultural structures and policies is provided and eventual differences between national and (IPCC 2006) standard values are being analysed and discussed. Furthermore, comparisons with data from other countries were conducted and discussed where possible. Agroscope (2019a) is periodically updated with the most recent inventory data.

A mutual peer review was conducted with the German GHG inventory group (Fuß et al. 2021). The respective recommendations were implemented as far as possible during the submission 2022.

Livestock data were compared with the livestock data provided by the FAO and checked for plausibility. In all cases the new recalculated data according to ART/SHL (2012) are considered more reliable than the FAO data. Small inconsistencies (usually in the order of ±2%) are due to updates of provisional data that are not considered by the FAO. For horses, mules and asses disagreements might be due to the different accounting of agricultural and non-agricultural horses. The Swiss inventory system accounts for all animals and differentiates between animals captured by the official agricultural census and livestock not covered by agricultural census. Moreover, the numbers of mules and asses is higher in the Swiss GHG inventory because unlike the FAO, Switzerland accounts also for ponies and lesser horses. For the categories "Fattening Pigs over 25 kg" (subcategory of swine) and "Broilers" (subcategory of poultry) adjustments were made in the GHG inventory in order to correctly consider animal turnover rates (Kupper et al. 2022; SFSO 2021b). The values for these subcategories are thus higher than in the official statistics. The total numbers of poultry in the GHG inventory and the FAO data also show minor discrepancies due to different accounting of turkeys, geese, ducks and quails.

Seasonal fluctuation of the cattle population was analysed for the years 2005–2007 based on detailed information from the Swiss Farmers Union (SBV 2007a). Seasonal fluctuations are usually in the order of ±3% with census data (April) always slightly above the annual mean. Data from the animal traffic database (i.e. cattle populations for the years 2009–2019) refer to annual mean population.

IPCC tables with data for estimating emission factors for cattle (such as weight, weight gain, milk production) were filled in, checked for consistency and confidence and compared with IPCC (2006) default values (refer to Annex A3.3).

Country-specific energy-intake rates for all cattle categories were compared to intake rates estimated with the IPCC (2006) Tier 2 default methodology (see Agroscope (2019a) for details). Both approaches are comparable in the assessment of net energy requirements. However, the IPCC approach resulted in higher estimates of GE-intake. Further analyses suggest that the IPCC conversion rates of net energy into gross energy are unrealistic for conditions in Switzerland. Given the experimentally verified high feed quality standards in Switzerland, the results of the country-specific inventory method are thus much more plausible than the estimates using the unaltered IPCC (2006) default method. Moreover, a discrepancy of approximatively 5.9% was found when comparing the overall GE-intake of the cattle population with the respective estimate of the Swiss Farmers Union (Giuliani 2019). As found for the comparison with the IPCC approach, different assumptions on net energy densities of the feed might explain the divergence.

For mature dairy cattle the implied methane emission factor was confirmed by a long term field study, where methane emissions from a herd of twenty dairy cows were measured over a full grazing season with the eddy covariance method (Felber et al. 2015).

During the past years a couple of studies were conducted to verify methane emissions at the regional scale, comparing bottom-up estimates with atmospheric measurements. While virtually all these measurements are subject to great uncertainties, the overall picture support the bottom-up approach in the Swiss GHG inventory or at least does not indicate the omission of a significant methane source. Hiller et al. (2014a) found that methane emissions might be underestimated by the inventory method when they measured atmospheric $CH_4$ concentrations over the Reuss-valley with an airplane. However, the methodological approach applied by Hiller et al. (2014a) still relies on a number of rather uncertain basic assumptions and is therefore not beyond doubts. Additionally, it should be noted, that methane emission estimates from the Agriculture sector in the Swiss GHG inventory were revised since, and currently lie approximately 10% above the estimates used by Hiller et al. (2014a) in their study. Stieger (2013) and Stieger et al. (2015) reported a very good agreement of bottom-up estimates and flux measurements with a tethered balloon system. Bamberger et al. (2014) conducted regional $CH_4$ measurements with a measurement device mounted on a car. Measurement precision and duration was not sufficient to validate bottom-up inventory estimates. Nonetheless, they concluded that a locally relevant emission source considered negligible in the emission inventory would have been identified. Finally Henne et al. (2015, 2016, 2017) found a very good agreement between inventory estimates of $CH_4$ emissions and independent atmospheric measurements over Switzerland (see A5.2).

### 5.2.5. Category-specific recalculations

General information on recalculations is provided in chp. 10.

Recalculations with an overall impact of >0.5 kt $CO_2$ equivalent are assessed quantitatively. All other recalculations are only described qualitatively.

- Emissions were recalculated for the years 2017–2019 due to new background data of the SFSO for livestock population statistics for horses, fattening pigs and broilers (AD; SFSO 2021b). The impact on overall emissions is negligible for 2017 and approximately +4 kt $CO_2$ eq for 2018 and 2019.
- Emissions from poultry were recalculated for the year 2019 due to an update of the number of other poultry (AD). The impact on overall emissions is negligible
- The reported values for milk yield in CRF Table3.As2 were adjusted for the whole time series. The new values refer now to the amount of ECM-Milk. Emission estimates were not affected by this adjustment of reporting.
- $CH_4$ emissions for mature dairy cattle were recalculated for the whole time series due to a new assessment of live weight (affecting IEF). A new time series of life weights was established by Burren et al. (2021) and was used for modelling GEI and VS-excretion rates instead of a constant weight of 650 kg. The impact on overall emissions ranges from -20 kt $CO_2$ eq in 1990 to +28 kt $CO_2$ eq in 2019.
- $CH_4$ emissions from enteric fermentation of sheep, swine, goats and poultry and "other" (livestock NCAC) were recalculated for the year 2018 and 2019. EF were revised based on updates of provisional estimates for net energy intake from the Swiss Farmers Union (Giuliani 2021). The impact on overall emissions is approximately -0.7 and +0.5 kt $CO_2$ eq for the years 2018 and 2019.
- $CH_4$ emissions from enteric fermentation of sheep were recalculated for the years 2015–2019 due to an adjustment of the methane conversion rate ($Y_m$, affecting IEF).

The weighing of the methane conversion rates for adult and young sheeps was adjusted based on new consistent time series of the number of young sheep (SFSO 2021b). The mean impact on overall emissions was -3.2 kt $CO_2$ eq for the period 2015–2019.

### 5.2.6. Category-specific planned improvements

During the internal review an error was detected in the reported values for average live weights of growing cattles. Emission calculations are not affected by this error. The correct values will be reported during future submissions.

## 5.3. Source category 3B – Manure management

### 5.3.1. Source category description

Table 5-9 Key categories of 3B Manure management. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 3B1-4 | Manure Management, all Livestock, direct | CH4 | L1, L2 |
| 3B1-4 | Manure Management, all Livestock, direct | N2O | L2 |
| 3B5 | Manure Management, indirect | N2O | L1, L2 |

The emission source is the domestic livestock population broken down into 3 cattle categories (mature dairy cattle, other mature cattle, growing cattle), sheep, swine, buffalo, camels, deer, goats, horses, mules and asses, poultry, rabbits and livestock not covered by agricultural census (Livestock NCAC) (Table 5-10). Six ($CH_4$) respectively five ($N_2O$) different manure management systems are considered as well as indirect $N_2O$ emissions from 3B Manure management (Table 5-11). Additionally, $NO_x$ and NMVOC emissions from manure management are estimated. In the reporting tables all $NO_x$ emissions are reported under 3D Agricultural soils.

The total emissions from 3B Manure management closely follow the development of the cattle population. Emissions declined from 1990 until 2004, increased until 2008 and subsequently declined slowly until 2015 and somewhat faster until 2020.

Significant contributors to $CH_4$ emissions from 3B Manure management are cattle with approximatively 66% and swine with approximatively 30% on average over the period 1990–2020. Cattle and swine contribute significantly to $N_2O$ emissions with 69% and 19%, respectively, on average over the period 1990–2019.

Leaching of $NO_3^-$ from manure management systems is not occurring in Switzerland and is thus not included in the estimates. This assessment is principally based on expert judgement from Thomas Kupper from the “School for Agricultural, Forest and Food Sciences (HAFL)” (Kupper 2014) and based on his personal expertise and on the following literature: Sagoo et al. (2007), Petersen et al. (1998), Webb (2001), Monteny et al. (2006), Oenema et al. (2007) and Chadwick (2005).

Emissions from fur-bearing animals are not occurring in Switzerland as provisions for the husbandry of wild animals are very strict according to the Swiss Animal Welfare Act (Swiss Confederation 2003). See also chp. 5.2.1.

Table 5-10 Specification of source category 3B Manure management by livestock categories.

| 3B | Source | Specification |
|---|---|---|
| 3B1 | Cattle | Mature Dairy Cattle |
| | | Other Mature Cattle |
| | | Growing Cattle (Fattening Calves[1], Pre-Weaned Calves, Breeding Cattle 1st year (Breeding Calves + Breeding Cattle 4-12 months), Breeding Cattle > 1 year (Breeding Cattle 2nd year + Breeding Cattle 3rd year), Fattening Cattle (Fattening Calves 0-4 months[2] + Fattening Cattle 4-12 months)) |
| 3B2 | Sheep | Lambs < 1 year |
| | | Mature Sheep |
| | | Fattening Sheep |
| | | Milk Sheep |
| 3B3 | Swine | Piglets |
| | | Fattening Pig over 25 kg |
| | | Dry Sows |
| | | Nursing Sows |
| | | Boars |
| 3B4a | Buffalo | Bisons < 3 years[3] |
| | | Bisons > 3 years[3] |
| 3B4b | Camels | Llamas < 2 years |
| | | Llamas > 2 years |
| | | Alpacas < 2 years |
| | | Alpacas > 2 years |
| 3B4c | Deer | Fallow Deer |
| | | Red Deer |
| 3B4d | Goats | Goat Places |
| 3B4e | Horses | Horses < 3 years |
| | | Horses > 3 years |
| 3B4f | Mules and Asses | Mules |
| | | Asses |
| 3B4g | Poultry | Growers |
| | | Layers |
| | | Broilers |
| | | Turkey |
| | | Other Poultry |
| 3B4h i | Rabbits | |
| 3B4h ii | Livestock NCAC | Sheep |
| | | Goats |
| | | Horses < 3 years |
| | | Horses > 3 years |
| | | Mules |
| | | Asses |

1) Fattening for veal with a milk based diet (slaughtere at ap. 100 days). See chp. 5.2.2.3.
2) Fattening for beef meat (slaughtered at ap. 400 days). See chp. 5.2.2.3.
3) Bisons (Bos bison and/or Bos bonasus). Water buffalos (Bubalus bubalis) are included under cattle. See chp. 5.2.2.3.

Table 5-11 Specification of source category 3B Manure management by manure management systems.

| 3B | Source | Specification $CH_4$ | | Specification $N_2O$ | |
|---|---|---|---|---|---|
| 3B6a | Direct Emissions | Liquid systems | | Liquid systems --> Pit storage below animal confinement | |
| 3B6b | | Solid storage and dry lot | | Solid storage and dry lot | |
| 3B6c / 3D | | Pasture, range and paddock | | NA[1] | |
| 3B6d | | Digesters (anaerobic digestion) | | Digesters (anaerobic digestion) | |
| 3B6e | | Other | Deep litter | Other | Deep litter |
| | | | Poultry system | | Poultry system |
| 3B5a | Indirect Emissions | NA | | Atmospherical deposition | |
| 3B5b | | NA | | Leaching and run-off | |

1) Reported under 3D Agricultural Soils

## 5.3.2. Methodological issues

### 5.3.2.1. Methodology

The calculation is based on methods described in the 2006 IPCC Guidelines ($CH_4$: IPCC 2006 equation 10.23; $N_2O$: IPCC 2006 equation 10.25).

$CH_4$ emissions from 3B Manure management were generally estimated using a Tier 2 methodology. For cattle a more detailed Tier 3 method was applied, estimating volatile solids (VS) excretion based on gross energy intake estimates as used for enteric fermentation. VS excretion from buffalo, camels, horses and deer was equally estimated based on gross energy intake. For the remaining livestock categories default parameters were used. Methane conversion factors (MCF) are from IPCC (2006; solid storage, pasture range and paddock, anaerobic digesters, poultry manure), country-specific (deep litter) or were modelled according to Mangino et al. (2001) (liquid systems, anaerobic digesters).

$N_2O$ emissions from 3B Manure management were estimated using a country-specific Tier 3 methodology. Activity data were adjusted to the particular situation of Switzerland in coordination with the Swiss ammonia model AGRAMMON (Kupper et al. 2022). Detailed country-specific data on nitrogen excretion rates, manure management system distribution and nitrogen volatilisation were applied. Emission factors for direct $N_2O$ emissions ($EF_3$) are based on IPCC (2006) whereas the emission factor for indirect emissions from atmospheric deposition is country-specific (Bühlmann et al. 2015, Bühlmann 2014).

The $N_2O$ emissions from pasture, range and paddock are reported under 3D Agricultural soils, source category 3Da3 Urine and dung deposited by grazing animals.

For calculation of $CH_4$ and $N_2O$ emissions, slightly different livestock sub-categories were used (Table 5-12). The livestock categories reported in the reporting tables (CRF) are the same, but the respective sub-categories as a basis for the calculation are different. The categorisation for the estimation of $CH_4$ emissions had to be adapted to data availability for energy requirements, while the categorisation for the estimation of $N_2O$ emissions is determined by the respective categorisation of the Swiss ammonia inventory (AGRAMMON, Kupper et al. 2022, Richner et al. 2017). Nevertheless, there is no inconsistency in the total number of animals as they are the same both for $CH_4$ and $N_2O$ emissions. Note that although not growing cattle in the proper sense, bulls are contained in the categories breeding cattle >1 year, breeding cattle $3^{rd}$ year and/or fattening cattle according to their purposes.

The calculation of $CH_4$ and $N_2O$ emissions is done by Agroscope, the Swiss centre of excellence for agricultural research (Agroscope 2022).

Table 5-12 Livestock categories for estimating $CH_4$ and $N_2O$ emissions from 3B Manure management.

| 3B | $CH_4$ | | $N_2O$ | |
|---|---|---|---|---|
| Cattle | Mature Dairy Cattle | | Mature Dairy Cattle | |
| | Other Mature Cattle | | Other Mature Cattle | |
| | Growing Cattle | Fattening Calves[1]<br>Pre-Weaned Calves<br>Breeding Cattle $1^{st}$ year (Breeding Calves + Breeding Cattle 4-12 months)<br>Breeding Cattle > 1 year<br>Fattening Cattle (Fattening Calves 0-4 months[2] + Fattening Cattle 4-12 months) | Growing Cattle | Fattening Calves[1]<br>Pre-Weaned Calves<br>Breeding Cattle $1^{st}$ year<br>Breeding Cattle $2^{nd}$ year<br>Breeding Cattle $3^{rd}$ year<br>Fattening Cattle |
| Sheep | Lambs < 1 year<br>Mature Sheep | | Fattening Sheep<br>Milk Sheep | |
| Swine | Swine | | Piglets<br>Fattening Pig over 25 kg<br>Dry Sows<br>Nursing Sows<br>Boars | |
| Buffalo | Bisons < 3 years[3]<br>Bisons > 3 years[3] | | Bisons < 3 years[3]<br>Bisons > 3 years[3] | |
| Camels | Llamas < 2 years<br>Llamas > 2 years<br>Alpacas < 2 years<br>Alpacas > 2 years | | Llamas < 2 years<br>Llamas > 2 years<br>Alpacas < 2 years<br>Alpacas > 2 years | |
| Deer | Fallow Deer<br>Red Deer | | Fallow Deer<br>Red Deer | |
| Goats | Goats | | Goat places | |
| Horses | Horses < 3 years<br>Horses > 3 years | | Horses < 3 years<br>Horses > 3 years | |
| Mules and Asses | Mules<br>Asses | | Mules<br>Asses | |
| Poultry | Poultry | | Growers<br>Layers<br>Broilers<br>Turkey<br>Other Poultry | |
| Rabbits | Rabbits | | Rabbits | |
| Livestock NCAC | Sheep<br>Goats<br>Horses < 3 years<br>Horses > 3 years<br>Mules<br>Asses | | Sheep<br>Goats<br>Horses < 3 years<br>Horses > 3 years<br>Mules<br>Asses | |

1) Fattening for veal with a milk based diet (slaughtere at ap. 100 days). See chp. 5.2.2.3.
2) Fattening for beef meat (slaughtered at ap. 400 days). See chp. 5.2.2.3.
3) Bisons (Bos bison and/or Bos bonasus). Water buffalos (Bubalus bubalis) are included under cattle. See chp. 5.2.2.3.

### 5.3.2.2. Emission factors $CH_4$

Calculation of $CH_4$ emissions from 3B Manure management is based on methods described in the 2006 IPCC Guidelines (IPCC 2006, equation 10.23):

$$EF_T = VS_T \bullet 365 days/year \bullet B_{0T} \bullet 0.67 kg/m^3 \bullet \sum_S MCF_S \bullet MS_{TS}$$

$EF_T$ = annual $CH_4$ emission factor for livestock category *T* (kg/head/year)

$VS_T$ = daily volatile solids (VS) excreted for livestock category *T* (kg/head/day)

$B_{0T}$ = maximum $CH_4$ producing capacity for manure produced by livestock category *T* ($m^3$/kg)

0.67 kg/$m^3$ = conversion factor of $m^3$ $CH_4$ to kilograms $CH_4$

$MCF_S$ = $CH_4$ conversion factors for each manure management system *S* (%)

$MS_{TS}$ = fraction of livestock category *T*'s manure handled using manure management system *S* (dimensionless)

#### *5.3.2.2.1. Volatile solids excretion (VS)*

The daily excretions of volatile solids (VS) for **all cattle sub-categories** were estimated based on equation 10.24 in the 2006 IPCC Guidelines (IPCC 2006):

$$VS = \left[GE * \left(1 - \frac{DE\%}{100}\right)\right] * \left[\frac{1 - ASH}{EDF}\right]$$

VS = volatile solids excretion per day on a dry-organic matter basis (kg/day)

GE = gross energy intake (MJ/head/day)

DE = digestibility of the feed (%)

ASH = ash content of manure calculated as a fraction of the dry matter feed intake

EDF = energy density of feed, conversion factor for dietary GE per kg of dry matter (MJ/kg)

IPCC equation 10.24 originally contains an additional term to take account for the urinary energy (IPCC 2006). However, Dämmgen et al. (2011) highlight that the organic matter in urine does not account for any $CH_4$ formation and the term was hence omitted.

Gross energy intake was calculated according to the method described in chp. 5.2.2.2.1. In the case of **mature dairy cattle** the same model was used as for the estimation of $CH_4$ emissions from 3A Enteric fermentation. Content of net energy, gross energy and ash in feed dry matter as well as feed digestibility were also estimated using the Agroscope feeding model (Agroscope 2014c). The digestibility of feed is of crucial importance for the calculation of volatile solids. The modelled values for dairy cattle are somewhat higher than the IPCC (2006) default and were compared to measurements from feeding trials in Switzerland. The comparison revealed that modelled values are on average slightly higher than measurements. Accordingly, an adjustment was made in order to take account of digestibility depression at high feeding levels that are usually above maintenance (Ramin and Huhtanen

2012). High feeding levels may lead to an increase in rumen passage rate and subsequently to lower feed digestibility (Nousiainen et al. 2009). The correction decreased the feed digestibility on average by 2.5 percent points. Resulting feed digestibility was 72.2% on average, gross energy content (EDF) was 18.26 MJ/kg and ash content was 9.0% each with very small fluctuations along the time series.

For **calves and other growing cattle** IPCC (2006) default values of 65% and 60%, respectively, were taken for the feed digestibility. For the energy density of the feed (EDF) the IPCC (2006) default value, i.e. 18.45 MJ/kg was adopted. Furthermore, an ash content of 8.0% was used for all these categories.

For VS excretion of the livestock categories **sheep**, **swine**, **goats**, **mules and asses**, **poultry**, **rabbits** and **livestock NCAC**, default values from IPCC were taken (IPCC 2006: Tables 10A-7, 10A-8, 10A-9).

For **buffalo**, **camels, horses** and **deer** VS excretion was again estimated based on equation 10.24 in the 2006 IPCC Guidelines with default values for feed digestibility and ash content (IPCC 2006). Feed digestibility was 55% for buffalos, 60% for camels and deer (assuming similar feed composition as for sheep) and 70% for horses. The energy density of the feed (EDF) was 18.45 MJ/kg. The ash content of manure was 8.0% for buffalo, camels and deer and 4.0% for horses (IPCC 2006).

Finally for **livestock NCAC** the same VS excretion rates as for the respective animal categories in the official census were used.

##### *5.3.2.2.2. Maximum $CH_4$ producing capacity ($B_0$)*

For the methane producing capacity ($B_o$) default values were used (IPCC 2006). For deer the same value as for sheep was applied as no default value was available (i.e. 0.19 $m^3$/kg).

##### *5.3.2.2.3. Methane conversion factor (MCF)*

For estimating $CH_4$ emissions from manure management, six different manure management systems are distinguished. Switzerland has an average annual temperature below 15°C (MeteoSwiss 2014) and was therefore allocated to the cool climate region without differentiation.

In the case of **solid manure** and **pasture range and paddock** the default MCF values from table 10.17 of the 2006 IPCC Guidelines were used (Table 5-13).

**Liquid/slurry systems** are responsible for the major part of methane emissions from Manure management (85% on average). Accordingly a more detailed model was used to determine the respective MCF. For this purpose the model developed by Mangino et al. (2001), that is also used to derive the IPCC (2006) default values, was adapted to the specific conditions of Switzerland. On a monthly time step, loading of a virtual liquid/slurry manure system was simulated according to the VS excretion of the total livestock herd and the manure management system distribution (MS) in the respective inventory year. Thereby it was assumed that excretion on pasture, range and paddock takes only place during summer months, i.e. from April to September. Subsequently, monthly manure degradation was forecast using the temperature-dependent van't Hoff-Arrhenius equation with the parametrization as suggested by Mangino et al. (2001). Monthly mean air temperatures for the Swiss central plateau during the 1981–2010 time period were obtained from the Federal Office of Meteorology and Climatology (MeteoSwiss 2014). Minimum temperature in the liquid/slurry system was allowed to drop to 1°C instead of 5°C as proposed in the original model (see e.g. Vergé et al. 2007, Van der Zaag et al. 2013). Any carry-over effect of undergraded manure from one month to the next was neglected (see e.g. Park et al. 2006, Van der Zaag et al. 2013). Finally, an annual methane conversion factor was calculated by dividing the total VS degraded by the total load of VS.

Several authors have found that the simulated MCF-values according to the model described above are unrealistically high (Park et al. 2006, Van der Zaag et al. 2013). Consequently they propose to use a management and design practice factor (MDP factor) to bring the modelled factors into accordance with measurements. Accordingly, a MDP factor of 0.8 was applied here as suggested by Mangino et al. (2001). The resulting MCF-values for liquid/slurry systems range from 13.3% to 14.3%. The variation of the MCF along the time series is due to varying shares of manure dropped on pasture, range and paddock. The higher the share of manure dropped on pasture, range and paddock, the lower is the overall MCF for liquid/slurry systems (as livestock is only grazing during summer, the relative share of low methane conversion factors during the cold winter month increases when summer grazing time increases).

**Anaerobic digestion** of animal manure is increasing in Switzerland since the 1990s but is still not widespread (7.2% of all volatile solids in 2020). Emissions from the digestion plant itself are reported under source category 5B2 (Anaerobic digestion at biogas facilities) and described in chp. 7.3.2.2. However, emissions from manure storage before alimentation into the digester are reported in source category 3B Manure management. The amount of manure digested anaerobically was estimated based on total energy production (SFOE 2021a) and eight monitoring protocols of agricultural biogas plants (Genossenschaft Ökostrom Schweiz 2014, GES Biogas GmbH 2014). According to the data in the monitoring protocols the total amount of manure entering the plant originated mainly from cattle manure stored as liquid/slurry (57%) and solid storage (23%) and from swine manure stored as liquid/slurry (20%). It is assumed that 22.5% of the liquid/slurry manure is coming from the farm where the biogas plant is located and is hence directly fed into the digester on a daily basis without being stored (Koehli 2014). The respective MCF was thus set to zero. As solid manure usually has a low MCF and is stored for only a short period before being fed into the digester, the respective MCF was also set to zero. The MCF for the remaining liquid/slurry manure that is delivered from neighbouring farms to the biogas plant was estimated with the methodology described in the "Standard method for compensating projects of the type "agricultural biogas plants"" (FOEN 2014n). This method is based on the "Approved small scale baseline and monitoring methodology AMS-III.D./Version 19.0. Methane recovery in animal manure management systems" and relies thus on a generally accepted foundation (UNFCCC 2013c).

According to this methodology the MCF value for conventional liquid/slurry systems given in Table 5-13 is reduced according to the duration of pre-storage before the manure is delivered to the digester:

$$MCF_{PSAD} = MCF_{LS} * \left(\frac{14.49 * \left(e^{-k*AI_j} - 1\right)}{AI_j} + 1\right)$$

$MCF_{PSAD}$ = $CH_4$ conversion factor for pre-storage of liquid manure before delivery to biogas plants (%)

$MCF_{LS}$ = $CH_4$ conversion factor for liquid/slurry systems (%)

k = degradation rate constant (0.069)

$AI_j$ = average pre-storage time period (day)

The average pre-storage time was estimated to be 12 days (Koehli 2014). The resulting weighted average MCF-value for anaerobic digestion varies between 2.5% and 2.7%. Variation is due to the variation of the underlying MCF of liquid/slurry systems.

Fattening calves, sheep, camels, deer and goats are kept in **deep litter systems**. A MCF of 10% was adopted, which is the mean value between the IPCC default values for cattle and swine deep bedding <1 month and >1 month at 10°C (IPCC 2006). The choice of a MCF of 10% for deep litter is supported by the specific feeding and manure management regime in Switzerland (especially cold winter temperatures) and confirmed by a number of studies representative for the country-specific management conditions (Amon et al. 2001, Külling et al. 2002, Külling et al. 2003, Moller et al. 2004, Hindrichsen et al. 2006, Park et al. 2006 and Sommer et al. 2007, Zeitz et al. 2012). For further details see FOEN 2011 (chp. 16.5 attachment E).

For all poultry categories a MCF value of 1.5% was used according to the default value for **poultry manure systems** in the 2006 IPCC Guidelines.

Table 5-13 Manure management systems and methane conversion factors (MCFs). Blue: annually changing parameters, value for 2020.

| Manure management system | | Description | MCF (%) |
|---|---|---|---|
| Pasture | | Manure is allowed to lie as it is, and is not managed (distributed, etc.). | 1.0 |
| Solid storage | | Dung and urine are excreted in a barn. The solids (with and without litter) are collected and stored in bulk for a long time (months) before disposal. | 2.0 |
| Liquid/slurry systems | | Combined storage of dung and urine under animal confinements for longer than 1 month. | 13.4 |
| Digesters | | Storage before alimentation into anaerobic digester. Storage system can be liquid/slurry or solid storage. | 2.6 |
| Other | Deep litter | Dung and urine is excreted in a barn with lots of litter and is not removed for a long time (months). | 10.0 |
| | Poultry system | Manure is excreted on the floor with or without bedding. | 1.5 |

#### *5.3.2.2.4. Manure management system distribution (MS)*

The fraction of animal manure handled using different manure management systems (MS) as well as the percentages of urine and dung deposited on pasture, range and paddock was separately assessed for each livestock category (Table 5-14). The fractions are determined by the livestock husbandry system (e.g. tie stall or loose housing system) as defined in Richner et al. (2017). Estimation is conducted within the Swiss ammonium model AGRAMMON based on expert judgement and values from the literature (1990, 1995) and on extensive farm surveys (2002, 2007, 2010, 2015 and 2019) (Kupper et al. 2022). The data clearly reproduce the shift towards an increased use of pasture, range and paddocks and a decrease in solid storage. The changes of the manure management system distribution reflect the shift to a more animal-friendly livestock husbandry in the course of the agricultural policy reforms during the 1990s and the early 20$^{th}$ century. One of the most important voluntary programmes in this context is called “RAUS” and implies at least 156 days of pasture per year (Swiss Confederation, 2008). Accordingly, the share of mature dairy cattle (and other animals) going to pastures increased substantially and so did the length of stay on the pasture. In the year 2007 78% of the dairy cattle were held on farms participating in the RAUS programme. The average number of pasture days (including all farms) in that year was 178, and it was 173 in 2010. It can thus be assumed, that already in the early years of the new millennium most farms accomplished the transition to RAUS and that a new management standard was reached at this point of time, which did not change significantly afterwards.

Data for manure management system distribution for cattle are different for VS and nitrogen. This is because cattle stables often have simultaneously both liquid and solid manure storage systems. As volatile solids are excreted mainly in dung and nitrogen mainly in urine, the proportion of VS stored as solid manure is higher compared to the proportion of N. For cattle categories the MS-distribution for nitrogen as provided by Kupper et al. (2022) was thus adjusted using data on stable systems and manure accumulation from Richner et al. (2017) as well as data on frequency of stable systems on farms from (Kupper et al. 2022)(for a more detailed description of the approach see chp. A3.3.4). More or less the same result could be gained by adjusting the distribution of nitrogen by the VS/N-ratio. Data provided in Table 5-14 refer to the distribution of nitrogen while data provided in CRF Table3.B(a)s2 refer to the distribution of VS.

The amount of manure digested anaerobically was estimated based on total energy production (SFOE 2021a) and eight monitoring protocols of agricultural biogas plants (Genossenschaft Ökostrom Schweiz 2014, GES Biogas GmbH 2014) as described under 5.3.2.2.3.

### 5.3.2.3. Activity data $CH_4$

Activity data of all livestock categories covered by the official census were obtained from SBV (2021) and the SFSO (2021a). In 2011 the respective data for the time series 1990–2010 were revised and harmonised during a joint effort of the Agroscope Reckenholz Tänikon Research Station (ART) and the Swiss College of Agriculture (SHL) (ART/SHL 2012). Additionally to official statistical data, population data of livestock not covered by the agricultural census of the Swiss Federal Statistical Office were assessed based on background data of the gross nutrient balance of the Swiss Federal Statistical Office (SFSO

2021b) and based on data of the Swiss animal traffic database (ATD 2021). For further details and additional data on a livestock sub-category level refer to chp. 5.2.2.3, Table 5-8 as well as Annex A3.3.

Table 5-14 Manure management system distribution for nitrogen (MS) according to the AGRAMMON model. Detailed data on livestock sub-category levels for the distribution of nitrogen and volatile solids are provided in Annex A3.3.

| MS Distribution | 1990 | | | | | 1995 | | | | | 2002 | | | | | 2007 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | | | | | % | | | | | % | | | | | % | | | | |
| | Liquid / Slurry | Solid storage | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) | Liquid / Slurry | Solid storage | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) | Liquid / Slurry | Solid storage | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) | Liquid / Slurry | Solid storage | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) |
| Mature Dairy Cattle | 65.7 | 25.6 | 8.3 | 0.5 | 0.0 | 67.5 | 22.5 | 9.6 | 0.4 | 0.0 | 65.4 | 17.1 | 16.9 | 0.5 | 0.0 | 68.1 | 13.1 | 17.3 | 1.4 | 0.0 |
| Other Mature Cattle | 41.1 | 28.9 | 29.6 | 0.5 | 0.0 | 38.6 | 31.4 | 29.6 | 0.4 | 0.0 | 43.3 | 19.5 | 36.7 | 0.5 | 0.0 | 53.8 | 17.0 | 27.8 | 1.4 | 0.0 |
| Growing Cattle (weighted average) | 49.5 | 29.9 | 15.8 | 0.5 | 4.4 | 50.0 | 29.3 | 15.9 | 0.4 | 4.4 | 45.3 | 22.3 | 27.1 | 0.5 | 4.8 | 48.7 | 20.3 | 25.2 | 1.4 | 4.4 |
| *Fattening Calves* | *15.9* | *0.0* | *0.0* | *0.5* | *83.6* | *15.6* | *0.0* | *0.0* | *0.4* | *84.0* | *14.9* | *0.0* | *0.7* | *0.5* | *83.9* | *25.2* | *0.0* | *0.4* | *1.4* | *73.0* |
| *Pre-Weaned Calves* | *41.1* | *28.9* | *29.6* | *0.5* | *0.0* | *38.6* | *31.4* | *29.6* | *0.4* | *0.0* | *40.2* | *23.8* | *35.5* | *0.5* | *0.0* | *52.7* | *16.7* | *29.2* | *1.4* | *0.0* |
| *Breeding Cattle 1st Year* | *39.2* | *46.3* | *14.1* | *0.5* | *0.0* | *40.1* | *45.3* | *14.2* | *0.4* | *0.0* | *37.3* | *34.7* | *27.4* | *0.5* | *0.0* | *44.9* | *28.9* | *24.8* | *1.4* | *0.0* |
| *Breeding Cattle 2nd Year* | *47.1* | *27.0* | *25.4* | *0.5* | *0.0* | *48.7* | *25.2* | *25.7* | *0.4* | *0.0* | *41.3* | *21.0* | *37.1* | *0.5* | *0.0* | *44.6* | *18.7* | *35.3* | *1.4* | *0.0* |
| *Breeding Cattle 3rd Year* | *52.4* | *27.1* | *20.0* | *0.5* | *0.0* | *52.9* | *26.3* | *20.4* | *0.4* | *0.0* | *45.7* | *19.6* | *34.2* | *0.5* | *0.0* | *48.9* | *17.2* | *32.6* | *1.4* | *0.0* |
| *Fattening Cattle* | *72.2* | *22.3* | *0.0* | *0.5* | *5.1* | *68.0* | *26.3* | *0.0* | *0.4* | *5.3* | *72.5* | *20.5* | *4.0* | *0.5* | *2.4* | *64.8* | *24.3* | *6.8* | *1.4* | *2.6* |
| Sheep (weighted average) | 0.0 | 0.0 | 30.1 | 0.0 | 69.9 | 0.0 | 0.0 | 30.3 | 0.0 | 69.7 | 0.0 | 0.0 | 48.7 | 0.0 | 51.3 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 |
| Swine (weighted average) | 98.9 | 0.0 | 0.0 | 1.1 | 0.0 | 99.0 | 0.0 | 0.0 | 1.0 | 0.0 | 97.4 | 1.0 | 0.3 | 1.3 | 0.0 | 95.3 | 0.2 | 0.9 | 3.7 | 0.0 |
| Buffalo (weighted average) | NA | NA | NA | NA | NA | 0.0 | 70.8 | 29.2 | 0.0 | 0.0 | 0.0 | 64.2 | 35.8 | 0.0 | 0.0 | 0.0 | 63.8 | 36.2 | 0.0 | 0.0 |
| Camels (weighted average) | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.0 | 0.0 | 47.2 | 0.0 | 52.8 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 |
| Deer (weighted average) | 0.0 | 0.0 | 35.7 | 0.0 | 64.3 | 0.0 | 0.0 | 35.7 | 0.0 | 64.3 | 0.0 | 0.0 | 47.2 | 0.0 | 52.8 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 |
| Goats | 0.0 | 0.0 | 13.6 | 0.0 | 86.4 | 0.0 | 0.0 | 13.6 | 0.0 | 86.4 | 0.0 | 0.0 | 28.5 | 0.0 | 71.5 | 0.0 | 0.0 | 27.3 | 0.0 | 72.7 |
| Horses (weighted average) | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 76.5 | 23.5 | 0.0 | 0.0 | 0.0 | 76.0 | 24.0 | 0.0 | 0.0 |
| Mules and Asses (weighted average) | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 84.0 | 16.0 | 0.0 | 0.0 | 0.0 | 76.7 | 23.3 | 0.0 | 0.0 |
| Poultry (weighted average) | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.5 | 0.0 | 99.5 | 0.0 | 0.0 | 2.7 | 0.0 | 97.3 | 0.0 | 0.0 | 3.2 | 0.0 | 96.8 |
| Rabbits | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| Livestock NCAC (weighted average) | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 80.8 | 12.8 | 0.0 | 6.3 | 0.0 | 36.5 | 35.0 | 0.0 | 28.4 | 0.0 | 39.5 | 33.3 | 0.0 | 27.2 |

| MS Distribution | 2010 | | | | | 2015 | | | | | 2019 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | | | | | % | | | | | % | | | | |
| | Liquid / Slurry | Solid storage | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) | Liquid / Slurry | Solid storage | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) | Liquid / Slurry | Solid storage | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) |
| Mature Dairy Cattle | 68.7 | 12.1 | 17.2 | 2.0 | 0.0 | 69.7 | 9.9 | 16.5 | 3.8 | 0.0 | 68.2 | 9.0 | 16.7 | 6.0 | 0.0 |
| Other Mature Cattle | 53.8 | 14.8 | 29.3 | 2.0 | 0.0 | 54.6 | 12.4 | 29.2 | 3.8 | 0.0 | 49.8 | 13.2 | 31.0 | 6.0 | 0.0 |
| Growing Cattle (weighted average) | 48.6 | 19.5 | 24.8 | 2.0 | 5.1 | 50.9 | 16.7 | 24.1 | 3.8 | 4.5 | 49.6 | 15.7 | 24.3 | 6.0 | 4.4 |
| *Fattening Calves* | *25.5* | *0.0* | *1.0* | *2.0* | *71.5* | *33.5* | *0.0* | *1.2* | *3.8* | *61.4* | *37.5* | *0.0* | *1.7* | *6.0* | *54.8* |
| *Pre-Weaned Calves* | *44.6* | *20.9* | *32.5* | *2.0* | *0.0* | *43.3* | *20.4* | *32.4* | *3.8* | *0.0* | *40.3* | *20.9* | *32.7* | *6.0* | *0.0* |
| *Breeding Cattle 1st Year* | *48.0* | *25.8* | *24.2* | *2.0* | *0.0* | *48.6* | *24.2* | *23.4* | *3.8* | *0.0* | *49.5* | *21.2* | *23.3* | *6.0* | *0.0* |
| *Breeding Cattle 2nd Year* | *46.3* | *16.8* | *34.8* | *2.0* | *0.0* | *45.7* | *15.5* | *35.0* | *3.8* | *0.0* | *47.4* | *12.8* | *33.8* | *6.0* | *0.0* |
| *Breeding Cattle 3rd Year* | *50.8* | *15.4* | *31.8* | *2.0* | *0.0* | *52.7* | *13.3* | *30.2* | *3.8* | *0.0* | *50.5* | *12.8* | *30.7* | *6.0* | *0.0* |
| *Fattening Cattle* | *60.3* | *28.4* | *5.9* | *2.0* | *3.3* | *68.3* | *19.1* | *6.3* | *3.8* | *2.4* | *60.6* | *21.4* | *9.2* | *6.0* | *2.7* |
| Sheep (weighted average) | 0.0 | 0.0 | 38.8 | 0.0 | 61.2 | 0.0 | 0.0 | 45.3 | 0.0 | 54.7 | 0.0 | 0.0 | 42.9 | 0.0 | 57.1 |
| Swine (weighted average) | 94.2 | 0.2 | 0.3 | 5.3 | 0.0 | 89.2 | 0.1 | 0.1 | 10.7 | 0.0 | 81.6 | 0.0 | 0.1 | 18.3 | 0.0 |
| Buffalo (weighted average) | 0.0 | 65.0 | 35.0 | 0.0 | 0.0 | 0.0 | 64.4 | 35.6 | 0.0 | 0.0 | 0.0 | 65.6 | 34.4 | 0.0 | 0.0 |
| Camels (weighted average) | 0.0 | 0.0 | 38.4 | 0.0 | 61.6 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 43.7 | 0.0 | 56.3 |
| Deer (weighted average) | 0.0 | 0.0 | 38.4 | 0.0 | 61.6 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 43.7 | 0.0 | 56.3 |
| Goats | 0.0 | 0.0 | 28.1 | 0.0 | 71.9 | 0.0 | 0.0 | 28.3 | 0.0 | 71.7 | 0.0 | 0.0 | 33.7 | 0.0 | 66.3 |
| Horses (weighted average) | 0.0 | 76.1 | 23.9 | 0.0 | 0.0 | 0.0 | 78.4 | 21.6 | 0.0 | 0.0 | 0.0 | 76.6 | 23.4 | 0.0 | 0.0 |
| Mules and Asses (weighted average) | 0.0 | 76.9 | 23.1 | 0.0 | 0.0 | 0.0 | 77.9 | 22.1 | 0.0 | 0.0 | 0.0 | 80.4 | 19.6 | 0.0 | 0.0 |
| Poultry (weighted average) | 0.0 | 0.0 | 2.8 | 0.0 | 97.2 | 0.0 | 0.0 | 3.0 | 0.0 | 97.0 | 0.0 | 0.0 | 3.4 | 0.0 | 96.6 |
| Rabbits | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| Livestock NCAC (weighted average) | 0.0 | 43.0 | 29.8 | 0.0 | 27.2 | 0.0 | 46.7 | 30.5 | 0.0 | 22.8 | 0.0 | 46.4 | 30.2 | 0.0 | 23.4 |

### 5.3.2.4. Emission factors $N_2O$

Estimation of direct $N_2O$ emissions from manure management relies basically on the same animal waste management systems as the estimation of $CH_4$ emissions (compare chp. 5.3.2.2). All emission factors are based on default values given in table 10.21 of the 2006 IPCC Guidelines (Table 5-15). For liquid/slurry storage systems an emission factor of 0.002 kg $N_2O$-N/kg N as suggested for “Pit storage below animal confinements” was considered appropriate.

Table 5-15 Emission factors for calculating $N_2O$ emissions from manure management. Blue: annually changing parameters, value for 2020.

| **Animal waste management system** | **Emission factor** |
|---|---|
| | kg $N_2O$-N / kg N |
| Liquid/Slurry: Pit storage below animal confinement | 0.002 |
| Solid storage | 0.005 |
| Anaerobic digester | 0.000 |
| Cattle and swine deep bedding: no mixing | 0.010 |
| Poultry manure | 0.001 |
| Indirect emissions due to volatilisation | 0.026 |

The emission factor for indirect $N_2O$ emissions after volatilisation of $NH_3$ and $NO_x$ from manure management systems was reassessed during a literature review by Bühlmann et al. 2015 and Bühlmann 2014. Due to the fragmented land use in Switzerland, where agricultural land use alternates with natural and semi-natural ecosystems over short distances, the share of volatilised nitrogen that is re-deposited in (semi-)natural habitats is on average higher than 55%. Thus, the assumption made in the 2006 IPCC Guidelines that “a substantial fraction of the indirect emissions will in fact originate from managed land”, cannot be applied to Switzerland. Accordingly, the overall emission factor for indirect emissions was estimated by calculating an area-weighted mean of the indirect emission factor for managed land (i.e. 0.01 based on IPCC 2006) and the indirect emission factor for (semi-)natural land (as provided in Bühlmann 2014 chp. 5.2.1) (Table 5-16). Due to slightly changing land use over the inventory time period, the resulting emission factor shows some small temporal variation around a mean value of 2.56% (see also chp. 9.2.2). Note that the emission factor in cell R37 of CRF Table3.B(b) refers to kg $N_2O$/kg N instead of kg $N_2O$-N/kg N.

Table 5-16 Data for estimating emission factors for indirect $N_2O$ emissions from atmospheric deposition according to Bühlmann (2014).

| **$EF_4$ atmospheric deposition** | | **1990-2011** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Unit** | **1990** | **1995** | **2000** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** |
| Share of deposition on agricultural land | % | 0.573 | 0.574 | 0.575 | 0.569 | 0.568 | 0.567 | 0.559 | 0.551 | 0.543 | 0.543 |
| Share of deposition in semi-natural ecosystems | % | 0.427 | 0.426 | 0.425 | 0.431 | 0.432 | 0.433 | 0.441 | 0.449 | 0.457 | 0.457 |
| $EF_4$ for agricultural land | kg $N_2O$-N / total kg N-deposited | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 |
| $EF_4$ for semi-natural ecosystems | kg $N_2O$ / kg N-deposited | 0.030 | 0.030 | 0.030 | 0.031 | 0.032 | 0.032 | 0.032 | 0.033 | 0.033 | 0.033 |
| $EF_4$ weighted | kg $N_2O$-N / kg N-deposited | 0.0248 | 0.0248 | 0.0248 | 0.0257 | 0.0259 | 0.0260 | 0.0262 | 0.0263 | 0.0264 | 0.0264 |

| **$EF_4$ atmospheric deposition** | | **2012-2020** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Unit** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | 2020 |
| Share of deposition on agricultural land | % | 0.543 | 0.543 | 0.543 | 0.543 | 0.543 | 0.543 | 0.543 | 0.543 | 0.543 |
| Share of deposition in semi-natural ecosystems | % | 0.457 | 0.457 | 0.457 | 0.457 | 0.457 | 0.457 | 0.457 | 0.457 | 0.457 |
| $EF_4$ for agricultural land | kg $N_2O$-N / total kg N-deposited | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.01 |
| $EF_4$ for semi-natural ecosystems | kg $N_2O$ / kg N-deposited | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 |
| $EF_4$ weighted | kg $N_2O$-N / kg N-deposited | 0.0264 | 0.0264 | 0.0264 | 0.0264 | 0.0264 | 0.0264 | 0.0264 | 0.0264 | 0.02643 |

### 5.3.2.5. Activity data $N_2O$

Activity data for $N_2O$ emissions from 3B Manure management were estimated according to equation 10.25 of the 2006 IPCC Guidelines:

$$N_2O_{D(mm)} = \left[ \sum_S \left[ \sum_T \left( N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)} \right) \right] \bullet EF_{3(S)} \right] \bullet \frac{44}{28}$$

$N_2O_{D(mm)}$ = direct $N_2O$ emissions from manure management (kg $N_2O$/year)

$N_{(T)}$ = number of head of livestock species/category *T* (head)

$Nex_{(T)}$ = annual average N excretion per head of species/category *T* (kg N/head/year)

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S*

$EF_{3(S)}$ = emission factor for direct $N_2O$ emissions from manure management system *S* (kg $N_2O$-N/kg N)

44/28 = conversion of $(N_2O\text{-}N)_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions

#### *5.3.2.5.1. Livestock population*

Activity data of all livestock categories covered by the official census were obtained from SBV (2021) and the SFSO (2021a). In 2011 the respective dataset for the time series 1990–2010 was revised and harmonised during a joint effort of the Agroscope Reckenholz Tänikon Research Station (ART) and the Swiss College of Agriculture (SHL) in 2011 (ART/SHL 2012). Additionally to official statistical data, population data of livestock not covered by the agricultural census of the Swiss Federal Statistical Office were assessed based on background data of the gross nutrient balance of the Swiss Federal Statistical Office (SFSO 2021b) and based on data of the Swiss animal traffic database (ATD 2021). For further details and additional data on a livestock sub-category level refer to chp. 5.2.2.3, Table 5-8 as well as Annex A3.3.

#### *5.3.2.5.2. Nitrogen excretion ($N_{ex}$)*

Data on nitrogen excretion per animal category (kg N/head/year) are country-specific and were obtained from Kupper et al. (2022) (Table 5-17). These values are based on the “Principles of Fertilisation in Arable and Forage Crop Production” (Richner et al. 2017). Unlike to the method in the 2006 IPCC Guidelines, the age structure of the animals and the different use of the animals (e.g. fattening and breeding) are considered. Standard nitrogen excretion rates are modified within the AGRAMMON model in order to account for changing agricultural structures and production techniques over the years (e.g. milk yield, use of feed concentrates, protein reduced animal feed etc.; Kupper et al. (2022)). This more disaggregated approach leads to considerable lower calculated nitrogen excretion rates compared to IPCC (2006) mainly because lower $N_{ex}$-rates of young animals are considered explicitly.

The nitrogen excretion rates are given on an annual basis, considering replacement of animals (growing cattle, swine, poultry, rabbits) and including excretions from corresponding offspring and other associated animals (sheep, deer, goats, swine, rabbits) (ART/SHL 2012).

Nitrogen excretion rates of **mature dairy cattle** were adopted from the most recent version of the AGRAMMON model (Kupper et al. 2022). Regional data of animal performance and feed ration composition were used to adjust standard nitrogen excretion rates from Richner et al. (2017). The calculations are based on the same feeding model as used for the estimation of gross energy intake and the excretion of volatile solids (Agroscope 2014c; chp.

5.2.2.2.1, 5.3.2.2.1) and are further described in Menzi et al. (2016). Nitrogen excretion is calculated as the nitrogen intake minus the nitrogen excretion in the milk minus the nitrogen in the calve assuming no change in body weight of the cow. Accordingly, nitrogen excretion of mature dairy cattle is dependent on feed composition (use of feed concentrates, corn silage, corn cubes, and hay in summer and winter rations), feed properties (N-content and digestibility of the individual feed components) and milk production. Estimated values of crude protein contents of animal feeds in the Swiss Feed Database are based on an extensive measurement program particularly also for roughages (Agroscope 2014b). Nitrogen content of the feed is estimated as crude protein content divided by 6.25. Protein content in the milk was set to 0.033 $g*kg\ milk^{-1}$. Nitrogen content in the milk is estimated as protein content divided by 6.38. After the year 2006 the yearly increase of nitrogen excretion slowed down due to an increased use of energy dense feedstuff (concentrates) and a slower increase of the milk yield compared to earlier years.

For the category **other mature cattle** as well as all **growing cattle** categories the nitrogen excretion rates of the AGRAMMON model (Kupper et al. 2022) were adopted which are again based on the standard values of Richner et al. (2017). The assessment of these standard values is based on the Swiss feeding recommendations (RAP et al. 1999, Morel et al. 2015) which are elaborated based on a great number of feeding trials at the Agroscope research station in Posieux. Nitrogen excretion rates of some sub-categories are fluctuating along the time series due to changes in feeding and management practices.

**Sheep** in Switzerland are fed mainly on roughage from extensive pasture and meadows (Richner et al. 2017) and are estimated to excrete approximately 8.0 kg N per head and year. This is considerably lower than IPCC default (IPCC 2006). However, nitrogen excretion is averaged over the whole population, of which roughly 40% are lambs and other immature animals. **Swine** show a significant decrease in nitrogen excretion rates until 2007, which can be explained by the increasing use of protein-reduced fodder (Kupper et al. 2022). Changing production techniques and increasing use of protein-reduced fodder are also drivers of nitrogen excretion rates for **poultry**.

Table 5-17 Nitrogen excretion rates of Swiss livestock. The complete time series on a livestock sub-category level are provided in Annex A3.3.

| Nitrogen Excretion | | 1990 | 1995 | 2000 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | kg N/head/year | | | | | | | | | |
| Mature Dairy Cattle | | 100.4 | 101.5 | 104.1 | 107.4 | 108.2 | 108.9 | 109.3 | 109.7 | 110.1 | 110.3 |
| Other Mature Cattle | | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 |
| Growing Cattle (weighted average) | | 33.0 | 33.1 | 33.1 | 32.6 | 32.7 | 32.7 | 32.9 | 32.8 | 32.7 | 32.8 |
| | *Fattening Calves* | *13.0* | *13.0* | *13.0* | *14.2* | *14.6* | *15.0* | *15.3* | *15.7* | *16.0* | *16.4* |
| | *Pre-Weaned Calves* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* |
| | *Breeding Cattle 1st Year* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* |
| | *Breeding Cattle 2nd Year* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* |
| | *Breeding Cattle 3rd Year* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* |
| | *Fattening Cattle* | *33.0* | *33.0* | *33.0* | *34.2* | *34.6* | *35.0* | *35.3* | *35.7* | *36.0* | *36.4* |
| Sheep (weighted average) | | 7.5 | 7.6 | 8.0 | 8.1 | 8.2 | 8.2 | 8.2 | 8.4 | 8.5 | 8.4 |
| Swine (weighted average) | | 14.3 | 14.0 | 11.0 | 9.6 | 9.4 | 9.2 | 9.2 | 9.3 | 9.2 | 9.2 |
| Buffalo (weighted average) | | NA | 37.2 | 41.1 | 38.7 | 38.0 | 34.9 | 34.4 | 36.5 | 37.3 | 38.4 |
| Camels (weighted average) | | NA | NA | 14.1 | 12.8 | 12.8 | 12.8 | 12.8 | 12.8 | 12.6 | 12.7 |
| Deer (weighted average) [1)] | | 20.0 | 21.9 | 22.3 | 21.9 | 22.1 | 22.1 | 22.4 | 22.5 | 22.4 | 22.4 |
| Goats | | 11.2 | 11.1 | 11.3 | 11.1 | 11.3 | 11.2 | 11.2 | 11.4 | 11.2 | 11.4 |
| Horses (weighted average) | | 43.6 | 43.5 | 43.6 | 43.7 | 43.7 | 43.7 | 43.7 | 43.7 | 43.7 | 43.7 |
| Mules and Asses (weighted average) | | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 |
| Poultry (weighted average) | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Rabbits | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Livestock NCAC (weighted average) | | 36.5 | 29.4 | 12.5 | 13.0 | 13.0 | 13.6 | 13.8 | 14.0 | 14.7 | 15.2 |

| Nitrogen Excretion | | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | kg N/head/year | | | | | | | | |
| Mature Dairy Cattle | | 110.5 | 110.7 | 110.9 | 111.1 | 111.1 | 111.2 | 111.3 | 111.4 | 111.4 |
| Other Mature Cattle | | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 |
| Growing Cattle (weighted average) | | 33.0 | 33.1 | 33.1 | 33.1 | 33.0 | 32.9 | 32.8 | 32.7 | 32.6 |
| | *Fattening Calves* | *16.8* | *17.2* | *17.6* | *18.0* | *18.0* | *18.0* | *18.0* | *18.0* | *18.0* |
| | *Pre-Weaned Calves* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* |
| | *Breeding Cattle 1st Year* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* |
| | *Breeding Cattle 2nd Year* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* |
| | *Breeding Cattle 3rd Year* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* |
| | *Fattening Cattle* | *36.8* | *37.2* | *37.6* | *38.0* | *38.0* | *38.0* | *38.0* | *38.0* | *38.0* |
| Sheep (weighted average) | | 8.5 | 8.6 | 8.5 | 8.4 | 8.4 | 8.5 | 8.5 | 8.5 | 8.5 |
| Swine (weighted average) | | 9.1 | 9.1 | 9.1 | 9.1 | 9.1 | 9.1 | 9.1 | 9.1 | 9.1 |
| Buffalo (weighted average) | | 36.9 | 36.9 | 36.4 | 36.4 | 36.4 | 35.9 | 47.1 | 45.9 | 45.7 |
| Camels (weighted average) | | 12.8 | 12.9 | 12.8 | 12.7 | 12.6 | 12.6 | 12.5 | 12.6 | 12.6 |
| Deer (weighted average) [1)] | | 22.5 | 23.0 | 23.0 | 23.0 | 23.1 | 23.3 | 23.4 | 23.6 | 23.6 |
| Goats | | 11.5 | 11.6 | 11.6 | 11.4 | 11.4 | 11.4 | 11.4 | 11.4 | 11.4 |
| Horses (weighted average) | | 43.7 | 43.8 | 43.8 | 43.8 | 43.8 | 43.9 | 43.9 | 43.9 | 43.9 |
| Mules and Asses (weighted average) | | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 |
| Poultry (weighted average) | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Rabbits | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Livestock NCAC (weighted average) | | 15.4 | 15.9 | 15.7 | 15.8 | 16.1 | 16.1 | 14.7 | 14.9 | 15.0 |

[1)] Deer: Excretion per animal place

### *5.3.2.5.3. Manure management system distribution (MS)*

The split of nitrogen flows into the different animal waste management systems and its temporal dynamics are based on the respective analysis in the AGRAMMON model (Kupper et al. 2022) and on data provided in Richner et al. (2017). For cattle, the distribution of animal excreta to the various manure management systems is different with regard to estimating $CH_4$ emissions from 3B Manure management compared to estimating $N_2O$ emissions from 3B Manure management (for further information refer to chp. 5.3.2.2.4 and chp. A3.3.4). This is because cattle stables often have simultaneously both liquid and solid manure storage systems. As volatile solids are excreted mainly in dung and nitrogen mainly in urine, the proportion of VS stored as solid manure is higher compared to the proportion of N. Data provided in Table 5-14 refer to the distribution of nitrogen while data provided in CRF Table3.B(a)s2 refer to the distribution of VS. A detailed table of the distribution of VS is contained in Annex A3.3.

#### *5.3.2.5.4. Volatilisation of $NH_3$, $NO_x$ and $N_2$ from manure management systems*

For indirect $N_2O$ emissions from manure management the deposition of volatilised $NH_3$ and $NO_x$ is considered. Losses of ammonia from stables and manure storage systems to the atmosphere are calculated according to the Swiss ammonia model AGRAMMON (Kupper et al. 2022). Specific loss-rates for all major livestock categories are estimated based on agricultural structures and techniques (e.g. stable type, manure management system, measures to reduce $NH_3$ emissions). Accordingly, the overall fraction of reactive nitrogen ($NH_3$, $NO_x$) volatilised underlies certain temporal dynamics that can be explained by changes in agricultural management practices (e.g. the transition to more animal friendly housing systems). It ranges from 14.5 to 20.4%.

For the volatilisation of $NO_x$ values from van Bruggen et al. (2014) were used. Accordingly, it is estimated that 0.2%, 0.5%, 1.0% and 0.1% of the total nitrogen in liquid/slurry, solid storage, deep litter and poultry manure systems are lost to the atmosphere, respectively. In this context the management systems “anaerobic digestion” is treated as liquid/slurry system.

For the estimation of the amount of animal manure applied to soils, the volatilisation of dinitrogen ($N_2$) during manure management is also considered. It is estimated that 0.020%, 0.025%, 0.050% and 0.025% of the total nitrogen in liquid/slurry, solid storage, deep litter and poultry manure systems are lost to the atmosphere, respectively (van Bruggen et al. 2014).

Note that volatilisation from pasture, range and paddock manure is included under 3Db (Indirect $N_2O$ emissions from managed soils). A graphical overview of the nitrogen flow system is given in Figure 5-6 and respective numbers are provided in Table 5-21.

### 5.3.2.6. NMVOC emissions from manure management

The NMVOC emissions from animal husbandry are calculated by a Tier 1 approach according to the EMEP/EEA guidebook using country-specific and default emission factors (EMEP/EEA 2019, chp. 3B Manure management, Table 3.4) for cattle and all other livestock categories, respectively. A comprehensive literature study by Bühler and Kupper (2018) has shown that the data base of NMVOC emissions from animal husbandry is very scarce and that the derived emission factors differ widely. The studies on which the emission factors in EMEP/EEA (2019) are based show several inconsistencies that could affect significantly the emission factors. It remains also unknown, how the emissions from the studies performed in the United States were adapted to European agricultural feeding conditions and how the corresponding emission factors were derived. Therefore, a study was conducted between 2018 and 2021 in order to measure NMVOC emissions from dairy cattle with and without silage feeding in an experimental housing system during summer, winter and the transitional season and to derive emission factors that are representative for cattle husbandry in Switzerland (Schrade et al. 2022). Switzerland's Informative Inventory Report (FOEN 2022b, chp. 5.2.2.) contains a detailed description of these country-specific emission factors for cattle.

### 5.3.3. Uncertainties and time-series consistency

For the uncertainty analysis the input data from ART (2008a) were used and were updated with current activity and emission data as well as with default uncertainties from the 2006 IPCC Guidelines. The detailed input uncertainty values for category 3B are reported in Annex A2.1. The resulting, combined uncertainty for emissions according to approach 1 (uncertainty propagation) are reported in Annex A2.2 and in Annex A2.3 for results obtained by approach 2 (Monte Carlo simulations). The 95% confidence intervals obtained by Monte Carlo simulations are slightly narrower.

Table 5-18 Uncertainties for 3B Manure management. (AD: Activity data; EF: Emission factor; CO: Combined; Approach 1: intervals are exactly from 2.5% to 97.5% of the distribution; Approach 2: the narrowest interval representing 95% of the distribution is given).

| **Uncertainty 3B** | **AD** | | **EF** | | **CO** | |
|---|---|---|---|---|---|---|
| | **(-)%** | **(+)%** | **(-)%** | **(+)%** | **(-)%** | **(+)%** |
| | **Approach 1** | | | | | |
| $CH_4$ (3B1-4) | 6.5 | 6.5 | 53.9 | 53.9 | 54.3 | 54.3 |
| $N_2O$ direct (3B1-4) | 22.8 | 22.8 | 52.2 | 71.2 | 57.0 | 74.7 |
| $N_2O$ indirect (3B5) | 42.9 | 54.7 | 99.9 | 400.2 | 108.7 | 403.9 |
| | **Approach 2** | | | | | |
| $CH_4$ (3B1-4) | 6.3 | 6.4 | 52.7 | 52.8 | 53.2 | 53.2 |
| $N_2O$ direct (3B1-4) | 22.0 | 22.6 | 57.5 | 63.2 | 60.5 | 67.3 |
| $N_2O$ indirect (3B5) | 46.1 | 50.3 | 100.0 | 282.7 | 100.0 | 288.1 |

The time series 1990–2020 are all considered consistent, although the following issues should be considered:

- For time series consistency of livestock population data and gross energy intake see chp. 5.2.3.
- The MCF for liquid/slurry systems varies according to the development of the grazing management over the years as described under chp. 5.3.2.2.3.
- Input data from the AGRAMMON-model are available for the years 1990 and 1995 (expert judgement and literature) as well as for 2002, 2007, 2010, 2015 and 2019 (extensive surveys on approximately 3000 farms). Values in-between the assessment years were interpolated linearly. For 2020 the same value as in 2019 was applied.
- The emission factor for indirect $N_2O$ emissions after volatilisation of $NH_3$ and $NO_x$ from manure management systems varies according to varying land use as described in chp. 5.3.2.4.

## 5.3.4. Category-specific QA/QC and verification

General QA/QC measures are described in NIR chp. 1.2.3.

All further category-specific QA/QC activities are described in a separate document (Agroscope 2019a). General information on agricultural structures and policies is provided and eventual differences between national and (IPCC 2006) standard values are being analysed and discussed. Furthermore, comparisons with data from other countries were conducted and discussed where possible. Agroscope (2019a) is periodically updated with the most recent inventory data.

A mutual peer review was conducted with the German GHG inventory group (Fuß et al. 2021). The respective recommendations were implemented as far as possible during the submission 2022.

For quality assurance of livestock population data and livestock energy intake consult chp. 5.2.4.

### 5.3.4.1. QA/QC and verification – $CH_4$

IPCC tables with data for estimating emission factors of all livestock categories (such as weight, feed digestibility, maximum $CH_4$ producing capacity ($B_0$) or daily excretion of volatile solids) were filled in, checked for consistency and confidence and compared with IPCC (2006) default values (refer to Annex A3.3).

VS excretion of various animal categories is based on IPCC default values (IPCC 2006). A cross check of these estimates was conducted during the 2016 submission. VS excretion of the total livestock population was estimated by using exclusively equation 10.24 of the 2006 IPCC Guidelines and GEI data for all animal categories. Using this approach, total VS excretion for the year 2014 was 4.1% higher than reported in the Swiss GHG inventory. Most of the discrepancy can be attributed to swine, for which the default value for VS excretion (also used in the inventory) is rather low (i.e. 0.31 kg/head/day as weighted mean for 2014 compared to 0.43 kg/head/day from the approach based on equation 10.24). However, Minonzio et al. 1998 also suggest a low VS-excretion of 0.30 kg/head/day on average, based on the Swiss typical feeding recommendations. They assume a digestibility of the organic matter of 83%. Using this value in IPCC equation 10.24 would also yield a VS-excretion of 0.31 kg/head/day. This finding supports the adoption of the IPCC default VS-excretion for swine. As for swine, equation 10.24 yields higher VS-excretion values for sheep and goats. Also in these cases the default values for feed digestibility (i.e. 60%) might be too low for Swiss specific conditions. In summary there is no clear indication that the approach using exclusively equation 10.24 would result in a better estimate of overall VS excretion. As for some of the parameters used in equation 10.24 (such as e.g. feed digestibility for swine) no reliable country-specific data were available, it was thus decided to still use the IPCC (2006) default values for VS excretion of the animal categories concerned.

Factors for methane conversion (MCF) and manure management system distribution (MS) were analysed considering the national agricultural context. The estimated MCF-values for liquid/slurry systems in Switzerland are lower than the IPCC (2006) default value for liquid/slurry system, without natural crust cover or pit storage below animal confinements > 1 month, at a temperature $\leq$10°C. However, a relatively low MCF is supported by the fact that more than 80% of all liquid/slurry storage tanks are covered and approximately one third of the remaining tanks have a surface crust (Kupper et al. 2022). Furthermore, a series of laboratory measurements of MCF-values by the group of animal nutrition from the Swiss Federal Institute of Technology in Zurich yielded consistently low MCF-values (Zeitz et al. 2012).

During the past years studies were conducted to verify methane emissions at the regional scale comparing bottom-up estimates with atmospheric measurements (Bamberger et al. 2014, Henne et al. 2015, Henne et al. 2016, Henne et al. 2017, Hiller et al. 2014, Hiller et al. 2014a, Stieger 2013, Stieger et al. 2015). For further information on these studies see chp. 5.2.4. and Annex A5.2.

#### 5.3.4.2. QA/QC and verification – $N_2O$

Estimation of $N_2O$ emissions is mainly based on the Swiss ammonium emission model AGRAMMON that is documented in Kupper et al. (2022).

All relevant data needed for the calculation of $N_2O$ emissions such as nitrogen excretion rates, manure management system distribution and $N_2O$ emission factors were checked for consistency and were compared to the corresponding values of other countries and to the IPCC (2006) default value if available (Agroscope 2019a).

As one of the most important parameters, nitrogen excretion rates were analysed in more detail. In order to validate the total nitrogen excretion of the whole livestock population a cross check was conducted comparing the bottom-up inventory estimates with an independent top down approach. Thereby, the total amount of nitrogen contained in animal livestock products such as meat, milk or eggs (output) was subtracted from the total amount of nitrogen in animal feedstuff produced in or imported to the country (input). Under the condition that the nitrogen pool in the animal population remains constant, the result should be equal to the amount of nitrogen excreted in the manure (see e.g. Spiess 2011). There was good agreement (average discrepancy of ±2%) for the years 1990–2005. However, for later years the top down estimates were on average 10% higher than the bottom-up estimates. Reasons for this observation are not yet clear and this finding will be subject to further analysis.

$N_{ex}$-values for the most important animal categories (mature dairy cattle and swine, being responsible for 65% of total nitrogen excretion) were compared to the values of the alternative gross energy approach suggested in equation 10.32 in the 2006 IPCC Guidelines. For swine, the IPCC approach estimated on average 18% lower $N_{ex}$ values for the years 1990–2004. This is probably due to an underestimation of the feed protein content in this model calculation and the inventory estimates are considered more realistic. Differences were smaller than 3% for years after 2005. All QA/QC checks of the $N_{ex}$ values are further elaborated in Agroscope (2019a).

Henne et al. (2019) conducted a top-down assessment of Swiss $N_2O$ emissions using atmospheric measurements and an inverse modelling framework. An update is presented in Annex A5.2. The best estimate of annual $N_2O$ emissions for the investigated period in 2017–2020 was 10.9±3.1 Gg $yr^{-1}$, which compares to 10.1 (4.1 to 18.3) Gg $yr^{-1}$ given for the same period in this NIR (2-σ confidence range). Due to the large uncertainties connected to both numbers, these estimates are not significantly different (see also Annex A5.2).

### 5.3.5. Category-specific recalculations

General information on recalculations is provided in chp. 10.

Recalculations with an overall impact of >0.5 kt $CO_2$ equivalent are assessed quantitatively. All other recalculations are only described qualitatively.

- Recalculation of livestock population data and gross energy intake (influencing VS-excretion rates) is reported under chp. 5.2.5.
- $CH_4$ and $N_2O$ emissions from manure management and agricultural soils were recalculated for 1990–2019 due to new projections of the AGRAMMON-model. The main effects are presumably due to lower nitrogen excretion rates for mature dairy cattle and swine in later inventory years. The main impact on overall emissions is a decrease of -14 kt $CO_2$ eq for the period 2006–2019.
- $CH_4$ emissions from manure management of cattle, camels, deer and buffalo were revised for the whole time series. As recommended during the peer review with the German inventory compiling group (Fuß et al. 2021), urea energy was not accounted for when estimating VS excretion (affecting EF). According to Dämmgen et al. (2011) there is no indication for methane formation from urine energy. The mean impact on overall emissions is -56 kt $CO_2$ eq (-52 to -60 kt $CO_2$ eq).
- $CH_4$ emissions from manure management in liquid systems and anaerobic digesters were recalculated for 1990–2019. The MCF-value for liquid systems (EF) was revised due to revised model projections based on slightly recalculated AGRAMMON data for manure management system distribution (MS). The impact on overall emissions is negligible for the period 1990–2007 (<1 kt $CO_2$ equivalent) and subsequently increases to a maximum of almost -5 kt $CO_2$ equivalent.
- The NMVOC emission factors of all cattle categories were completely revised for the entire time series. The new factors are based on extensive measurements of NMVOC emissions from dairy cattle with and without silage feeding in an experimental dairy housing during summer, winter and transitional season (Schrade et al. 2022). Note that these NMVOC emissions are not part of the GHG emissions as they are of biogenic origin.

### 5.3.6. Category-specific planned improvements

During the internal review an error was detected in the reported values for average live weights of growing cattles. Emission calculations are not affected by this error. The correct values will be reported during future submissions.

## 5.4. Source category 3C – Rice cultivation

Rice cultivation is of minor importance in Switzerland. The agricultural land used for rice cultivation and the annual harvest of rice are not estimated by the Swiss Farmers Union (SBV 2021). Only one farm in the south of Switzerland is cultivating upland rice since 1997.

$CH_4$ emissions are assumed to be zero. The area of upland rice is reported from 1997 onward in CRF Table3.C (EMIS 2022/4C “Reisanbau”).

## 5.5. Source category 3D – Agricultural soils

### 5.5.1. Source category description

Table 5-19 Key categories of 3D Agricultural soils. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 3Da | Direct Emissions from Managed Soils | N2O | L1, T1, L2 |
| 3Db | Indirect Emissions from Managed Soils | N2O | L1, L2 |

The source category 3D includes direct and indirect $N_2O$ emissions from managed soils (Table 5-20). Direct emissions are further subdivided in emissions from 1. Inorganic N fertilisers, 2. Organic N fertilisers, 3. Urine and dung deposited by grazing animals, 4. Crop residues, 5. Mineralisation/immobilisation associated with loss/gain of soil organic matter, 6. Cultivation of organic soils (i.e. histosols) and 7. Other (i.e. Domestic use of synthetic fertilisers). Indirect $N_2O$ emissions are further subdivided in 1. Atmospheric deposition and 2. Nitrogen leaching and run-off. All indirect $N_2O$ emissions after deposition of $NO_x$ and $NH_3$ or after leaching of $NO_3^-$ are reported under source category 3Db Indirect $N_2O$ Emissions from managed soils. This includes indirect $N_2O$ emissions after $NO_3^-$ leaching from N mineralisation in Cropland remaining cropland and Grassland remaining grassland. To avoid double counting the respective emissions are not reported under source category 4(IV) Indirect $N_2O$ emissions from managed soils and not included in CRF Table6 (see also chp. 9).

Table 5-20 Specification of source category 3D Agricultural soils.

| 3D | Source | Specification |
|---|---|---|
| 3Da | Direct $N_2O$ emissions from managed soils | 1. Inorganic N fertilisers<br>2. Organic N fertilisers (animal manure applied to soils, sewage sludge applied to soils, other organic fertilisers applied to soils)<br>3. Urine and dung deposited by grazing animals<br>4. Crop residues (incl. residues from meadows and pasture)<br>5. Mineralisation/immobilisation associated with loss/gain of soil organic matter<br>6. Cultivation of organic soils (i.e. histosols)<br>7. Other (domestic use of synthetic fertilisers) |
| 3Db | Indirect $N_2O$ emissions from managed soils | 1. Atmospheric deposition<br>2. Nitrogen leaching and run-off |

Furthermore, $NO_x$ emissions from managed soils as well as NMVOC emissions are estimated.

Direct and indirect $N_2O$ emissions from managed soils have decreased since 1990 in almost all major sub-categories. Only $N_2O$ emissions from 3Da3 (Urine and dung deposited by grazing animals) increased due to a higher share of manure excreted on pasture, range and paddock. $NO_x$ emissions have declined by 26% since 1990. The general trends can be explained by a reduction in the number of cattle and a reduced input of mineral fertilisers due to the introduction of the “Proof of Ecological Performance (PEP)” requiring a balanced fertiliser management (Agroscope 2019a, Leifeld and Fuhrer 2005). Major changes occurred mainly in the 1990s while most emissions were more or less stable after the year 2000. The latest years of the time series show a slight downward trend.

The most significant $N_2O$ emission sources are animal manure applied to soils (26%, mean 1990–2020), nitrogen input from atmospheric deposition (19%, mean 1990–2020), inorganic nitrogen fertilisers (15%, mean 1990–2020) and urine and dung deposited by grazing animals (12%, mean 1990–2020).

## 5.5.2. Methodological issues

### 5.5.2.1. Methodology

For the calculation of most $N_2O$ emissions from 3D Agricultural soils a Tier 1 method was applied that is based on the IULIA model from Schmid et al. (2000). IULIA is an IPCC-derived method for the calculation of $N_2O$ emissions from agriculture that basically uses the default emission factors (IPCC 2006), but adjusts the activity data to the particular situation of Switzerland. For the estimation of $N_2O$ emissions from animal manure applied to soils as well as for the estimation of indirect $N_2O$ emissions a more detailed Tier 3 approach was used. IULIA is continuously updated. New values for nitrogen excretion rates, manure management system distribution and ammonium emission factors from the Swiss ammonium model AGRAMMON were adopted (Kupper et al. 2022). Furthermore, the updated version of the "Principles of Fertilisation in Arable and Forage Crop Production" (GRUD; Richner et al. 2017) was used instead of obsolete data from Flisch et al. (2009), FAL/RAC (2001) and Walther et al. (1994). More recently, the N-flow model was extended to include all gaseous N-species (including $N_2$) and new $NO_x$ emission factors were implemented (Kupper 2017). Emission factors for $N_2O$ are all IPCC (2006) default with the exception of the emission factor for indirect $N_2O$ emissions from atmospheric deposition of N volatilised from managed soils ($EF_4$) which is country-specific.

The modelling of the $N_2O$ emissions is done by Agroscope, the Swiss centre of excellence for agricultural research (Agroscope 2022) and is consistent with source category 3B $N_2O$ emissions from manure management. The model structure is displayed in Figure 5-6 and the corresponding amounts of nitrogen are given in Table 5-21.

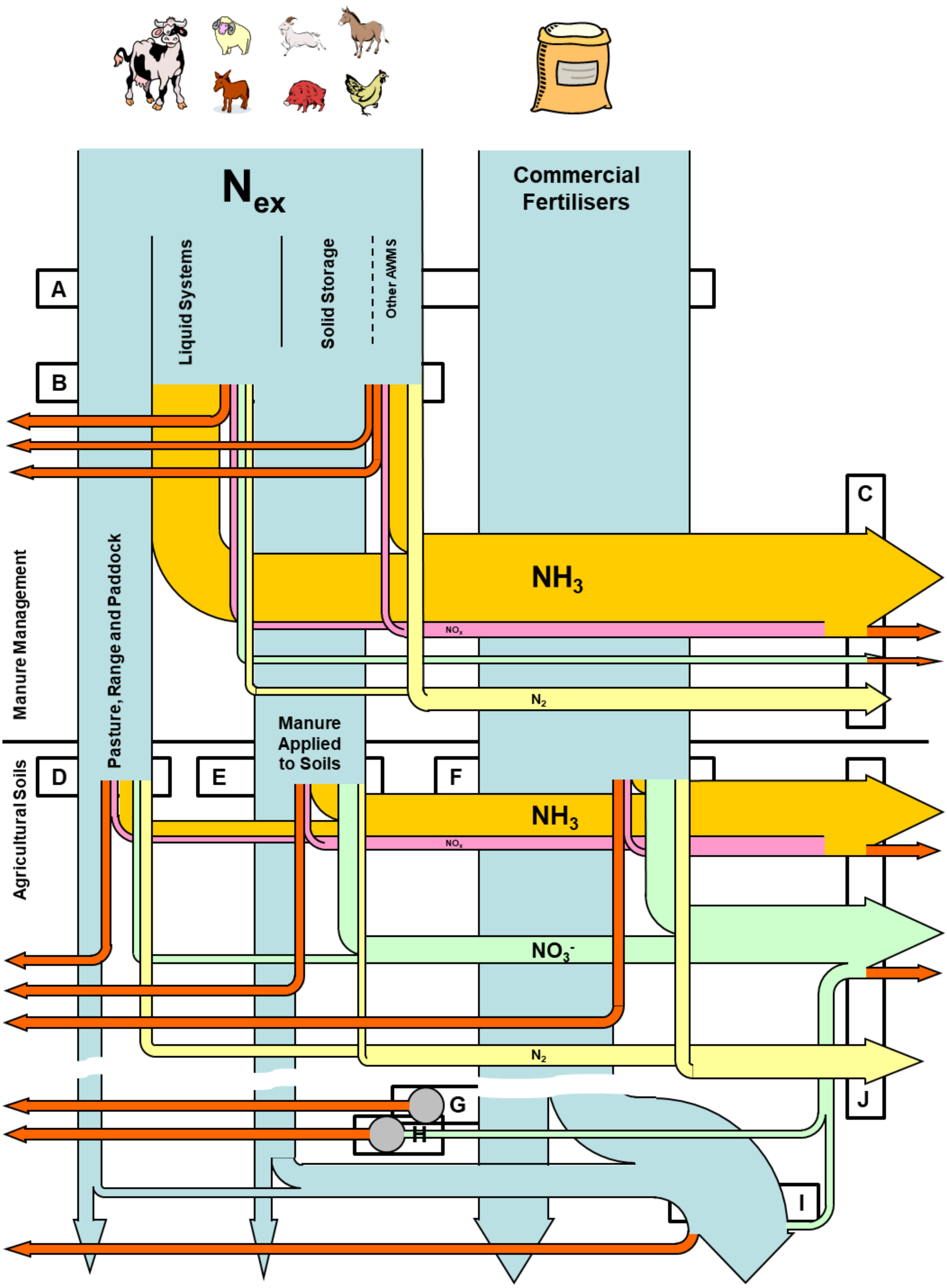


Figure 5-6 Diagram depicting the methodology of the approach to calculate the $N_2O$ emissions in agriculture (red arrows). Black frames and the respective letters refer to the nitrogen flows in Table 5-21. Note that the figure shows explicitly the methodology of the approach and not necessarily the physical nitrogen flows. Commercial fertilisers refer to the sum of urea, other mineral fertilisers, sewage sludge, other organic fertilisers and domestic use of fertilisers. Blue: nitrogen; orange: ammonia ($NH_3$); pink: nitrogen oxides ($NO_x$); green: nitrate ($NO_3^-$); yellow: dinitrogen ($N_2$).

Table 5-21 Nitrogen flows of the N-flow-model for Swiss agriculture. Letters refer to the letters in Figure 5-6. Processes refer to the nitrogen flows in the black frames in Figure 5-6 from left to right or from top to bottom.

| | Process | Amount of N 1990 | Amount of N 2020 | | CRF table |
|---|---|---|---|---|---|
| | | tN | tN | | |
| A | 1 Pasture, range and paddock | 13'546 | 23'464 | = B | 3.Da3 |
| | 2 Liquid/slurry systems | 97'276 | 70'724 | | 3.B(b) |
| | 3 Solid storage | 32'578 | 13'810 | | 3.B(b) |
| | 4 Other AWMS | 9'041 | 20'503 | | 3.B(b) |
| | 5 Commercial fertiliser | 75'085 | 49'207 | = F | 3.Da1,2bc,7 |
| B | 1 Pasture, range and paddock | 13'546 | 23'464 | = A1 + A2 + A3 + A4 | 3.Da3 |
| | 2 $NH_3$ volatilisation housing | 11'623 | 13'884 | | 3.B(b)5 |
| | 3 $N_2O$ emission liquid/slurry | 195 | 141 | | 3.B(b) |
| | 4 $NO_x$ volatilisation liquid/slurry and digester | 196 | 160 | | 3.B(b)5 |
| | 5 Leaching manure management | 0 | 0 | | 3.B(b)5 |
| | 6 $N_2$ volatilisation liquid/slurry and digester | 1'963 | 1'599 | | |
| | 7 Manure applied to soils | 115'221 | 81'436 | | 3.Da2a |
| | 8 $N_2O$ emission solid storage | 163 | 69 | | 3.B(b) |
| | 9 $N_2O$ emission other AWMS | 46 | 50 | | 3.B(b) |
| | 10 $NO_x$ volatilisation solid storage and deep litter | 209 | 120 | | 3.B(b)5 |
| | 11 $NH_3$ volatilisation storage | 8'154 | 6'842 | | 3.B(b)5 |
| | 12 $N_2$ volatilisation solid storage and deep litter | 1'125 | 736 | | |
| C | 1 $NH_3$ deposition manure management | 19'776 | 20'726 | = B2+B11 | 3.B(b)5 |
| | 2 $NO_x$ deposition manure management | 406 | 279 | = B4+B10 | |
| | 3 Leaching manure management | 0 | 0 | = B5 | |
| D | 1 Plant available N PR&P and N2 volatilisation | 9'791 | 17'528 | = B1 | |
| | 2 $N_2O$ emission PR&P | 259 | 440 | | 3.Da3 |
| | 3 $NO_x$ volatilisation PR&P | 75 | 129 | | |
| | 4 $NH_3$ volatilisation PR&P | 630 | 1'181 | | |
| | 5 Leaching and run-off PR&P | 2'791 | 4'186 | | |
| E | 1 Plant available N animal manure and $N_2$ vol. | 61'204 | 48'838 | = B7 | |
| | 2 $N_2O$ emission application animal manure | 1'152 | 814 | | 3.Da2a |
| | 3 $NO_x$ volatilisation application animal manure | 634 | 448 | | |
| | 4 $NH_3$ volatilisation application animal manure | 28'487 | 16'808 | | |
| | 5 Leaching and run-off application animal manure | 23'745 | 14'528 | | |
| F | 1 Plant available N com. fertiliser and $N_2$ vol. | 53'804 | 36'919 | = A5 | |
| | 2 $N_2O$ emission application com. fertiliser | 751 | 477 | | 3.Da1,2bc,7 |
| | 3 $NO_x$ volatilisation application com. fertiliser | 413 | 271 | | |
| | 4 $NH_3$ volatilisation application com. fertiliser | 4'644 | 2'918 | | |
| | 5 Leaching and run-off application com. fertiliser | 15'474 | 8'622 | | |
| G | 1 Cultivation of organic soils (ha) | *18'039* | *17'250* | | 3.Da6 |
| H | 1 Mineralisation/immobilisation soil organic matter | 2'777 | 12'358 | | 3.Da5 |
| I | 1 N in crop residues pasture, range and paddock | 27'117 | 25'921 | | 3.Da4 |
| | 2 N in crop residues arable crops | 11'953 | 11'972 | | |
| J | 1 $NH_3$ deposition fertiliser appl. and PR&P | 33'761 | 20'907 | = D4+E4+F4 | 3.Db1 |
| | 2 $NO_x$ deposition fertiliser appl. and PR&P | 1'121 | 848 | = D3+E3+F3 | |
| | 4 Leaching and run-off fertiliser appl. and PR&P | 42'010 | 27'335 | = D5+E5+F5 | 3.Db2 |
| | 5 Leaching and run-off mineralisation SOM | 572 | 2'205 | | |
| | 6 Leaching and run-off crop residues | 8'052 | 6'760 | | |

### 5.5.2.2. Direct $N_2O$ emissions from managed soils (3Da)

Calculation of Direct $N_2O$ emissions from managed soils is based on IPCC 2006 equation 11.1 including six terms for activity data and three different emission factors:

$$N_2O_{Direct} - N = \left(F_{SN} + F_{ON} + F_{CR} + F_{SOM}\right) \bullet EF_1 + F_{OS} \bullet EF_2 + F_{PRP} \bullet EF_3$$

$N_2O_{Direct}$-N = annual direct $N_2O$–N emissions produced from managed soils (kg $N_2O$–N/year)

$F_{SN}$ = annual amount of synthetic fertiliser N applied to soils (kg N/year)

$F_{ON}$ = annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils (kg N/year)

$F_{CR}$ = annual amount of N in crop residues, including N-fixing crops, returned to soils (kg N/year)

$F_{SOM}$ = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes of land use or management (kg N/year)

$F_{OS}$ = annual area of managed/drained organic soils (ha)

$F_{PRP}$ = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock (kg N/year)

$EF_1$ = emission factor for $N_2O$ emissions from N inputs (kg $N_2O$–N/kg N input)

$EF_2$ = emission factor for $N_2O$ emissions from drained/managed organic soils (kg $N_2O$–N/ha)

$EF_3$ = emission factor for $N_2O$ emissions from urine and dung N deposited on pasture, range and paddock by grazing animals (kg $N_2O$–N/kg N input)

#### *5.5.2.2.1. Emission factors*

Emission factors for calculating 3Da Direct $N_2O$ emissions from managed soils are based on default values as provided in the 2006 IPCC Guidelines (Table 5-22). Since the year 2007 mineral fertilisers with nitrification inhibitors are used in Switzerland. The use of nitrification inhibitors reduces direct $N_2O$ emissions from these fertilisers by 65% (Pfab et al. 2012). The applied amounts are still small and the weighted emission factor ($EF_1$) reported is thus only slightly below 1.0%. The amount of fertilisers with nitrification inhibitors is classified as confidential (C). An additional table is available to reviewers on request, including all confidential data and information (Table 5-23). Due to the lack of data no other source specific emission factors were applied for $EF_1$. The emission factor for urine and dung deposited by grazing animals was calculated as the weighted mean between the emission factor for cattle, poultry and pigs ($EF_{3PRP,CPP}$ = 0.02 kg $N_2O$–N/kg N) and the emission factor for sheep and “other animals” ($EF_{3PRP,SO}$ = 0.01 kg $N_2O$–N/kg N) according to the shares of nitrogen excreted by the respective animals.

Table 5-22 Emission factors for calculating direct $N_2O$ emissions from managed soils (IPCC 2006). Blue: annually changing parameters, value for 2020.

| Emission source | Emission factor |
|---|---|
| $EF_1$ Inorganic N fertilisers (kg $N_2O$-N/kg) | 0.0097 |
| $EF_1$ Organic N fertilisers (kg $N_2O$-N/kg) | 0.01 |
| $EF_1$ Crop residue (kg $N_2O$-N/kg) | 0.01 |
| $EF_1$ Mineralisation/immobilisation soil organic matter (kg $N_2O$-N/kg) | 0.01 |
| $EF_1$ Other (domestic synthetic fertilisers) (kg $N_2O$-N/kg) | 0.01 |
| $EF_2$ Cultivation of organic soils (kg $N_2O$-N/ha) | 8 |
| $EF_3$ Urine and dung deposited by grazing animals (kg $N_2O$-N/kg) | 0.0187 |

Table 5-23 In the confidential NIR, the amount of mineral fertilisers with and without nitrification inhibitors and corresponding emission factors are separately reported and available to reviewers.

#### *5.5.2.2.2. Activity data*

Activity data for calculation of 3Da Direct soil emissions include 1. Inorganic N fertilisers, 2. Organic N fertilisers, 3. Urine and dung deposited by grazing animals, 4. Crop residues, 5. Nitrogen from mineralisation/immobilisation associated with loss/gain of soil organic matter 6. Area of organic soils (i.e. histosols) and 7. Other (i.e. Domestic use of inorganic fertilisers).

Emissions from **inorganic nitrogen fertilisers** include urea and other mineral fertilisers (mainly ammonium-nitrate). The amount of nitrogen input due to these fertilisers is obtained from Agricura (2020). Fertiliser statistics are based on sales statistics of the compulsory stockpiling of fertilisers (“Pflichtlagerhalter”) and small importers. Agricura conducts plausibility checks with import-data received by the Directorate General of Customs (“Oberzolldirektion”). The estimates contain fertilisers used in Liechtenstein which are subtracted for the Swiss GHG inventory. Furthermore, it is estimated that 4% of the mineral fertilisers are used for non-agricultural purposes (i.e. domestic use of inorganic fertilisers; Kupper et al. 2022). These fertilisers are used in public green areas, sports grounds and home gardens. In the reporting tables (CRF) they are reported under 3Da7 **Other (Domestic inorganic fertilisers)** while emission calculation is conducted together with 3Da1. In some occasions, as for instance for the estimation of indirect $N_2O$ emissions from managed soils, the sum of urea, other mineral fertilisers, sewage sludge, other organic fertilisers and domestic use of fertilisers is referred to as “commercial fertilisers” (see also Figure 5-6 and Table 5-21).

**Organic nitrogen fertilisers** include animal manure, sewage sludge and other organic fertilisers. The amount of nitrogen in **animal manure applied to soils** is calculated according to the methods described in chp. 5.3.2.5. As suggested in chp. 10.5.4. and equation 10.34 of the 2006 IPCC Guidelines, all nitrogen excreted on pasture, range and paddock as well as all nitrogen volatilised prior to final application to managed soils is subtracted from the total excreted manure (for the estimation of the respective N–volatilisation during manure management see chp. 5.3.2.5, compare also Figure 5-6). $Frac_{GASM}$ in CRF Table3.D represents the amount of nitrogen volatilised as $NH_3$, $NO_x$, $N_2O$ and $N_2$ from housing and manure storage divided by the manure excreted in the stable (liquid/slurry, solid storage, digesters, deep litter and poultry manure). The nitrogen input from manure applied to soils under 3Da2a in CRF Table3.D can thus be calculated with the numbers given in CRF Table3.B(b) and 3.D. Nitrogen from bedding material was not accounted for under animal manure applied to soils. The respective nitrogen is included in the nitrogen returned to soils as crop residues.

The amount of **sewage sludge** applied to agricultural soils was estimated according to Kupper et al. (2022). Since 2003 it is forbidden in Switzerland to use sewage sludge as a fertiliser. As of 2006, this prohibition has been made effective for all agricultural areas with a transition period to 2008 (UVEK 2003). **Other organic fertilisers** include compost as well as liquid and solid digestates from biogas plants and are also estimated according to Kupper et al. (2022). Additionally nitrogen input through co-substrates in agricultural biogas plants is accounted for under this sub-category.

Calculation of emissions from **urine and dung deposited by grazing animals** is based on equation 11.5 of the 2006 IPCC Guidelines. Estimation of total livestock nitrogen excretion was described under chp. 5.3.2.5. The share of manure nitrogen excreted on pasture, range and paddock was estimated according to the AGRAMMON-model (Kupper et al. 2022; Table 5-14). For each livestock category the share of animals that have access to grazing, the number of days per year they are actually grazing as well as the number of hours per day grazing takes place was assessed. Estimates are based on values from the literature and expert judgement (1990, 1995) and on surveys on approximatively 3000 Swiss farms (2000, 2007, 2010, 2015, 2019).

$N_2O$ emissions from **crop residues** are based on the amount of nitrogen in crop residues returned to soil. For **arable crops**, data on total annual crop harvests were adopted from the statistical yearbooks of the Swiss Farmers Union (SBV 2021, note that this data refers to total harvest and not to yields per ha). Harvest data is based on surveys at the primary recipients (e.g. mills, sugar processing industry), yield assessment at approximately 1000 producers, as well as on data from central accounting evaluations of roughly 3000 farms (Agroscope, 2019a). To estimate the amount of nitrogen in crop residues, the harvested amount in tonnes is multiplied with the term $NR_T/SY_T$ which corresponds to the amount of nitrogen in crop residues per amount of fresh matter crop yield. Standard values for $NR_T$ and $SY_T$ are published in Richner et al. (2017) and FAL/RAC (2001) and are based on long-term field trials by Agroscope.

$$F_{CR,AC} = \sum_T \left( Y_T \bullet \frac{NR_T}{SY_T} \right)$$

$F_{CR,AC}$ = amount of nitrogen in crop residues from arable crops returned to soils (t N)

$Y_T$ = amount of fresh matter crop harvest for crop *T* (t)

$NR_T$ = standard amount of nitrogen in crop residues for crop *T* (dt/ha)

$SY_T$ = standard amount of fresh matter crop yield for crop *T* (dt/ha)

For sugar beet and fodder beet it is assumed that 10% of the crop residues are removed from the fields for animal fodder. The use of crop residues for fuel or the (open) burning of crop residues are not common practice in Switzerland and are subject to strong regulations. These activities are therefore not considered to reduce the amount of N returned to soils.

Crop residues from **meadows and pastures** were also assessed. Two thirds of the agricultural land consists of grassland which underscores the importance of this source for Switzerland. According to the 2006 IPCC Guidelines (chp. 11.2.1.3) crop residues on pastures should be included in the estimation of $N_2O$ emission from agricultural soils only for years when renewal of pastures happened. However, the area of meadows and pastures applied here refers to permanent grassland (in contrast to leys and intensive meadows). Renewal of these grasslands is not common practice in Switzerland. Crop residues from meadows and pasture therefore refer here only to field losses during harvest, from feed not eaten by the animals and feed losses due to trampling effects.

With the elaboration of the “Model-based carbon inventory for national greenhouse gas reporting of mineral agricultural soils” (Wüst-Galley et al. 2019) the estimation of nitrogen inputs from crop residues from meadows and pastures was revised in order to assure consistent reporting of C- and N-fluxes in agricultural soils. For the assessment of total crop dry matter produced a mixed approached based on reported annual harvest data (overall harvest in tonnes, e.g. SBV 2021), standard yields (dt/ha, Richner et al. 2017; attribution to the different grassland types) and surface data of detailed grassland types (in ha, background data of the Swiss Federal Statistical Office, unpublished) was applied. The former is affected primarily by meteorological conditions. The latter two data sets allowed fluctuations in the management intensity of the grassland surface to be accounted for. For each year the different yields of the grassland types are weighted according to the respective areas (compare also chp. 6.6.2.1.1). Nitrogen contents of dry matter were adopted from Richner et al. (2017) and yield losses in percent were adopted from Agridea (2016).

Estimated values of total crop production, nitrogen incorporated with crop residues $F_{(CR)}$, residue/crop ratio, dry matter fraction of residues and nitrogen content of residues are provided in Annex A3.3.

Assessment of nitrogen **mineralisation/immobilisation associated with loss/gain of soil organic matter** was conducted based on data from the LULUCF sector. For reasons of consistency, losses and gains of soil organic matter on cropland and grasslands were accounted for. The same methodology as described under chp. 6.10.2 was applied. Nitrogen mineralisation was estimated by dividing the carbon loss on Cropland remaining cropland and Grassland remaining grassland with a C/N-ratio of 9.8 according to Leifeld et al. (2007). It should be noted that the carbon losses were assessed based on land-use changes on a sub-category level. Only land-use changes that led to a net carbon stock loss were considered, excluding land-use changes that led to a net carbon stock increase. Consequently, the carbon losses used for calculating $N_2O$ emissions from nitrogen mineralisation are not identical with the net carbon stock changes reported in the reporting tables (CRF Table4.B and Table4.C). $N_2O$ emissions from nitrogen mineralisation of land converted to cropland or land converted to grassland are reported under source category 4(III) “Direct nitrous oxide ($N_2O$) emissions from nitrogen (N) mineralisation/immobilisation associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils”.

Estimates of $N_2O$ emissions from **cultivated organic soils** are based on the area of cultivated organic soils and the IPCC default emission factor for $N_2O$ emissions from cultivated organic soils (IPCC 2006). The area of cultivated organic soils corresponds to the total area of organic soils under cropland and grassland as reported in CRF Table4.B and 4.C (see also chp. 6.2.2.1).

The relevant activity data for calculating $N_2O$ emissions from soils are displayed in Table 5-24. Additional information is given in Annex A3.3.

Table 5-24 Activity data for calculating 3Da Direct $N_2O$ emissions from managed soils.

| **Activity Data** | | **1990-2011** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **1990** | **1995** | **2000** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** |
| | | t N/yr | | | | | | | | | |
| 1. Inorganic N fertilisers | Urea | 16'284 | 10'707 | 7'631 | 6'605 | 5'977 | 8'305 | 6'607 | 5'312 | 7'101 | 6'517 |
| | Other mineral fertilisers | 50'391 | 47'652 | 43'042 | 43'478 | 43'227 | 43'282 | 41'979 | 40'446 | 45'986 | 40'213 |
| 2. Organic N fertilisers | a. Animal manure | 115'221 | 106'496 | 87'264 | 82'437 | 83'196 | 83'882 | 85'866 | 85'284 | 85'963 | 85'488 |
| | b. Sewage sludge | 4'815 | 4'942 | 3'356 | 1'054 | 859 | 573 | 286 | 0 | 0 | 0 |
| | c. Other organic fertilisers | 817 | 1'286 | 1'829 | 2'169 | 2'359 | 2'566 | 2'694 | 2'939 | 3'281 | 3'676 |
| 3. Urine and dung deposited by grazing animals | | 13'546 | 14'279 | 21'269 | 23'955 | 24'178 | 24'263 | 24'726 | 24'429 | 24'234 | 24'032 |
| 4. Crop residues | Arable crops | 11'953 | 11'350 | 12'345 | 11'750 | 10'876 | 11'786 | 11'690 | 12'103 | 10'740 | 12'460 |
| | Residues M&P | 27'117 | 26'263 | 27'166 | 26'912 | 26'673 | 26'462 | 26'238 | 26'248 | 26'365 | 25'659 |
| 5. Min./imm. associated with loss/gain of SOM | | 2'777 | 9'539 | 10'852 | 3'633 | 3'903 | 4'988 | 4'628 | 5'551 | 6'407 | 7'693 |
| 6. Cultivation of organic soils (ha) | | 18'039 | 17'912 | 17'751 | 17'584 | 17'555 | 17'528 | 17'502 | 17'479 | 17'457 | 17'435 |
| 7. Other (domestic inorganic fertilisers) | | 2'778 | 2'432 | 2'111 | 2'087 | 2'050 | 2'149 | 2'024 | 1'907 | 2'212 | 1'947 |

| **Activity Data** | | **2012-2020** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
| | | t N/yr | | | | | | | | |
| 1. Inorganic N fertilisers | Urea | 5'378 | 5'793 | 7'942 | 7'223 | 8'872 | 9'250 | 8'326 | 7'753 | 7'395 |
| | Other mineral fertilisers | 39'771 | 37'924 | 41'393 | 36'521 | 37'531 | 40'113 | 37'446 | 32'403 | 33'680 |
| 2. Organic N fertilisers | a. Animal manure | 85'359 | 84'754 | 85'071 | 84'570 | 84'077 | 83'390 | 82'822 | 81'713 | 81'436 |
| | b. Sewage sludge | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | c. Other organic fertilisers | 4'345 | 4'670 | 4'709 | 4'908 | 5'435 | 5'542 | 5'668 | 6'211 | 6'421 |
| 3. Urine and dung deposited by grazing animals | | 24'094 | 23'922 | 23'867 | 23'672 | 23'718 | 23'767 | 23'736 | 23'615 | 23'464 |
| 4. Crop residues | Arable crops | 11'429 | 10'330 | 12'504 | 10'925 | 10'144 | 11'850 | 11'171 | 11'463 | 11'972 |
| | Residues M&P | 26'114 | 25'754 | 27'102 | 26'232 | 26'606 | 26'122 | 25'222 | 26'475 | 25'921 |
| 5. Min./imm. associated with loss/gain of SOM | | 9'652 | 11'425 | 16'600 | 15'370 | 11'273 | 11'374 | 11'654 | 12'390 | 12'358 |
| 6. Cultivation of organic soils (ha) | | 17'413 | 17'391 | 17'369 | 17'347 | 17'326 | 17'307 | 17'288 | 17'269 | 17'250 |
| 7. Other (domestic inorganic fertilisers) | | 1'881 | 1'822 | 2'056 | 1'823 | 1'933 | 2'057 | 1'907 | 1'673 | 1'711 |

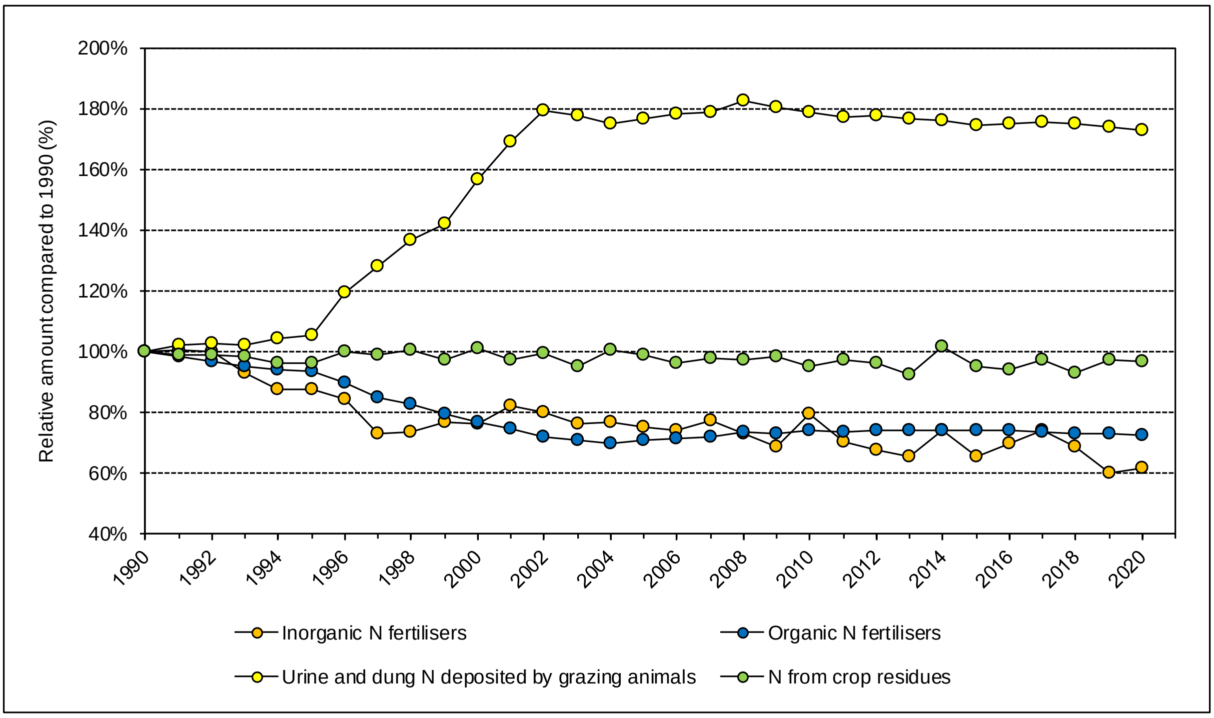


Figure 5-7 Relative development of the most important activity data for 3Da Direct $N_2O$ emissions from managed soils.

Figure 5-7 represents the development of the most important activity data for 3Da Direct $N_2O$ emissions from managed soils. The use of inorganic N-fertiliser declined mainly during the 1990s due to the agricultural policy reforms and the introduction of the “Proof of Ecological Performance (PEP)” that requires a balanced fertiliser management. Simultaneously, nitrogen input from animal manure declined due to declining livestock populations (mainly cattle). Urine and dung deposited by grazing animals increased substantially due to the shift to more animal-friendly livestock husbandry in the course of the agricultural policy reforms during the 1990s and the early 21$^{st}$ century (see also chp. 5.3.2.2.4). N inputs from crop residues remained more or less constant during the inventory time period due to more or less stable crop production.

### 5.5.2.3. Indirect $N_2O$ emissions from atmospheric deposition of N volatilised from managed soils (3Db1)

$N_2O$ emissions from atmospheric deposition of N volatilised from managed soils were estimated based on equations 11.9 and 11.11 of the 2006 IPCC Guidelines. However, the method was adapted to the far more detailed approach of Switzerland:

$$N_2O_{(ATD)} - N = \left\{\left[\sum_i \left(F_{CN_i} * Frac_{GASF_i}\right) + \sum_T \left(F_{AM_T} * Frac_{GASM_T}\right) + \sum_T \left(F_{PRP_T} * Frac_{GASP_T}\right)\right] + \left[\left(F_{CN} + F_{AM}\right) * Frac_{NOXA} + F_{PRP} * Frac_{NOXP}\right]\right\} * EF_4$$

$N_2O_{(ATD)}$-N = annual amount of $N_2O$–N produced from atmospheric deposition of N volatilised from managed soils (kg $N_2O$–N/year)

$F_{CNi}$ = annual amount of commercial fertiliser N of type *i* applied to soils (kg N/year)

$Frac_{GASFi}$ = fraction of commercial fertiliser N of type *i* that volatilises as $NH_3$ (kg N/kg N)

$F_{AMT}$ = annual amount of managed animal manure N of livestock category *T* applied to soils (kg N/year)

$Frac_{GASMT}$ = fraction of applied animal manure N of livestock category *T* that volatilises as $NH_3$ (kg N/kg N)

$F_{PRPT}$ = annual amount of urine and dung N deposited on pasture, range and paddock by grazing animals of livestock category *T* (kg N/year)

$Frac_{GASPT}$ = fraction of urine and dung N deposited on pasture, range and paddock by grazing animals of livestock category *T* that volatilises as $NH_3$ (kg N/kg of N)

$F_{CN}$ = total amount of commercial fertiliser N applied to soils (kg N/year)

$F_{AM}$ = total amount of managed animal manure N applied to soils (kg N/year)

$Frac_{NOXA}$ = fraction of applied N (commercial fertilisers and animal manure) that volatilises as $NO_x$ (kg N/kg N)

$F_{PRP}$ = total amount of urine and dung N deposited on pasture, range and paddock by grazing animals (kg N/year)

$Frac_{NOXP}$ = fraction of urine and dung N deposited on pasture, range and paddock that volatilises as $NO_x$ (kg N/kg of N)

$EF_4$ = emission factor for $N_2O$ emissions from atmospheric deposition of N on soils and water surfaces (kg $N_2O$-N/ kg N volatilised).

#### *5.5.2.3.1. Emission factor*

The emission factor for indirect $N_2O$ emissions from atmospheric deposition of N volatilised from managed soils is the same as used for the assessment of indirect $N_2O$ emissions after volatilisation of $NH_3$ and $NO_x$ from manure management systems. The emission factor was reassessed by a literature review by Bühlmann et al. (2015) and Bühlmann (2014). Due to slightly changing land use, the resulting emission factor shows some small variations around a mean value of 2.56%. For further information see chp. 5.3.2.4.

#### *5.5.2.3.2. Activity data*

The estimation of volatilisation of ammonia and $NO_x$ was harmonised with the Swiss ammonia model AGRAMMON using the same emission factors and basic parameters (Table 5-25). Losses of commercial fertiliser nitrogen, animal manure N applied to soils, as well as urine and dung N deposited on pasture, range and paddock by grazing animals were considered. For the calculation of $NH_3$ emissions, changes of agricultural structures (changes to more animal friendly housing systems) and techniques (manure management, measures to reduce $NH_3$ emissions) are considered and explain temporal dynamics.

Ammonia volatilisation from **commercial fertiliser N** was estimated separately for synthetic fertilisers (based on EMEP/EEA 2016), sewage sludge, and other organic fertilisers (compost, liquid and solid digestates from biogas plants). Ammonia volatilisation of nitrogen in synthetic fertilisers was assessed separately for individual fertiliser types based on the EMEP/EEA guidebook (EMEP/EEA 2016). The weighted mean value for synthetic fertilisers excluding urea is 2.8% (mean 1990–2019). Furthermore 13.1% of urea-nitrogen is lost as ammonia. Ammonia emission factors for sewage sludge range from 20% to 26% depending on the composition of the sludge (Kupper et al. 2022). Other organic fertilisers include compost as well as liquid and solid digestates. Ammonia emission factors are 3.4% for compost, 21%–30% for liquid digestate and 4.0% for solid digestate. The ammonia loss rate for liquid digestates decreased from 2001 until 2010 due to the increasing use of trailing hoses during field application.

Total $Frac_{GASF}$ (including $NO_x$ emissions) as reported in CRF Table3.D declined considerably from 6.7% in 1990 to 5.0% in 2006 and then increased again to 6.5% in 2020 due to a change in the shares of the different commercial fertilisers.

Different ammonia loss factors were used for **animal manure N applied to soils** from different livestock categories according to the detailed approach of the AGRAMMON model (Kupper et al. 2022). Overall weighted $Frac_{GASMT}$ for animal manure applied to soils slightly declined from 25.3% in the early 1990s to 21.2% in 2020 (Table 5-25).

Ammonia volatilisation from **urine and dung N deposited on pasture, range and paddock by grazing animals** was also assessed individually for each livestock category. Weighted mean loss rates ($Frac_{GASPT}$) range from 5.2% to 5.6%.

**$NO_x$ emissions** were estimated separately for applied fertiliser N (commercial fertilisers, animal manure) and for urine and dung N deposited on pasture, range and paddock by grazing animals. $NO_x$ emission factors ($Frac_{NOXA}$ and $Frac_{NOXP}$) for applied fertilisers and for urine and dung N deposited on pasture, range and paddock are 0.55% each, based on Stehfest and Bouwman (2006).

Nitrogen pools and flows for calculating 3Db Indirect $N_2O$ emissions from managed soils are displayed in Table 5-26. Additional information is given in Annex A3.3.

Table 5-25 Overview of $NH_3$ and $NO_x$ emission factors used for the assessment of 3Db Indirect $N_2O$ emissions from atmospheric deposition. Complete time series on a livestock sub-category level are provided in Annex A3.3.

| **Emission factors volatilisation** | **1990-2011** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **1990** | **1995** | **2000** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** |
| | % | | | | | | | | | |
| $NH_3$ from commercial fertiliser N ($Frac_{GASFi}$) | 6.19 | 6.05 | 5.42 | 4.66 | 4.44 | 4.81 | 4.67 | 4.55 | 4.69 | 4.77 |
| Urea | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 |
| Other Mineral Fertilisers | 2.72 | 2.72 | 2.51 | 2.76 | 2.65 | 2.74 | 2.94 | 3.11 | 3.07 | 2.98 |
| Recycling Fertilisers (weighted average) | 17.60 | 19.97 | 18.80 | 13.40 | 12.78 | 11.78 | 10.48 | 9.03 | 9.37 | 9.80 |
| Sewage Sludge | 20.00 | 23.94 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 |
| Compost | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 |
| Digestate Liquid | 30.00 | 30.00 | 30.00 | 26.06 | 25.05 | 24.04 | 23.03 | 22.01 | 21.00 | 21.00 |
| Digestate Solid | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 |
| $NH_3$ from application of animal manure N ($Frac_{GASMT}$) | 24.72 | 24.54 | 23.47 | 23.32 | 23.50 | 23.60 | 23.10 | 22.51 | 21.95 | 21.72 |
| Mature Dairy Cattle | 26.85 | 26.78 | 26.04 | 26.21 | 26.37 | 26.53 | 25.99 | 25.46 | 24.94 | 24.61 |
| Other Mature Cattle | 22.86 | 22.06 | 22.38 | 22.72 | 22.78 | 22.83 | 22.71 | 22.59 | 22.47 | 22.30 |
| Growing Cattle (weighted average) | 23.68 | 23.51 | 23.14 | 23.48 | 23.68 | 23.86 | 23.48 | 23.09 | 22.71 | 22.41 |
| Sheep (weighted average) | 4.89 | 4.89 | 4.75 | 5.33 | 5.54 | 5.75 | 5.64 | 5.54 | 5.45 | 5.36 |
| Swine (weighted average) | 24.20 | 23.95 | 21.93 | 21.28 | 21.49 | 21.74 | 20.81 | 19.94 | 19.09 | 18.92 |
| Other Livestock (weighted average) | 10.12 | 10.09 | 9.09 | 9.54 | 9.51 | 9.87 | 9.91 | 9.92 | 9.98 | 10.03 |
| $NH_3$ from urine and dung N deposited on PR&P ($Frac_{GASPT}$) | 4.65 | 4.69 | 4.80 | 4.89 | 4.90 | 4.93 | 4.91 | 4.90 | 4.89 | 4.89 |
| Mature Dairy Cattle | 4.67 | 4.65 | 4.63 | 4.61 | 4.61 | 4.60 | 4.60 | 4.60 | 4.60 | 4.60 |
| Other Mature Cattle | 4.56 | 4.57 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 |
| Growing Cattle (weighted average) | 4.56 | 4.56 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 |
| Sheep (weighted average) | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Swine (weighted average) | NA | NA | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 |
| Other Livestock (weighted average) | 5.00 | 6.47 | 7.58 | 8.48 | 8.54 | 8.83 | 8.65 | 8.55 | 8.51 | 8.51 |
| $NO_x$ from applied fertilisers ($Frac_{NOXA}$) | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |
| $NO_x$ from urine and dung N deposited on PR&P ($Frac_{NOXP}$) | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |

| **Emission factors volatilisation** | **2012-2020** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
| | % | | | | | | | | |
| $NH_3$ from commercial fertiliser N ($Frac_{GASFi}$) | 4.81 | 5.02 | 5.20 | 5.57 | 5.47 | 5.56 | 5.65 | 5.95 | 5.93 |
| Urea | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 |
| Other Mineral Fertilisers | 3.10 | 3.11 | 3.03 | 3.29 | 2.80 | 2.99 | 3.05 | 3.12 | 3.20 |
| Recycling Fertilisers (weighted average) | 10.41 | 10.73 | 11.24 | 11.74 | 11.64 | 11.83 | 12.07 | 12.04 | 12.21 |
| Sewage Sludge | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 |
| Compost | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 |
| Digestate Liquid | 21.00 | 21.00 | 21.00 | 21.00 | 21.00 | 21.00 | 21.00 | 21.00 | 21.00 |
| Digestate Solid | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 |
| $NH_3$ from application of animal manure N ($Frac_{GASMT}$) | 21.46 | 21.21 | 20.96 | 20.70 | 20.69 | 20.69 | 20.71 | 20.69 | 20.64 |
| Mature Dairy Cattle | 24.28 | 23.96 | 23.63 | 23.31 | 23.32 | 23.33 | 23.34 | 23.36 | 23.36 |
| Other Mature Cattle | 22.12 | 21.94 | 21.77 | 21.59 | 21.53 | 21.46 | 21.40 | 21.34 | 21.33 |
| Growing Cattle (weighted average) | 22.13 | 21.82 | 21.52 | 21.22 | 21.28 | 21.37 | 21.42 | 21.48 | 21.46 |
| Sheep (weighted average) | 5.26 | 5.16 | 5.05 | 4.93 | 4.98 | 5.03 | 5.07 | 5.11 | 5.12 |
| Swine (weighted average) | 18.76 | 18.57 | 18.40 | 18.22 | 18.24 | 18.27 | 18.30 | 18.32 | 18.34 |
| Other Livestock (weighted average) | 9.98 | 10.02 | 10.08 | 10.04 | 10.16 | 10.16 | 10.41 | 10.43 | 10.57 |
| $NH_3$ from urine and dung N deposited on PR&P ($Frac_{GASPT}$) | 4.90 | 4.90 | 4.90 | 4.91 | 4.94 | 4.96 | 4.98 | 5.00 | 5.03 |
| Mature Dairy Cattle | 4.60 | 4.59 | 4.59 | 4.59 | 4.59 | 4.59 | 4.59 | 4.59 | 4.59 |
| Other Mature Cattle | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 |
| Growing Cattle (weighted average) | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 |
| Sheep (weighted average) | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Swine (weighted average) | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 |
| Other Livestock (weighted average) | 8.44 | 8.54 | 8.67 | 8.76 | 9.09 | 9.24 | 9.67 | 9.83 | 10.27 |
| $NO_x$ from applied fertilisers ($Frac_{NOXA}$) | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |
| $NO_x$ from urine and dung N deposited on PR&P ($Frac_{NOXP}$) | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |

Table 5-26 Overview of N pools and flows for calculating 3Db Indirect $N_2O$ emission from managed soils. Complete time series are provided in Annex A3.3.

| Nitrogen pools and flows | | 1990-2011 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1990 | 1995 | 2000 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
| | | t N/yr | | | | | | | | | |
| | Animals manure N applied to soils | 115'221 | 106'496 | 87'264 | 82'437 | 83'196 | 83'882 | 85'866 | 85'284 | 85'963 | 85'488 |
| | Commercial fertiliser | 75'085 | 67'018 | 57'969 | 55'393 | 54'472 | 56'875 | 53'590 | 50'603 | 58'580 | 52'353 |
| Deposition | Sum volatised N ($NH_3$ and $NO_x$) | 34'883 | 31'897 | 25'558 | 23'870 | 24'046 | 24'634 | 24'455 | 23'579 | 23'729 | 23'134 |
| | $NH_3$ emissions from commercial fertilisers | 4'644 | 4'058 | 3'142 | 2'582 | 2'420 | 2'737 | 2'500 | 2'302 | 2'747 | 2'499 |
| | $NH_3$ emissions from applied animal manure | 28'487 | 26'136 | 20'479 | 19'226 | 19'550 | 19'792 | 19'838 | 19'198 | 18'868 | 18'570 |
| | $NH_3$ emissions from pasture, range and paddock | 630 | 670 | 1'021 | 1'172 | 1'186 | 1'197 | 1'214 | 1'197 | 1'185 | 1'175 |
| | $NO_x$ emissions from commercial fertilisers | 413 | 369 | 319 | 305 | 300 | 313 | 295 | 278 | 322 | 288 |
| | $NO_x$ emissions from applied animal manure | 634 | 586 | 480 | 453 | 458 | 461 | 472 | 469 | 473 | 470 |
| | $NO_x$ emissions from PR&P | 75 | 79 | 117 | 132 | 133 | 133 | 136 | 134 | 133 | 132 |
| Leaching and run-off | Sum leaching and run-off | 50'634 | 48'418 | 42'691 | 38'290 | 37'768 | 38'276 | 37'606 | 36'792 | 37'850 | 37'023 |
| | Leaching and run-off from commercial fertilisers | 15'474 | 13'811 | 11'411 | 10'393 | 10'120 | 10'432 | 9'721 | 9'105 | 10'429 | 9'313 |
| | Leaching and run-off from applied animal manure | 23'745 | 21'947 | 17'178 | 15'467 | 15'456 | 15'428 | 15'635 | 15'371 | 15'335 | 15'250 |
| | Leaching and run-off from pasture, range and paddock | 2'791 | 2'943 | 4'187 | 4'495 | 4'492 | 4'463 | 4'502 | 4'403 | 4'323 | 4'287 |
| | Leaching and run-off from crop residues | 8'052 | 7'751 | 7'778 | 7'254 | 6'976 | 7'035 | 6'906 | 6'912 | 6'619 | 6'800 |
| | Leaching and run-off from mineralisation of SOM | 572 | 1'966 | 2'136 | 682 | 725 | 917 | 843 | 1'000 | 1'143 | 1'372 |

| Nitrogen pools and flows | | 2012-2020 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
| | | t N/yr | | | | | | | | |
| | Animals manure N applied to soils | 85'359 | 84'754 | 85'071 | 84'570 | 84'077 | 83'390 | 82'822 | 81'713 | 81'436 |
| | Commercial fertiliser | 51'374 | 50'208 | 56'100 | 50'475 | 53'771 | 56'962 | 53'348 | 48'040 | 49'207 |
| Deposition | Sum volatised N ($NH_3$ and $NO_x$) | 22'853 | 22'540 | 22'828 | 22'358 | 22'394 | 22'499 | 22'223 | 21'788 | 21'755 |
| | $NH_3$ emissions from commercial fertilisers | 2'471 | 2'521 | 2'919 | 2'812 | 2'940 | 3'167 | 3'012 | 2'859 | 2'918 |
| | $NH_3$ emissions from applied animal manure | 18'318 | 17'973 | 17'831 | 17'509 | 17'394 | 17'252 | 17'150 | 16'905 | 16'808 |
| | $NH_3$ emissions from pasture, range and paddock | 1'179 | 1'172 | 1'170 | 1'163 | 1'172 | 1'178 | 1'182 | 1'180 | 1'181 |
| | $NO_x$ emissions from commercial fertilisers | 283 | 276 | 309 | 278 | 296 | 313 | 293 | 264 | 271 |
| | $NO_x$ emissions from applied animal manure | 469 | 466 | 468 | 465 | 462 | 459 | 456 | 449 | 448 |
| | $NO_x$ emissions from PR&P | 133 | 132 | 131 | 130 | 130 | 131 | 131 | 130 | 129 |
| Leaching and run-off | Sum leaching and run-off | 37'082 | 36'791 | 39'443 | 37'657 | 37'355 | 37'996 | 36'985 | 36'179 | 36'300 |
| | Leaching and run-off from commercial fertilisers | 9'137 | 8'929 | 9'983 | 8'977 | 9'558 | 10'077 | 9'404 | 8'411 | 8'622 |
| | Leaching and run-off from applied animal manure | 15'227 | 15'119 | 15'176 | 15'087 | 14'999 | 14'876 | 14'775 | 14'577 | 14'528 |
| | Leaching and run-off from pasture, range and paddock | 4'298 | 4'268 | 4'258 | 4'223 | 4'231 | 4'240 | 4'234 | 4'213 | 4'186 |
| | Leaching and run-off from crop residues | 6'697 | 6'437 | 7'065 | 6'629 | 6'556 | 6'774 | 6'492 | 6'768 | 6'760 |
| | Leaching and run-off from mineralisation of SOM | 1'722 | 2'038 | 2'961 | 2'742 | 2'011 | 2'029 | 2'079 | 2'210 | 2'205 |

Figure 5-8 shows the development of the most important activity data for 3Db Indirect $N_2O$ emissions from managed soils. Ammonia emissions from application of commercial fertilisers declined mainly due to reduced fertiliser use and partly also due to the decreasing share of fertilisers with high ammonia emission rates (i.e. urea and sewage sludge). Ammonia emissions from applied animal manure declined mainly due to declining livestock populations and hence due to the reductions of available manure N. The fraction of applied animal manure N that volatilises as $NH_3$ ($Frac_{GASMT}$) declined slightly and also contributed to the decreasing trend.

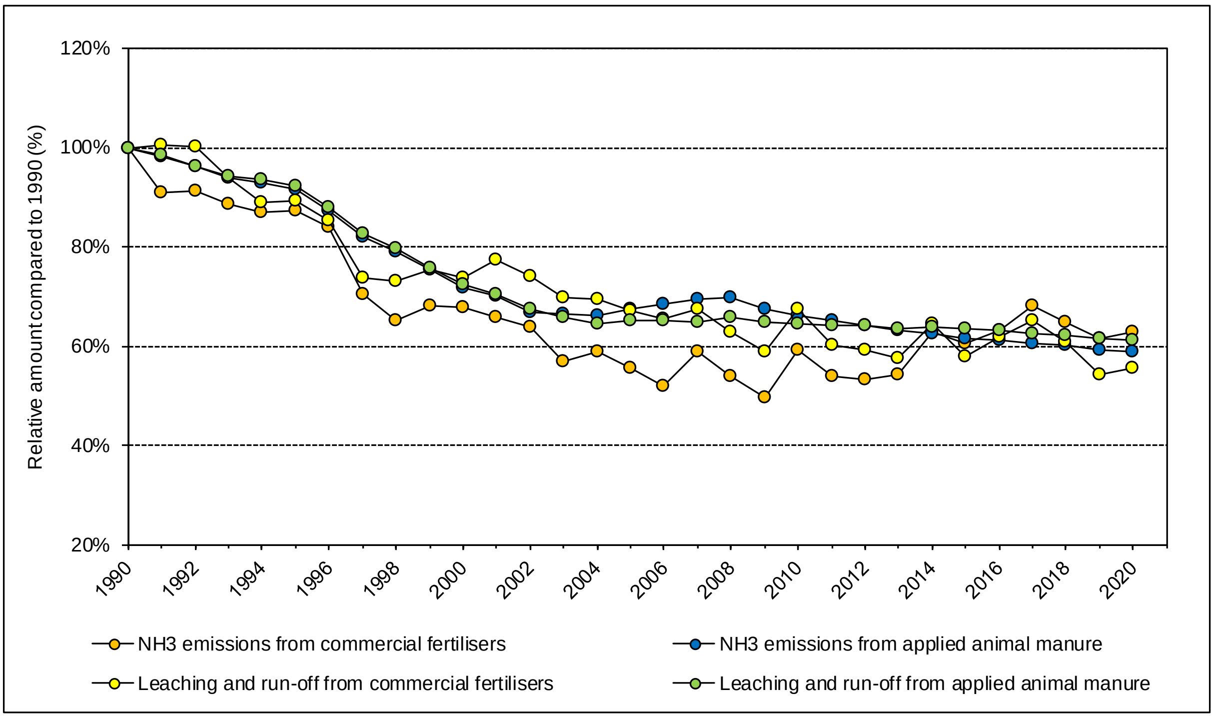


Figure 5-8 Relative development of the most important activity data for 3Db Indirect $N_2O$ emissions from managed soils.

### 5.5.2.4. Indirect $N_2O$ emissions from leaching and run-off from managed soils (3Db2)

$N_2O$ emissions from leaching and run-off from managed soils are estimated based on equation 11.10 of the 2006 IPCC Guidelines:

$$N_2O_{(L)} - N = (F_{CN} + F_{AM} + F_{PRP} + F_{CR} + F_{SOM}) \bullet Frac_{LEACH-(H)} \bullet EF_5$$

$N_2O_{(L)}$–N = annual amount of $N_2O$–N produced from leaching and run-off of N additions to managed soils (kg $N_2O$–N/year)

$F_{CN}$ = annual amount of commercial fertiliser N applied to soils (kg N/year)

$F_{AM}$ = annual amount of managed animal manure N applied to soils (kg N/year)

$F_{PRP}$ = annual amount of urine and dung N deposited by grazing animals (kg N/year)

$F_{CR}$ = annual amount of N in crop residues, including N-fixing crops, returned to soils (kg N/year)

$F_{SOM}$ = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes of land use or management (kg N/year)

$Frac_{LEACH-(H)}$ = fraction of all N added to/mineralised in managed soils that is lost through leaching and runoff (kg N/kg of N additions)

$EF_5$ = emission factor for $N_2O$ emissions from N leaching and run-off (kg $N_2O$–N/kg N leached and run-off)

#### *5.5.2.4.1. Emission factor*

The emission factor for indirect $N_2O$ emissions from leaching and run-off from managed soils is 0.0075 kg $N_2O$–N/kg N according to the 2006 IPCC Guidelines (IPCC 2006).

#### *5.5.2.4.2. Activity data*

For the calculation of $N_2O$ emissions from leaching and run-off from managed soils, N-leaching from commercial fertilisers (including synthetic fertilisers, sewage sludge, compost, and liquid and solid digestates from biogas plants) ($F_{CN}$), managed animal manure N applied to soils ($F_{AM}$), urine and dung N deposited by grazing animals ($F_{PRP}$), N in crop residues returned to soils ($F_{CR}$) and N mineralised in mineral soils ($F_{SOM}$) were accounted for. The method for the assessment of the respective amounts of nitrogen is described in chp. 5.5.2.2 and activity data are contained in Table 5-24.

$Frac_{LEACH-H}$ was estimated for the years 1990 and 2010 by dividing the available amount of nitrogen by the amount of nitrogen that is lost due to leaching and run-off in Switzerland according to model estimates of Prasuhn (2016). The respective loss rates are 20.6% for 1990 and 17.8% for 2010. Spiess and Prasuhn (2006) confirm that the loss rates were somewhat higher in the early 1990s and then declined due to the agricultural policy reforms. Accordingly, the reduction in the nitrate loss rate was implemented between 1995 and 2010 with constant loss rates after 2010. The same loss rates were applied to all nitrogen pools independent of their origin and composition. An additional reduction of the nitrate loss rate originates from the application of fertilisers with nitrification inhibitors. The nitrogen loss rate is reduced by 23% for fertilisers with nitrification inhibitors (Weiske et al. 2001). Due to the limited application of nitrification inhibitors the respective effect is still small (see also chp. 5.5.2.2.1). The overall amount of nitrogen that is lost through leaching and run-off is given in Table 5-26.

Figure 5-8 illustrates the development of the most important activity data for 3Bb Indirect $N_2O$ emissions from managed soils. Both leaching and run-off from commercial fertiliser and animal manure N declined during the inventory time period due to the reduced nitrogen inputs and the decreasing nitrate loss rates ($Frac_{LEACH-H}$).

### 5.5.2.5. NMVOC emissions from agricultural soils

The NMVOC emissions from crop production and agricultural soils are calculated based on the Tier 2 approach of the EMEP/EEA guidebook (EMEP/EEA 2019). Three types of agricultural areas are differentiated, i.e. cropland, grassland and summer pastures. The NMVOC emission factors for cropland and grassland are based on the values for wheat and grass (15°C), respectively, of Table 3.3 of the EMEP/EEA guidebook (EMEP/EEA 2019) taking into account country-specific values for the mean dry matter yield (Richner et al. 2017). For summer pastures, the same NMVOC emission value as for grass (15°C) and a fraction of the growing period of 0.3 (Bühler and Kupper 2018) are assumed using a country-specific value for the mean dry matter yield (Richner et al. 2017). The resulting NMVOC emission factors are constant for the entire time series.

### 5.5.3. Uncertainties and time-series consistency

For the uncertainty analysis the input data from ART (2008a) were used and were updated with current activity and emission data as well as with new default uncertainties of the 2006 IPCC Guidelines. The detailed input uncertainty values for category 3D are reported in Annex A2.1. The resulting, combined uncertainty for emissions according to approach 1 (uncertainty propagation) are reported in Annex A2.2 and in Annex A2.3 for results obtained by approach 2 (Monte Carlo simulations). The 95% confidence intervals obtained by Monte Carlo simulations are slightly narrower.

Table 5-27 Uncertainties for 3D Agricultural soils. (AD: Activity data; EF: Emission factor; CO: Combined; Approach 1: intervals are exactly from 2.5% to 97.5% of the distribution; Approach 2: the narrowest interval representing 95% of the distribution is given).

| **Uncertainty 3D** | **AD** | | **EF** | | **CO** | |
|---|---|---|---|---|---|---|
| | **(-)%** | **(+)%** | **(-)%** | **(+)%** | **(-)%** | **(+)%** |
| | **Approach 1** | | | | | |
| Direct soil emissions (3Da) | 16.4 | 17.9 | 83.3 | 156.2 | 84.9 | 157.2 |
| Indirect soil emissions (3Db) | 29.0 | 33.8 | 98.0 | 281.6 | 102.2 | 283.6 |
| | **Approach 2** | | | | | |
| Direct soil emissions (3Da) | 16.9 | 17.4 | 94.3 | 123.3 | 94.2 | 125.2 |
| Indirect soil emissions (3Db) | 30.3 | 32.1 | 100.0 | 207.5 | 100.0 | 211.3 |

The time series 1990–2020 are all considered consistent, although the following issues should be considered:

- For time series consistency of livestock population data see chp. 5.2.3.
- Input data from the AGRAMMON model are available for the years 1990 and 1995 (expert judgement and literature) as well as for 2002, 2007, 2010, 2015 and 2019 (extensive surveys on approximatively 3000 farms). Values in-between the assessment years were interpolated linearly. For 2020 the same values as in 2019 were used.
- $Frac_{GASF}$, $Frac_{GASM}$ and $Frac_{GASP}$ are fluctuating along the time series due to fluctuating shares of different fertiliser types and animal populations with different ammonia emission factors.
- The emission factor for indirect $N_2O$ emissions following volatilisation of $NH_3$ and $NO_x$ from applied fertilisers and urine and dung excreted on pasture, range and paddock varies according to varying land use as described in chp. 5.3.2.4.

For more details on time-series consistency see also chp. 5.2.3 and 5.3.3.

### 5.5.4. Category-specific QA/QC and verification

General QA/QC measures are described in NIR chp. 1.2.3.

All further category-specific QA/QC activities are described in a separate document (Agroscope 2019a). General information on agricultural structures and policies is provided and eventual differences between national and (IPCC 2006) standard values are being analysed and discussed.

The Swiss ammonium emission model AGRAMMON is documented in Kupper et al. (2022) and Agrammon (2021). Generally the reporting of $N_2O$ emissions in the Swiss national GHG inventory is consistent with the reporting of other nitrogen compounds ($NH_3$, $NO_x$) under the CLRTAP.

All relevant parameters needed for the calculation of direct and indirect nitrogen inputs to agricultural soils (e.g. $F_{CN}$, MS-distribution, $Frac_{GASF}$, $N_{ex}$, $Frac_{GASMT}$, $F_{ON}$, $F_{CR}$, $Frac_{LEACH-H}$) were checked for consistency and confidence and were compared (where possible) to IPCC default values (IPCC 2006), values of other countries as well as values in the literature. Nitrogen excretion, being one of the most important parameters, was analysed in more detail as described in chp. 5.3.4.2.

For quality assurance of livestock population data consult chp. 5.2.4.

$N_2O$ emission factors were compared to values in the literature to ensure plausibility. Implied emission factors are similar to measured values from the literature representative for Swiss conditions (Agroscope 2019a). In 2018 a focus study in the context of the national research programme 68 (Nationales Forschungsprogramm 68: Ressource Boden) made an independent assessment of the $N_2O$ emission factors under Swiss conditions based on a literature review (Krause et al. 2018). The authors found that the $N_2O$ emission factors of mineral soils were 2.06±2.66% for arable soils and 1.45±1.07% for grassland soils. Based on the limited data availability and on the great variability between the different measurements they concluded, that these emission factors are not significantly different to the IPCC (2006) values. Still, the numerical difference indicated that further efforts should be made to development country-specific emission factors (see chp. 5.5.6). In 2020, Ammann et al. (2020) investigated the effect of management and weather variations on $N_2O$ emissions and the greenhouse gas budget of two grasslands in the central plateau of Switzerland during a 10-year experiment. $N_2O$ emissions were measures quasi-continuously with the eddy-covariance method. The total $N_2O$-flux was partitioned to the different source categories using the IPCC emission factor approach and confirmed the validity of the respective default values. The $N_2O$ emission factor for cultivated organic soils was validated by a study from Leifeld (2018) that used a large dataset of C/N ratios in Swiss organic soils to predict $N_2O$ emissions. The study concluded that the current national GHG inventory neither systematically over- nor underestimates total emissions.

A study by Agroscope (2019b) analysed the greenhouse gas flux measurements of a grazed pasture system for dairy cows in western Switzerland over five years. While the fertiliser-related $N_2O$ emission factor was on average close to the corresponding IPCC default value, the excreta-related factor was significantly lower than the presently used default value of 2%. It could also be shown that there is a clear difference in the individual emission factors for urine and dung patches on the pasture. Further experimental measurements at other sites as well as process-based modelling are planned in order to consolidate these first results (see chp. 5.5.6).

The estimate for the area of cultivated histosols in the agricultural sector is consistent with the estimates reported under cropland and grassland in the LULUCF sector. A literature study conducted by Leifeld et al. (2003) estimates 17’000±5’000 ha which is close to the numbers reported in the LULUCF sector (17’700 ha on average).

The country-specific value of $Frac_{LEACH-H}$ is based on a very detailed model for the assessment of leaching and run-off in Switzerland (Hürdler et al. 2015, Prasuhn 2016) that takes into account regional parameters such as topography, different crop species as well as fertiliser application levels.

Henne et al. (2019) conducted a top-down assessment of Swiss $N_2O$ emissions using atmospheric measurements and an inverse modelling framework. An update is presented in Annex A5.2. The best estimate of annual $N_2O$ emissions for the investigated period in 2017–2020 was 10.9±3.1 Gg $yr^{-1}$, which compares to 10.1 (4.1 to 18.3) Gg $yr^{-1}$ given for the same period in this NIR (2-σ confidence range). Due to the large uncertainties connected to both numbers, these estimates are not significantly different (see also Annex A5.2).

## 5.5.5. Category-specific recalculations

General information on recalculations is provided in chp. 10.

Recalculations with an overall impact of >0.5 kt $CO_2$ equivalent are assessed quantitatively. All other recalculations are only described qualitatively.

- For recalculations of livestock population data and emissions from manure management (affecting the amount of animal manure applied to soils) refer to chp. 5.2.5 and chp.5.3.5.
- $N_2O$ emissions due to "N input from application of other organic fertilisers" were recalculated for the years 2014–2019. Nitrogen inputs from compost were revised (AD). The impact on overall emissions is negligible: <1.0 kt $CO_2$ eq.
- $N_2O$ emissions from “N in crop residues returned to soils” were recalculated for the years 2016–2019 due to revised data on crop yields (AD). Provisional data on crop harvests from the Swiss Farmers Union (SFU/SBV) were updated. The impact on overall emissions is negligible (<0.5 kt $CO_2$ equivalent).
- $N_2O$ emissions from mineralisation associated with loss of soil organic matter were recalculated for 1990–2019. The amount of mineralized nitrogen (AD) was revised due to new projections of soil carbon losses. The main effects are due to new meteodata (whole time series) and an error correction for 2019 in the Roth-C model (see chp. 6.5.5 and chp. 6.6.5). The main impact on overall emissions are: negligible for the period 1990–2008 (<±2 kt $CO_2$ eq), approximately +9 kt $CO_2$ eq for the years 2014–2016 and -24 kt $CO_2$ eq for the years 2017–2019.
- $N_2O$ emissions from the cultivation of organic soils were recalculated for the years 1996–2019. Area estimates (AD) were revised due to the new land use projections (LULUCF-sector). The impact on overall emissions is negligible (<±0.1 kt $CO_2$ eq).
- Indirect $N_2O$ emissions from agricultural soils were revised according to the revised estimates of nitrogen volatilized or leached as consequence of the recalculations mentioned above.

## 5.5.6. Category-specific planned improvements

FOEN funds the development and evaluation of a process-oriented model for $N_2O$ emissions in agricultural soils subject to common Swiss management practices. Additional $N_2O$-measurements with automated static chambers on cropland will support the calibration and validation of the simulation model. The project started in 2019 and continues for several years.

A number of measurement projects at Agroscope, partially financed by FOEN, contribute to the establishment of a country specific emission factor for direct $N_2O$ emissions from urine and dung deposited by grazing animals ($EF_{3PRP,CPP}$). Accordingly, it is foreseen that the respective estimates for direct $N_2O$ emissions will be revised during the submission 2024 at the latest.

An update of the area of organic soils is planned as described in chp. 6.3.6.

# 5.6. Source category 3E – Prescribed burning of savannahs

Burning of savannahs does not occur (NO) in Switzerland.

# 5.7. Source category 3F – Field burning of agricultural residues

Field burning of agricultural residues does not occur (NO) in Switzerland.

Open burning of natural forest, field and garden waste is regulated in the Ordinance on Air Pollution Control OAPC, (Swiss Confederation 1985: Art. 26b). In Switzerland, cantonal authorities are responsible for the enforcement of the OAPC regulations. The 26 cantons have thus probably slightly different interpretations and implementations of the federal ordinance. An inquiry of some cantonal authorities was performed in order to assess the activity data for these processes (INFRAS 2014).

Emissions from open burning of branches in agriculture and forestry were reported here in the past. However, the respective emissions were moved to the sectors 4 LULUCF and 5 Waste based on recommendations from the UNFCCC expert review teams (e.g. FCCC/ARR/2016/CHE W12 and W13). Respective information can be found under source category 4V “Biomass Burning” (see chp. 6.4.2.12) and source category 5C “Incineration and open burning of waste” (see chp. 7.4).

# 5.8. Source category 3G – Liming

## 5.8.1. Source category description

$CO_2$ emission from 3G Liming is not a key category.

Emissions from the application of lime ($Ca(CO_3)$) and dolomite ($CaMg(CO_3)_2$) to agricultural soils are reported.

The emissions due to liming of agricultural soils range from 22.2 to 32.9 kt $CO_2$ per year.

## 5.8.2. Methodological issues

A simple Tier 1 approach was adopted using estimated amounts of lime and dolomite applied and IPCC (2006) default emission factors.

### 5.8.2.1. Emission factor

The availability of country-specific emission factors for agricultural lime and dolomite application was investigated, but no domestic measurement data could be found. Consequently, the IPCC default carbon conversion factors for carbonate containing lime (0.12 t C per t $Ca(CO_3)$) and for dolomite (0.13 t C per t $CaMg(CO_3)_2$) were used (IPCC 2006).

### 5.8.2.2. Activity data

The total annual amount of lime and dolomite applied to agricultural soils is between 50’300 Mg (1990) and 74'050 Mg (2008–2020). It was estimated by Agroscope in 2009 for the period 1990–2008. Major retailers / providers of lime in Switzerland were directly contacted and interviewed. For 2009–2019 the same value as for 2008 was used: An inquiry in 2013 including the most important production and trading companies of lime products suggests that the consumption of limestone remains constant (Agroscope 2014a). This assumption is further supported by the fact that agricultural structures and management did not change fundamentally in recent years. Furthermore, the import of calcium carbonate mixed with ammonium nitrate (contributing 20% to lime use in Switzerland) is assessed yearly via the import statistics. These statistics do not show a significant trend along the past 20 years (FOCBS 2021a).

The split of lime into calcium carbonate and dolomite is based on the following assumptions and data:

- $Ca(CO_3)$ contained in mixed compound fertilisers as reported by Agricura (2020)
- All material originating from nuclear power plants and from the sugar beet industry is $Ca(CO_3)$
- The remaining lime not covered under the points above was divided equally into $Ca(CO_3)$ and $CaMg(CO_3)_2$.

## 5.8.3. Uncertainties and time-series consistency

The amount of total lime applied in agriculture is mainly based on expert judgement; the resulting number is uncertain. A relative uncertainty of ±40% was used as an approximation (Agroscope 2014a). For the emission factor of lime a lower uncertainty of ±5% was chosen, because it is a simple chemical process. The detailed input uncertainty values for category 3G are reported in Annex A2.1. The resulting, combined uncertainty for emissions according to approach 1 (uncertainty propagation) is thus ±40.3% (see Annex A2.2), in general concordance with results from approach 2 (Monte Carlo simulations, Annex A2.3).

Consistency: Time series for 3G Liming are all considered consistent.

### 5.8.4. Category-specific QA/QC and verification

General QA/QC measures are described in NIR chp. 1.2.3.

No further category-specific quality assurance activities were conducted.

### 5.8.5. Category-specific recalculations

General information on recalculations is provided in chp. 10.

There were no recalculations implemented in submission 2022.

### 5.8.6. Category-specific planned improvements

No category-specific improvements are planned.

## 5.9. Source category 3H – Urea application

### 5.9.1. Source category description

$CO_2$ emission from 3H Urea application is not a key category.

Adding urea to soils during fertilisation leads to a loss of $CO_2$ that was fixed during the industrial production process of the fertiliser. Emissions in Switzerland range from 8.7 to 26.7 kt $CO_2$ per year with a general decreasing trend during the 1990s and values near 12 kt $CO_2$ per year for the later part of the time series.

### 5.9.2. Methodological issues

A simple Tier 1 approach was adopted using estimated amounts of urea applied and IPCC (2006) default emission factors.

#### 5.9.2.1. Emission factor

No country-specific emission factors are available. Consequently, the IPCC (2006) default emission factor of 0.20 t of C per t of urea was applied.

#### 5.9.2.2. Activity data

The amount of urea applied to agricultural soils was obtained from Agricura (2020). Two positions of the customs tariff list were considered, namely “urea” (tariff number 3102.1000.011) and “urea-ammonia-nitrate” (tariff number 3102.8000.011). Fertiliser statistics are based on sales statistics by the compulsory stockpiler of fertilisers (Pflichtlagerhalter) and small importers. Agricura conducts plausibility checks with import-data received by the Directorate General of Customs (“Oberzolldirektion”).

### 5.9.3. Uncertainties and time-series consistency

An uncertainty of ±5% for the activity data was estimated according to ART (2008a). An uncertainty of ±5% was assumed for the emission factor since it is a simple chemical process (see inut uncertainty values in Annex A2.1). The resulting, combined uncertainty for emissions according to approach 1 (uncertainty propagation) is reported in Annex A2.2 and in Annex A2.3 for approach 2 (Monte Carlo simulations).The combined approach 1 uncertainty is ±7.1%, in concordance with approach 2.

Consistency: Time series for 3H Urea application are all considered consistent.

### 5.9.4. Category-specific QA/QC and verification

General QA/QC measures are described in NIR chp. 1.2.3.

No further category-specific quality assurance activities were conducted.

### 5.9.5. Category-specific recalculations

General information on recalculations is provided in chp. 10.

There were no recalculations implemented in submission 2022.

### 5.9.6. Category-specific planned improvements

No category-specific improvements are planned.

# 6. Land use, land-use change and forestry (LULUCF)

| Responsibilities for sector Land use, land-use change and forestry (LULUCF) | |
|---|---|
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| Lead author | Beat Rihm (Meteotest) |
| Authors and sector experts (including QC) | Daniel Bretscher (Agroscope; Cropland, Grassland), Markus Didion (WSL; Forest Land, Yasso07 Modelling), Andreas Gubler (Agroscope; NABO Data), Sonja Keel (Agroscope; Cropland Soils, Grassland Soils), Nele Rogiers (FOEN; Forest Land), Andreas Schellenberger (FOEN; QA/QC, Cross-cutting Issues), Esther Thürig (WSL; Forest Land, National Forest Inventory), Chloé Wüst (Agroscope; Cropland Soils, Grassland Soils, Organic Soils) |
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| EMIS database operation | Anouk-Aimée Bass (FOEN) |
| Technical contributors (including QC) | Dominik Eggli (Meteotest), Pascal Graf (Meteotest) |
| Internal review | Daniel Bretscher (Agroscope), Markus Didion (WSL), Martin Lindenmann (Sigmaplan), Andreas Schellenberger (FOEN) |

## 6.1. Overview of LULUCF

### 6.1.1. Methodology

Chapter 6 presents estimates of GHG emissions by sources and removals by sinks from land use, land-use change and forestry (LULUCF). The sector LULUCF includes emissions and removals from the carbon pool in Harvested wood products (HWP). Data acquisition and calculations are based on the Guidelines for National Greenhouse Gas Inventories (IPCC 2006), Volume 4 "Agriculture, Forestry and Other Land Use" (AFOLU). In many subcategories country-specific emission factors were used.

The land areas in the period 1990–2020 are represented by geographically explicit land use data with a resolution of one hectare (following approach 3 for representing land areas; IPCC 2006). Direct and repeated assessment of land use with full spatial coverage also enables to calculate spatially explicit land-use change matrices. In 2004, the Swiss Land Use Statistics AREA was launched. Simultaneously, aerial photos from two earlier Swiss Land Use Statistics (1979/85 and 1992/97) were re-evaluated, applying the same approach. The latest survey (AREA 4) was completed in 2021, allowing a harmonised tracking of land use and land-use change of the entire national territory over four time periods.

The six main land-use categories required by IPCC (2006) are: A. Forest land, B. Cropland, C. Grassland, D. Wetlands, E. Settlements and F. Other land. These categories were divided into 18 sub-divisions of land use. Following the guidelines, lands in each category were stratified by mineral and organic soils. Due to the topography of Switzerland, lands in selected categories were further separated by elevation using three zones (<601 m, 601–

1200 m, >1200 m). For Forest land, an additional stratification based on the five production regions of the National Forest Inventory (NFI) was used.

Country-specific emission factors and carbon stocks for Forest land were derived from four National Forest Inventories (NFI1, NFI2, NFI3, NFI4, finalized in 1985, 1995, 2006 and 2017, respectively) and two annual tranches of the continuous NFI5 (2018, 2019). The inventories comprised ca. 1'350 (NFI5), 6'000 (NFI2, NFI3, NFI4) and 11'000 (NFI1) terrestrial plots (see Table 6-12), where biomass stock, growth, cut and mortality were measured.

For the remaining land-use categories, carbon stocks and GHG emissions and removals were derived from domestic surveys, particular research activities, measurements, and modelling approaches. Partially, IPCC (2006) default values and expert estimates were used.

### 6.1.2. Emissions and removals

Table 6-1 and Figure 6-1 summarize the $CO_2$ emissions and removals as a result of carbon losses and gains over the inventory period. The total net emissions and removals of $CO_2$ varied between -5'626 kt (1996) and 5'127 kt (2000).

Table 6-1 and Figure 6-1 show a breakdown of Switzerland's $CO_2$ balance in the LULUCF sector. Five components were differentiated:

- Carbon gains in living biomass on all land uses and due to land-use changes; this component represents the largest sink of carbon.
- Carbon losses in living biomass on all land uses and due to land-use changes; this component represents the largest source of carbon. The highest losses were observed in the year 2000 after a heavy storm with windfall in December 1999.
- Net carbon stock changes in dead organic matter (DOM; consisting of dead wood and litter) on Forest land remaining forest land as well as land converted to or from Forest land. This component represents a sink of carbon in most years.
- Net carbon stock changes (1) in soils due to the use of mineral and organic soils and (2) in mineral and organic soils due to land-use changes. In all years soils are net emitters of CO2.
- Net carbon stock changes in Harvested wood products (HWP). With the exception of the years 2013 and 2019 this component represents a sink of carbon, i.e. the overall carbon stock stored in wood products was increasing.

The largest part of gains and losses in carbon stocks of living biomass occurred in forests, where growth of biomass (carbon gains) exceeded cut and mortality (carbon losses), except for the year 2000 (see also chp. 2.3.3). Overall, the LULUCF sector was a net sink of on average -2'435 kt $CO_2$ $yr^{-1}$ between 1990 and 2020 (see Table 6-1).

Table 6-1 $CO_2$ emissions and removals in the LULUCF sector broken down by (1) $CO_2$ removals due to carbon gains in living biomass, (2) $CO_2$ emissions due to carbon losses in living biomass, (3) net $CO_2$ changes in dead organic matter, (4) net $CO_2$ changes in organic and mineral soils, and (5) net $CO_2$ changes in Harvested wood products. Positive values refer to emissions; negative values refer to removals. In this table, both $CH_4$ and $N_2O$ emissions are not included.

| **LULUCF** | **Unit** | **1990** | **1991** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Gains in living biomass | kt $CO_2$ | -12'808 | -12'855 | -12'744 | -12'759 | -12'821 | -12'809 | -12'703 | -12'700 | -12'814 | -12'678 |
| Losses in living biomass | kt CO2 | 12'000 | 9'223 | 8'961 | 8'754 | 9'237 | 9'313 | 9'141 | 9'928 | 11'006 | 10'718 |
| Net change in dead organic matter | kt CO2 | -325 | -1'027 | -303 | -463 | 254 | -542 | -2'180 | -1'226 | -1'199 | -792 |
| Net change in organic and mineral soils | kt CO2 | 174 | 154 | 265 | 399 | 468 | 516 | 417 | 249 | 340 | 566 |
| LULUCF (excluding HWP) | kt CO2 | -959 | -4506 | -3820 | -4068 | -2863 | -3522 | -5324 | -3749 | -2667 | -2186 |
| Net change in Harvested wood products (HWP) | kt CO2 | -1'169 | -764 | -556 | -477 | -358 | -487 | -302 | -256 | -308 | -386 |
| Total LULUCF | kt CO2 | -2128 | -5270 | -4377 | -4545 | -3221 | -4009 | -5626 | -4005 | -2975 | -2572 |

| **LULUCF** | **Unit** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Gains in living biomass | kt $CO_2$ | -12'690 | -12'684 | -12'897 | -12'701 | -12'743 | -12'784 | -13'123 | -13'018 | -13'081 | -13'303 |
| Losses in living biomass | kt CO2 | 18'400 | 12'281 | 10'161 | 11'190 | 11'163 | 11'517 | 12'598 | 12'649 | 11'860 | 11'177 |
| Net change in dead organic matter | kt CO2 | -528 | -732 | -189 | -1'243 | -729 | -1'143 | -1'209 | -525 | -850 | -985 |
| Net change in organic and mineral soils | kt CO2 | 668 | 511 | 473 | 385 | 207 | 202 | 277 | 337 | 240 | 237 |
| LULUCF (excluding HWP) | kt CO2 | 5849 | -623 | -2451 | -2369 | -2102 | -2208 | -1458 | -557 | -1830 | -2873 |
| Net change in Harvested wood products (HWP) | kt CO2 | -723 | -427 | -300 | -358 | -581 | -727 | -541 | -363 | -430 | -420 |
| Total LULUCF | kt CO2 | 5'127 | -1050 | -2752 | -2727 | -2683 | -2935 | -1999 | -920 | -2261 | -3294 |

| **LULUCF** | **Unit** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **Mean** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gains in living biomass | kt $CO_2$ | -13'169 | -13'159 | -13'329 | -13'228 | -13'247 | -13'304 | -13'284 | -13'247 | -13'379 | -13'567 | -13'347 | -12'988 |
| Losses in living biomass | kt CO2 | 11'766 | 11'794 | 10'816 | 11'196 | 11'699 | 10'722 | 10'587 | 11'156 | 11'988 | 10'878 | 11'068 | 11'129 |
| Net change in dead organic matter | kt CO2 | -1'486 | -77 | -518 | -803 | 406 | -390 | -121 | -478 | -96 | -68 | 172 | -652 |
| Net change in organic and mineral soils | kt CO2 | 352 | 488 | 615 | 695 | 889 | 838 | 671 | 625 | 615 | 522 | 391 | 446 |
| LULUCF (excluding HWP) | kt CO2 | -2538 | -954 | -2417 | -2141 | -253 | -2134 | -2147 | -1945 | -872 | -2235 | -1716 | -2'064 |
| Net change in Harvested wood products (HWP) | kt CO2 | -455 | -354 | -133 | 58 | -112 | -95 | -52 | -15 | -96 | 57 | -51 | -371 |
| Total LULUCF | kt CO2 | -2993 | -1308 | -2549 | -2083 | -365 | -2230 | -2199 | -1959 | -968 | -2178 | -1768 | -2'435 |

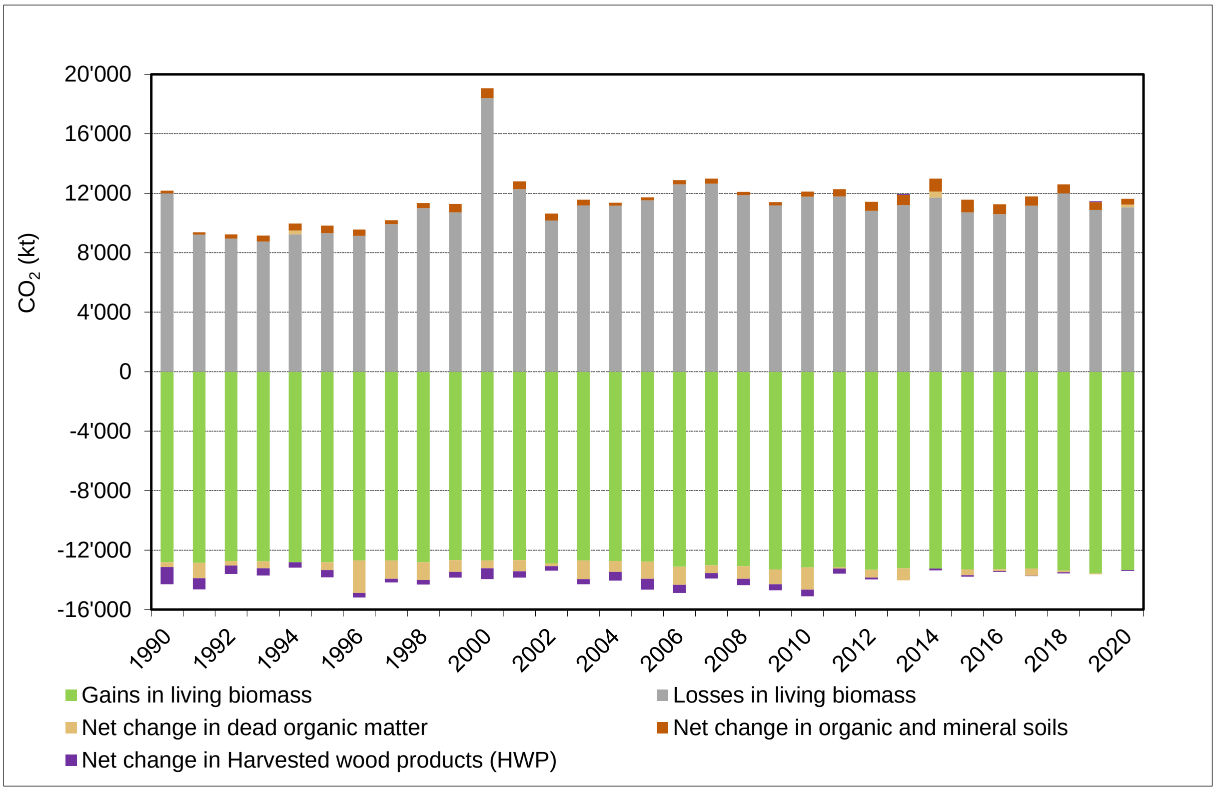



Figure 6-1 $CO_2$ emissions and removals in the LULUCF sector (in kt $CO_2$) broken down by (1) $CO_2$ removals due to carbon gains in living biomass, (2) $CO_2$ emissions due to carbon losses in living biomass, (3) net $CO_2$ changes in dead organic matter, (4) net $CO_2$ changes in organic and mineral soils, and (5) net $CO_2$ changes in Harvested wood products. Positive values refer to net emissions, negative values refer to net removals.

The non-$CO_2$ emissions associated with land use, land-use change and forestry were relatively small. Maximum annual $CH_4$ emissions were 1.24 kt $yr^{-1}$ (31 kt $CO_2$ eq; 1997), and maximum annual $N_2O$ emissions were 0.19 kt $yr^{-1}$ (57 kt $CO_2$ eq; 1997) (Figure 6-2). The emissions arose from (1) drained organic soils ($N_2O$; CRF Table4(II)), (2) flooded lands/reservoirs ($CH_4$; CRF Table4(II)), (3) nitrogen mineralisation associated with loss of soil organic matter resulting from land use on non-agricultural soils and land-use change (direct $N_2O$ emissions; CRF Table4(III)), (4) nitrogen leaching and run-off on non-agricultural soils and land-use change (indirect $N_2O$ emissions; CRF Table4(IV)), (5) wildfires on Forest land and Grassland ($CH_4$ and $N_2O$; CRF Table4(V)), and (6) controlled burning of residues from forestry ($CH_4$ and $N_2O$; CRF Table4(V)).

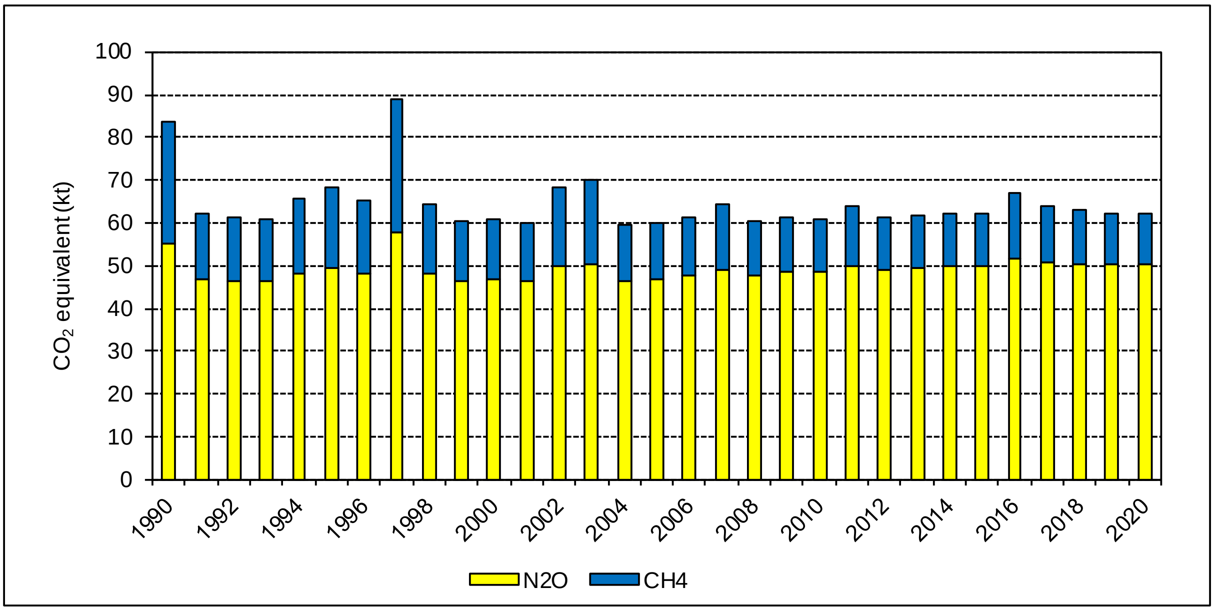



Figure 6-2 $N_2O$ and $CH_4$ emissions in the LULUCF sector (in kt $CO_2$ eq).

Figure 6-3 shows the resulting net GHG ($CO_2$, $CH_4$, $N_2O$) emissions and removals in the LULUCF sector over the inventory period broken down by categories 4A–4G. GHG fluxes were dominated by biomass dynamics in forests (4A). Further explanatory notes on LULUCF data can be found in chp. 2.3.3 “Emission trends in sector 4 LULUCF”.

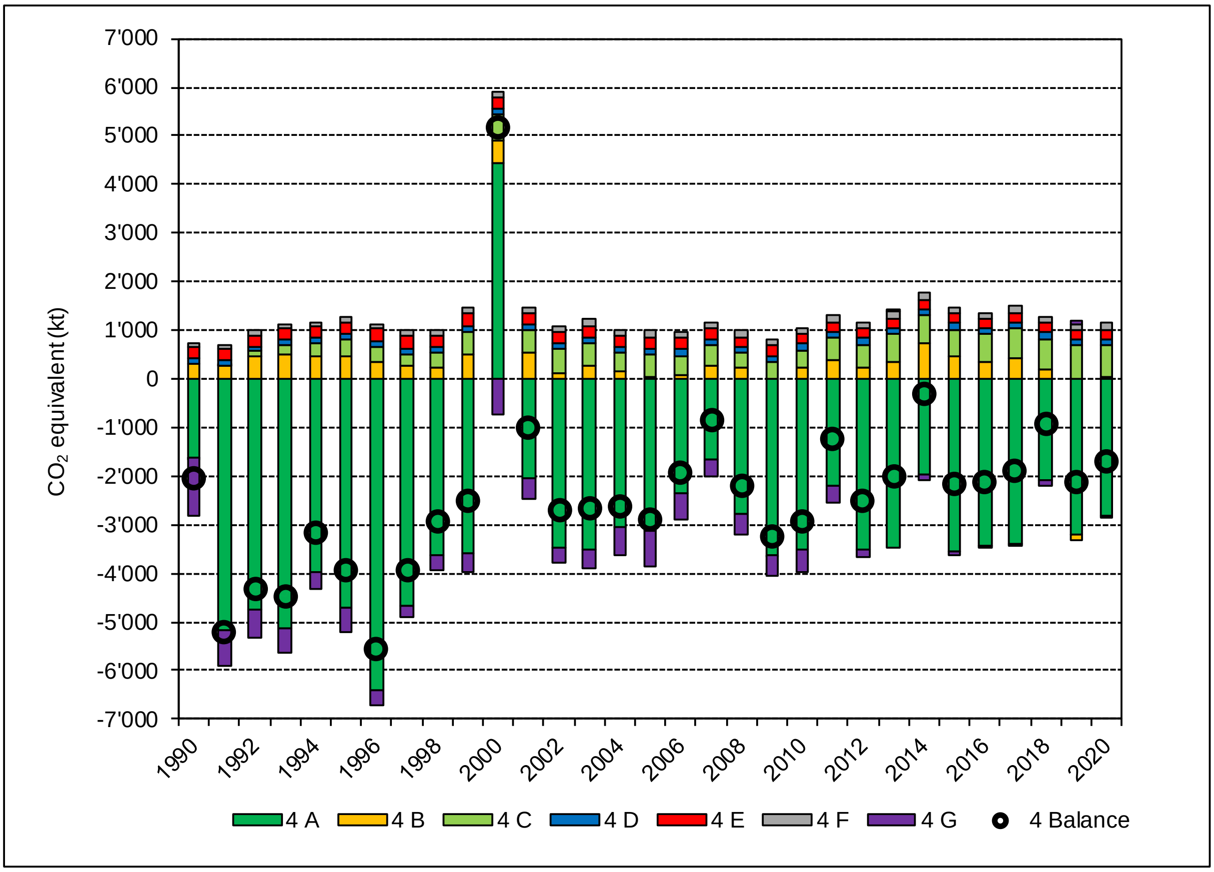



Figure 6-3 Stacked net GHG ($CO_2$, $CH_4$, $N_2O$) emissions and removals in the LULUCF sector (in kt $CO_2$ eq) broken down by categories 4A–4G. “Balance” reflects the annual mean. Positive values refer to net emissions, negative values refer to net removals. Figure 2-8 shows a simplified and Figure 2-9 an unstacked representation of the data set.

## 6.1.3. Approach for calculating carbon emissions and removals

### 6.1.3.1. Work steps

The selected procedure for calculating carbon emissions and removals in the LULUCF sector corresponds to a Tier 2 approach as described in IPCC 2006 (Volume 4, chp. 3). It can be summarised as follows:

- Define managed and unmanaged land: In Switzerland, all land besides Other land is considered to be managed. Other land (CC61, see Table 6-2) is unmanaged. It is defined as the residual country's land area without relevant human activity.
- Define land-use categories and sub-divisions with respect to available land use data (see Table 6-2). Combination categories (CC) were defined on the basis of the AREA land-use and land-cover categories (Table 6-6; SFSO 2006a).
- Define criteria and collect data for the spatial stratification of the land-use categories.
- For Forest land: Measure, model or estimate the carbon stocks in living biomass ($stockC_l$), in dead wood ($stockC_d$), in litter ($stockC_h$), and in soil ($stockC_s$) for each spatial stratum of the combination categories (CC).
  For non-Forest land: Measure, model or estimate the carbon stocks in living biomass ($stockC_l$), in dead organic matter ($stockC_{dom}$), and in soil ($stockC_s$) for each spatial stratum of the combination categories (CC).

- For Forest land: Measure, model or estimate the gain of carbon in living biomass (gain$C_l$), the loss of carbon in living biomass (loss$C_l$), the net carbon stock change in dead wood (change$C_d$), in litter (change$C_h$), and in soil (change$C_s$) for each spatial stratum of the combination categories (CC).
  For non-Forest land: Measure, model or estimate the gain of carbon in living biomass (gain$C_l$), the loss of carbon in living biomass (loss$C_l$), the net carbon stock change in dead organic matter (change$C_{dom}$), and in soil (change$C_s$) for each spatial stratum of the combination categories (CC).
- Calculate the land use and the land-use change matrix for each spatial stratum.
- For Forest land: Calculate the net carbon stock changes in living biomass (delta$C_l$), in dead wood (delta$C_d$), in litter (delta$C_h$), and in soil (delta$C_s$) for all cells of the land-use change matrix for each year under consideration.
  For non-Forest land: Calculate the net carbon stock changes in living biomass (delta$C_l$), in dead organic matter (delta$C_{dom}$), and in soil (delta$C_s$) for all cells of the land-use change matrix for each year under consideration.
- Finally, aggregate the results by summarising the carbon stock changes over combination categories and spatial strata according to the level of disaggregation displayed in the reporting tables.
- Calculate emissions and removals of the carbon pool in Harvested wood products (HWP).

The combination category CC11 (see Table 6-2) refers to a conversion from land to Forest land that corresponds to the Swiss definition for afforestation activities under Article 3, paragraph 3, of the Kyoto Protocol as defined in the Initial Report for the first commitment period (FOEN 2006h). For the reporting under the UNFCCC, afforested areas were allocated to category 4A2 (Land converted to forest land), where they were reported in an individual sub-division afforestation (no capitalisation, first letter in lowercase; see chp. 6.4.1). The identical afforested areas were reported as Afforestations (with capitalisation, first letter in uppercase) under the Kyoto-Protocol (see chp. 11.1.3). In a nutshell, the diction Afforestation was consistently used to indicate the Kyoto Protocol Article 3, paragraph 3 activity.

Table 6-2 Land-use categories used in this report (combination categories CC): 6 main land-use categories (identical to the UNFCCC land-use categories) and 18 sub-divisions. Additionally, descriptive remarks, abbreviations used in the reporting tables, and CC codes are given. For a detailed definition of the combination categories see Table 6-6 and SFSO (2006a).

| CC Main category | CC Sub-division | Remarks | Terminology in CRF tables | CC code |
|---|---|---|---|---|
| A. Forest Land | afforestation | areas converted to forest by active measures, e.g. planting | afforestation | 11 |
| | productive forest | dense and open forest meeting the criteria of forest land | 4A1: CC12<br>4A2: productive | 12 |
| | unproductive forest | brush forest and forest on unproductive areas meeting the criteria of forest land | 4A1: CC13<br>4A2: unproductive | 13 |
| B. Cropland | | arable and tillage land (annual crops and leys in arable rotations) | CC21 | 21 |
| C. Grassland | permanent grassland | meadows, pastures (low-land and alpine) | 4C1: CC31<br>4C2: permanent | 31 |
| | shrub vegetation | agricultural and unproductive areas predominantly covered by shrubs | 4C1: CC32<br>4C2: woody | 32 |
| | vineyard, low-stem orchard, tree nursery | perennial agricultural plants with woody biomass | 4C1: CC33<br>4C2: woody | 33 |
| | copse | agricultural and unproductive areas covered by perennial woody biomass including trees | 4C1: CC34<br>4C2: woody | 34 |
| | orchard | permanent grassland with fruit trees | 4C1: CC35<br>4C2: woody | 35 |
| | stony grassland | grass, herbs and shrubs on stony surfaces | 4C1: CC36<br>4C2: unproductive | 36 |
| | unproductive grassland | unproductive grass vegetation | 4C1: CC37<br>4C2: unproductive | 37 |
| D. Wetlands | surface water | lakes and rivers | surface water | 41 |
| | unproductive wetland | reed, extensively managed wetland | unprod wetland | 42 |
| E. Settlements | buildings and constructions | areas without vegetation such as houses, roads, construction sites, dumps | building | 51 |
| | herbaceous biomass in settlements | areas with low vegetation, e.g. lawns | herb | 52 |
| | shrubs in settlements | areas with perennial woody biomass (no trees) | shrub | 53 |
| | trees in settlements | areas with perennial woody biomass including trees | tree | 54 |
| F. Other Land | | unmanaged areas without soil and vegetation: rocks, sand, scree, glaciers | | 61 |

### 6.1.3.2. Calculating carbon stock changes

For calculating carbon stock changes, the following input parameters (mean values per hectare) were quantified for all combination categories (CC) and spatial strata (i):

$stockC_{l,i,CC}$ carbon stock in living biomass (t C $ha^{-1}$)

$stockC_{d,i,CC}$ carbon stock in dead wood (t C $ha^{-1}$)

$stockC_{h,i,CC}$ carbon stock litter (organic soil horizons) (t C $ha^{-1}$)

$stockC_{s,i,CC}$ carbon stock in soil (t C $ha^{-1}$)

$gainC_{l,i,CC}$ annual carbon gain in living biomass (t C $ha^{-1}$ $yr^{-1}$)

$lossC_{l,i,CC}$ annual carbon loss in living biomass (t C $ha^{-1}$ $yr^{-1}$)

$changeC_{d,i,CC}$ annual net carbon stock change in dead wood (t C $ha^{-1}$ $yr^{-1}$)

$changeC_{h,,i,CC}$ annual net carbon stock change in litter (t C $ha^{-1}$ $yr^{-1}$)

$changeC_{s,i,CC}$ annual net carbon stock change in soil (t C $ha^{-1}$ $yr^{-1}$)

In the reporting tables on non-Forest land under the UNFCCC (Table4.B to Table4.F), the carbon stocks and carbon stock changes of litter and dead wood are merged into "dead organic matter" (DOM):

$$stockC_{dom,i,CC} = stockC_{d,i,CC} + stockC_{h,i,CC}$$

$$changeC_{dom,i,CC} = changeC_{d,i,CC} + changeC_{h,i,CC}$$

On this basis, the total changes in carbon stocks (t C $yr^{-1}$) in living biomass ($deltaC_l$), in dead wood ($deltaC_d$), in litter ($deltaC_h$), and in soils ($deltaC_s$) were calculated for all cells of the land-use change matrix for each year under consideration. Each cell is characterized by a land-use category before the conversion (b), a land-use category after the conversion (a), and the area of converted land within the spatial stratum (i). This approach includes cases without any land-use change (a = b).

Equations 6.1–6.8 show, according to the AFOLU guidelines (IPCC 2006, Volume 4), two approaches and their application for calculating carbon gains and losses: (1) the gain-loss approach (Equation 2.4; IPCC 2006, Volume 4) and (2) the stock-difference approach (Equation 2.5; IPCC 2006, Volume 4).

The gain-loss approach for calculating (net) carbon stock changes is defined as:

$$deltaC_{l,i,ba} = ( gainC_{l,i,a} – lossC_{l,i,a} ) * A_{i,ba} \quad (6.1)$$

$$deltaC_{d,i,ba} = changeC_{d,i,a} * A_{i,ba} \quad (6.2)$$

$$deltaC_{h,i,ba} = changeC_{h,i,a} * A_{i,ba} \quad (6.3)$$

$$deltaC_{s,i,ba} = changeC_{s,i,a} * A_{i,ba} \quad (6.4)$$

The stock-difference approach for calculating carbon stock changes is defined as:

$$deltaC_{l,i,ba} = [ ( stockC_{l,i,a} – stockC_{l,i,b} ) / CT ] * A_{i,ba} \quad (6.5)$$

$$deltaC_{d,i,ba} = [ ( stockC_{d,i,a} – stockC_{d,i,b} ) / CT ] * A_{i,ba} \quad (6.6)$$

$$deltaC_{h,i,ba} = [ ( stockC_{h,i,a} – stockC_{h,i,b} ) / CT ] * A_{i,ba} \quad (6.7)$$

$$deltaC_{s,i,ba} = [ ( stockC_{s,i,a} – stockC_{s,i,b} ) / CT ] * A_{i,ba} \quad (6.8)$$

where:

| | |
|---|---|
| a | land-use category after conversion (CC = a) |
| b | land-use category before conversion (CC = b) |
| ba | land-use conversion from b to a |
| i | spatial stratum |
| $A_{i,ba}$ | area of land (ha) converted from b to a in the spatial stratum i (area converted in the inventory year if CT=1 year, or the sum of the areas converted within the last 20 years if CT=20 years) |
| CT | conversion time (yr), see chp. 6.1.3.3. |

Table 6-3 pinpoints which approach was used for calculating the carbon stock changes for the various types of land-use conversion and carbon pools (living biomass, dead wood / litter, mineral soil and organic soil).

The gain-loss approach was used in cases of no land-use change and generally for continuous transitions, e.g. the growth of living biomass on land converted to forest land. The stock-difference approach was used for abrupt changes following discrete events (e.g. loss of biomass by deforestation, CT = 1 year) as well as for slow processes such as the change in soil carbon content (CT = 20 years, see chp. 6.1.3.3).

For the conversions between different forest combination categories the approach was chosen in such a way that potential carbon losses of living biomass cannot be underestimated: e.g. for CC12 to CC13 stock-difference is used, and for CC13 to CC12 gain-loss is used, respectively (see Table 6-3).

In case of land-use changes to "Buildings and constructions" (CC51) a loss of 20% of the initial soil carbon stock was reported (for a detailed documentation see chp. 6.8.2.2.3). In case of land-use changes from CC51 to other categories the regular stock-difference approach according to equation 6.8 and Table 6-3, respectively, were applied.

Table 6-3 Calculation approach (gain-loss or stock-difference with conversion time in years) applied for different land-use changes and carbon pools. KP = corresponding activity under the Kyoto Protocol; NF = non-forest combination categories. Combination categories CC11–CC61 were introduced in Table 6-2.

| Change in main land-use category or sub-division | Living biomass | Dead wood, litter | Mineral soil | Organic soil | Remarks |
|---|---|---|---|---|---|
| no change in category<br>KP and UNFCCC | gain-loss | gain-loss | gain-loss | gain-loss | |
| CC13 to CC12<br>UNFCCC: 4A1<br>KP: Forest management | gain-loss | stock-diff., 20 | stock-diff., 20 | gain-loss | |
| CC12 to CC13<br>UNFCCC: 4A1<br>KP: Forest management | stock-diff., 20 | stock-diff., 20 | stock-diff., 20 | gain-loss | |
| CC11 to CC12<br>UNFCCC: 4A1<br>KP: Afforestation >20 yr | gain-loss | gain-loss | gain-loss | gain-loss | |
| change to CC11<br>UNFCCC: 4A2<br>KP: Afforestation ≤20 yr | gain-loss | stock-diff., 20 | stock-diff., 20 | gain-loss | dead organic matter is 0 in CC11 and in NF; direct human-induced |
| NF to CC12/CC13<br>UNFCCC: 4A2<br>KP: Forest management | gain-loss | stock-diff., 20 | stock-diff., 20 | gain-loss | |
| change to CC21<br>UNFCCC: 4B2<br>KP: Deforestation | stock-diff., 1 | stock-diff., 1 | stock-diff., 20 | gain-loss | change to cropland |
| change to CC31-37<br>UNFCCC: 4C2<br>KP: Deforestation | stock-diff., 1 | stock-diff., 1 | stock-diff., 20 | gain-loss | change to grassland |
| change among CC31-37<br>UNFCCC: 4C1<br>KP: not applicable | stock-diff., 1 | stock-diff., 1 | stock-diff., 1 | gain-loss | grassland internal changes |
| change to CC41<br>UNFCCC: 4D2<br>KP: Deforestation | stock-diff., 1 | stock-diff., 1 | stock-diff., 1 | gain-loss | change to surface water |
| change to CC42<br>UNFCCC: 4D2<br>KP: Deforestation | stock-diff., 1 | stock-diff., 1 | stock-diff., 20 | gain-loss | change to unproductive wetland |
| change among CC41-42<br>UNFCCC: 4D1<br>KP: not applicable | stock-diff., 1 | stock-diff., 1 | stock-diff., 1 | gain-loss | wetlands internal changes |
| change to CC51<br>UNFCCC: 4E2<br>KP: Deforestation | stock-diff., 1 | stock-diff., 1 | stock-diff., 20 (20%) | stock-diff., 20 (20%) | change to sealed settlement areas; soil carbon stock reduced by 20% |
| change to CC52-54<br>UNFCCC: 4E2<br>KP: Deforestation | stock-diff., 1 | stock-diff., 1 | stock-diff., 20 | gain-loss | change to unsealed settlement areas |
| change among CC51-54<br>UNFCCC: 4E1<br>KP: not applicable | stock-diff., 1 | stock-diff., 1 | stock-diff., 1 | gain-loss | settlement internal changes |
| change to CC61<br>UNFCCC: 4F2<br>KP: Deforestation | stock-diff., 1 | stock-diff., 1 | stock-diff., 20 | stock-diff., 20 | change to other land |

### 6.1.3.3. Conversion time (CT) in the stock-difference approach

Table 6-3 shows the conversion times applied in the stock-difference approach to carbon stock changes in living biomass, in dead organic matter (dead wood, litter), and in soils for different land-use changes.

Changes in the soil carbon stock, and this is also true for the increase of woody biomass, as a result of land-use changes are slow processes that might take decades. Therefore, IPCC (2006, Volume 4, chp. 2) suggests implementing a conversion time (CT). Following the IPCC default value (CT = 20 years), carbon emissions or removals due to a soil carbon stock difference ($stockC_{s,i,a}$ – $stockC_{s,i,b}$) do not occur in one year but are distributed evenly over the 20 years following the land-use conversion.

A conversion time of 20 years was applied to all mineral soil carbon stock changes (except for land converted to surface water and for internal changes in Grassland, Wetlands and Settlements). Accordingly, the area of mineral soil of each category 2 in reporting tables Table4.A to Table4.F contains the cumulative area remaining in the respective category in the reporting year.

The combination category afforestations (CC11) is a transitional category by definition in the land-use survey. Areas converted to afforestations are reported in category 2 in CRF Table4.A with the same conversion time as for other forest subcategories (20 years). However, after 20 years afforestations remaining afforestations (according to the land-use survey) are reported in category 1 of CRF Table4.A and are merged with productive forests (CC12). Under the Kyoto Protocol Afforestations are processed differently (see chp. 11.2.3).

There are no consistent data sources on land-use changes before 1990, but it is well known, that the main trends of the Swiss land-use dynamics, e.g. increase of forest area (FOEN 2022f: chp. 1) and settlements (ARE/FOEN 2007) did arise before 1972. Therefore, it was assumed that between 1971 and 1989 the annual rate of all land-use changes was the same as in 1990. Based on this assumption it was possible to produce the land-use data required for the consideration of the conversion time in that period and to consider it in the years 1990 to 2009 in accordance with the 20 years conversion period.

#### 6.1.3.4. Displaying results in the Common Reporting Format (CRF)

In the reporting tables Table4.A to Table4.F, a part of the combination categories (CC) and associated spatial strata are shown at an aggregated level for optimal documentation and overview. The values of deltaC are accordingly summarised. Positive values of $deltaC_{l,i,ba}$ were inserted in the column “Gains” and negative values in the column “Losses”, respectively. The values of $deltaC_{d,i,ba}$, $deltaC_{h,i,ba}$ were inserted into columns “Net carbon stock change in dead wood” and “Net carbon stock change in litter” in CRF Table4.A, and the values of $deltaC_{dom,i,ba}$ were inserted into columns “Net carbon stock change in dead organic matter” in the reporting tables Table4.B to Table4.F. The values of $deltaC_{s,i,ba}$ were inserted into columns "Net carbon stock change in soils" in the reporting tables Table4.A to Table4.F.

The reporting tables Table4.B to Table4.F are subdivided in two parts: (1) X land remaining X land and (2) Land converted to X land. Changes of areas from one combination category to another within the same main land-use category are reported in part (1) of the reporting tables. For example, the area of ”shrub vegetation” (CC32) converted to ”permanent grassland” (CC31) would be reported in CRF Table4.C under 4C1 in the sub-division “permanent”. As CC31 and CC32 do have different carbon stocks in biomass and soils, carbon stock changes would be calculated according to the equations presented in chp. 6.1.3.2.

The CRF reporter generated errors or inconsistent content in several reporting tables related to the LULUCF sector (see Annex 6).

### 6.1.4. Overview: Carbon stocks and carbon stock changes of the combination categories

Table 6-4 lists carbon stocks, carbon gains, carbon losses and net changes in carbon stocks for the pools living biomass, dead wood, litter, and mineral and organic soil stratified by combination category (CC) and spatial strata for the year 1990. These data were used to calculate the carbon stock changes presented in the reporting tables according to the methods in chp. 6.1.3.

The values shown in Table 6-4 remain constant during the inventory period with the following exceptions (highlighted cells):

- Productive forest (CC12): (1) Carbon stocks in living biomass, carbon gains and carbon losses in living biomass, (2) carbon stocks and net carbon stock changes in dead wood, (3) carbon stocks and net carbon stock changes in litter, and (4) net carbon stock changes in mineral soil. Derivation of data and annual values are described in chp. 6.4.2.4, chp. 6.4.2.5 and chp. 6.4.2.6.
- Cropland (CC21): (1) Carbon stocks in living biomass, carbon gains and carbon losses in living biomass, (2) carbon stocks and net carbon stock changes in mineral soil. Derivation of data and annual values are described in chp. 6.5.2.
- Permanent grassland (CC31): (1) Carbon stocks in living biomass, carbon gains and carbon losses in living biomass, (2) carbon stocks and net carbon stock changes in mineral soil. Derivation of data and annual values are described in chp. 6.6.2.

The derivation of the individual carbon stocks, carbon gains, carbon losses, and net carbon stock changes is explained in detail in chapters 6.4 to 6.9.

With regard to the columns "Carbon stock in dead wood", "Carbon stock in litter", and "Carbon stock in dead organic matter" in Table 6-4, the entry "0" indicates the absence of biomass in the corresponding carbon pool.

With regard to the columns "Carbon gains in living biomass", "Carbon losses in living biomass", and "Net change in", the following applies:

- Positive values refer to gains in carbon stock, negative values refer to losses in carbon stocks.
- The entry "0" indicates a Tier 1 approach, where the carbon pool is assumed to be in equilibrium.

For Forest land, the net change of carbon stocks in drained organic soils is -2.6 t C $ha^{-1}$ $yr^{-1}$. 3% of the area of organic soils is estimated to be drained (see chp. 6.4.2.9), resulting in a correspondingly smaller value in CRF Table4.A. In contrast, all organic soils on non-Forest land are assumed to have 100% drainage.

Table 6-4 Carbon stocks and carbon stock changes in living biomass, in dead wood, in litter, in mineral soil, and in organic soil for combination categories (CC), stratified by elevation zone, NFI production region, and soil type. Data on carbon stock changes apply where the gain-loss calculation approach is used (cf. Table 6-3). The values are valid for the whole inventory period with the exception of the values in the highlighted cells, which change annually (numbers given here are for the year 1990); cf. main text.

| Combination category (CC) | NFI region | Elevation zone | Carbon stock in living biomass (stockCl,i) | Carbon stock in dead wood (stockCd,i) | Carbon stock in litter (stockCh,i) | Carbon stock in mineral soil (stockCs,i) | Carbon stock in organic soil (stockCs,i) | Carbon gains in living biomass (gainCl,i) | Carbon losses in living biomass (lossCl,i) | Net change in dead wood (changeCd,i) | Net change in litter (changeCh,i) | Net change in mineral soil (changeCs,i) | Net change in (drained) organic soil (changeCs,i) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Strata | | [t C ha$^{-1}$] | | | | | [t C ha$^{-1}$ yr$^{-1}$] | | | | | |
| 11 Afforestations | 1 | 1 | 10.00 | 0 | 0 | 56.55 | 145.6 | 2.39 | -0.21 | 0 | 0 | 0 | -2.6 |
| | 1 | 2 | 10.00 | 0 | 0 | 101.29 | 145.6 | 2.39 | -0.21 | 0 | 0 | 0 | -2.6 |
| | 1 | 3 | 7.50 | 0 | 0 | 128.44 | 145.6 | 1.35 | -0.1 | 0 | 0 | 0 | -2.6 |
| | 2 | 1 | 10.00 | 0 | 0 | 50.67 | 145.6 | 2.39 | -0.21 | 0 | 0 | 0 | -2.6 |
| | 2 | 2 | 10.00 | 0 | 0 | 64.11 | 145.6 | 2.39 | -0.21 | 0 | 0 | 0 | -2.6 |
| | 2 | 3 | 7.50 | 0 | 0 | 127.56 | 145.6 | 1.35 | -0.1 | 0 | 0 | 0 | -2.6 |
| | 3 | 1 | 10.00 | 0 | 0 | 63.34 | 145.6 | 2.39 | -0.21 | 0 | 0 | 0 | -2.6 |
| | 3 | 2 | 10.00 | 0 | 0 | 79.88 | 145.6 | 2.39 | -0.21 | 0 | 0 | 0 | -2.6 |
| | 3 | 3 | 7.50 | 0 | 0 | 103.34 | 145.6 | 1.35 | -0.1 | 0 | 0 | 0 | -2.6 |
| | 4 | 1 | 10.00 | 0 | 0 | 69.61 | 145.6 | 2.39 | -0.21 | 0 | 0 | 0 | -2.6 |
| | 4 | 2 | 10.00 | 0 | 0 | 77.41 | 145.6 | 2.39 | -0.21 | 0 | 0 | 0 | -2.6 |
| | 4 | 3 | 7.50 | 0 | 0 | 75.29 | 145.6 | 1.35 | -0.1 | 0 | 0 | 0 | -2.6 |
| | 5 | 1 | 10.00 | 0 | 0 | 118.48 | 145.6 | 2.39 | -0.21 | 0 | 0 | 0 | -2.6 |
| | 5 | 2 | 10.00 | 0 | 0 | 111.66 | 145.6 | 2.39 | -0.21 | 0 | 0 | 0 | -2.6 |
| | 5 | 3 | 7.50 | 0 | 0 | 98.10 | 145.6 | 1.35 | -0.1 | 0 | 0 | 0 | -2.6 |
| 12 Productive forest | 1 | 1 | 128.65 | 4.89 | 11.97 | 56.55 | 145.6 | 3.60 | -2.38 | 0.03 | -0.12 | 0.00 | -2.6 |
| | 1 | 2 | 125.27 | 5.26 | 12.16 | 101.29 | 145.6 | 3.21 | -2.28 | 0.03 | -0.06 | 0.00 | -2.6 |
| | 1 | 3 | 84.74 | 4.65 | 10.35 | 128.44 | 145.6 | 1.95 | -1.36 | -0.03 | -0.16 | 0.00 | -2.6 |
| | 2 | 1 | 134.51 | 8.10 | 12.35 | 50.67 | 145.6 | 4.63 | -4.77 | 0.03 | -0.13 | 0.00 | -2.6 |
| | 2 | 2 | 147.20 | 7.86 | 13.23 | 64.11 | 145.6 | 4.63 | -4.61 | 0.03 | -0.09 | 0.00 | -2.6 |
| | 2 | 3 | 102.11 | 7.86 | 13.23 | 127.56 | 145.6 | 1.60 | -1.05 | 0.03 | -0.09 | 0.00 | -2.6 |
| | 3 | 1 | 135.07 | 7.54 | 14.09 | 63.34 | 145.6 | 4.56 | -3.35 | 0.09 | -0.01 | 0.00 | -2.6 |
| | 3 | 2 | 147.49 | 7.54 | 14.09 | 79.88 | 145.6 | 4.15 | -3.78 | 0.09 | -0.01 | 0.00 | -2.6 |
| | 3 | 3 | 118.79 | 6.03 | 13.63 | 103.34 | 145.6 | 2.48 | -2.75 | 0.02 | -0.04 | 0.00 | -2.6 |
| | 4 | 1 | 92.97 | 5.39 | 11.14 | 69.61 | 145.6 | 3.24 | -3.19 | 0.09 | 0.01 | 0.00 | -2.6 |
| | 4 | 2 | 103.37 | 5.39 | 11.14 | 77.41 | 145.6 | 2.49 | -2.59 | 0.09 | 0.01 | 0.00 | -2.6 |
| | 4 | 3 | 94.98 | 4.98 | 14.06 | 75.29 | 145.6 | 1.81 | -2.47 | 0.11 | 0.10 | 0.00 | -2.6 |
| | 5 | 1 | 72.68 | 2.15 | 8.14 | 118.48 | 145.6 | 2.74 | -0.92 | 0.05 | 0.01 | 0.00 | -2.6 |
| | 5 | 2 | 76.85 | 2.09 | 9.62 | 111.66 | 145.6 | 2.20 | -0.61 | 0.07 | 0.12 | 0.00 | -2.6 |
| | 5 | 3 | 76.43 | 1.77 | 11.17 | 98.10 | 145.6 | 1.61 | -0.30 | 0.02 | 0.16 | 0.00 | -2.6 |
| 13 Unproductive forest | 1 | 1 | 38.53 | 0 | 12.10 | 56.55 | 145.6 | 0 | 0 | 0 | 0 | 0 | -2.6 |
| | 1 | 2 | 51.10 | 0 | 12.92 | 101.29 | 145.6 | 0 | 0 | 0 | 0 | 0 | -2.6 |
| | 1 | 3 | 51.34 | 0 | 10.57 | 128.44 | 145.6 | 0 | 0 | 0 | 0 | 0 | -2.6 |
| | 2 | 1 | 20.45 | 0 | 12.07 | 50.67 | 145.6 | 0 | 0 | 0 | 0 | 0 | -2.6 |
| | 2 | 2 | 35.83 | 0 | 13.01 | 64.11 | 145.6 | 0 | 0 | 0 | 0 | 0 | -2.6 |
| | 2 | 3 | 51.33 | 0 | 13.01 | 127.56 | 145.6 | 0 | 0 | 0 | 0 | 0 | -2.6 |
| | 3 | 1 | 20.45 | 0 | 14.62 | 63.34 | 145.6 | 0 | 0 | 0 | 0 | 0 | -2.6 |
| | 3 | 2 | 47.53 | 0 | 14.62 | 79.88 | 145.6 | 0 | 0 | 0 | 0 | 0 | -2.6 |
| | 3 | 3 | 42.36 | 0 | 13.55 | 103.34 | 145.6 | 0 | 0 | 0 | 0 | 0 | -2.6 |
| | 4 | 1 | 21.60 | 0 | 12.02 | 69.61 | 145.6 | 0 | 0 | 0 | 0 | 0 | -2.6 |
| | 4 | 2 | 31.48 | 0 | 12.02 | 77.41 | 145.6 | 0 | 0 | 0 | 0 | 0 | -2.6 |
| | 4 | 3 | 29.88 | 0 | 14.86 | 75.29 | 145.6 | 0 | 0 | 0 | 0 | 0 | -2.6 |
| | 5 | 1 | 20.83 | 0 | 8.74 | 118.48 | 145.6 | 0 | 0 | 0 | 0 | 0 | -2.6 |
| | 5 | 2 | 23.82 | 0 | 11.45 | 111.66 | 145.6 | 0 | 0 | 0 | 0 | 0 | -2.6 |
| | 5 | 3 | 24.35 | 0 | 12.53 | 98.10 | 145.6 | 0 | 0 | 0 | 0 | 0 | -2.6 |

(Table 6-4 continued)

| Combination category (CC) | NFI region | Elevation zone | Carbon stock in living biomass (stockCl,i) | Carbon stock in dead organic matter (DOM) (stockCd,i + stockCh,i) | Carbon stock in mineral soil (stockCs,i) | Carbon stock in organic soil (stockCs,i) | Carbon gains in living biomass (gainCl,i) | Carbon losses in living biomass (lossCl,i) | Net change in dead organic matter (DOM) (changeCd,i + changeCh,i) | Net change in mineral soil (changeCs,i) | Net change in (drained) organic soil (changeCs,i) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Strata | | [t C ha$^{-1}$] | | | | [t C ha$^{-1}$ yr$^{-1}$] | | | | |
| 21 Cropland | n.s. | 1 | 6.44 | 0 | 50.21 | 240 | 0.07 | 0.00 | 0 | 0.01 | -9.52 |
| | n.s. | 2 | 6.46 | 0 | 50.22 | 240 | 0.06 | 0.00 | 0 | 0.02 | -9.52 |
| | n.s. | 3 | 6.07 | 0 | 42.43 | 240 | 0.09 | 0.00 | 0 | 0.13 | -9.52 |
| 31 Permanent Grassland | n.s. | 1 | 5.88 | 0 | 60.51 | 240 | 0.00 | -0.02 | 0 | -0.02 | -9.52 |
| | n.s. | 2 | 5.38 | 0 | 65.39 | 240 | 0.00 | -0.01 | 0 | -0.05 | -9.52 |
| | n.s. | 3 | 3.31 | 0 | 62.65 | 240 | 0.00 | 0.00 | 0 | 0.18 | -9.52 |
| 32 Shrub Vegetation | n.s. | 1 | 20.45 | 0 | 58.65 | 240 | 0 | 0 | 0 | 0 | -5.30 |
| | n.s. | 2 | 20.45 | 0 | 63.89 | 240 | 0 | 0 | 0 | 0 | -5.30 |
| | n.s. | 3 | 20.45 | 0 | 63.88 | 240 | 0 | 0 | 0 | 0 | -5.30 |
| 33 Vineyards et al. | n.s. | n.s. | 5.58 | 0 | 50.58 | 240 | 0 | 0 | 0 | 0 | -9.52 |
| 34 Copse | n.s. | 1 | 20.45 | 0 | 58.65 | 240 | 0 | 0 | 0 | 0 | -5.30 |
| | n.s. | 2 | 20.45 | 0 | 63.89 | 240 | 0 | 0 | 0 | 0 | -5.30 |
| | n.s. | 3 | 20.45 | 0 | 63.88 | 240 | 0 | 0 | 0 | 0 | -5.30 |
| 35 Orchards | n.s. | n.s. | 23.32 | 0 | 59.70 | 240 | 0 | 0 | 0 | 0 | -9.52 |
| 36 Stony Grassland | n.s. | n.s. | 7.16 | 0 | 22.35 | 240 | 0 | 0 | 0 | 0 | -5.30 |
| 37 Unproductive Grassland | n.s. | n.s. | 3.45 | 0 | 63.65 | 240 | 0 | 0 | 0 | 0 | -5.30 |
| 41 Surface Waters | n.s. | n.s. | 0 | 0 | 0 | 240 | 0 | 0 | 0 | 0 | 0 |
| 42 Unproductive Wetland | n.s. | n.s. | 6.50 | 0 | 62.80 | 240 | 0 | 0 | 0 | 0 | -5.30 |
| 51 Buildings, Constructions | n.s. | n.s. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 52 Herbaceous Biomass in S. | n.s. | n.s. | 9.54 | 0 | 50.38 | 240 | 0 | 0 | 0 | 0 | -9.52 |
| 53 Shrubs in Settlements | n.s. | n.s. | 15.43 | 0 | 50.38 | 240 | 0 | 0 | 0 | 0 | -5.30 |
| 54 Trees in Settlements | n.s. | n.s. | 20.72 | 0 | 50.43 | 240 | 0 | 0 | 0 | 0 | -5.30 |
| 61 Other Land | n.s. | n.s. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Legend | | | | | |
|---|---|---|---|---|---|
| | *Elevation zones:* | | *NFI regions:* | | n.s. = no stratification |
| | 1 | < 601 m | 1 | Jura | Annual data |
| | 2 | 601 - 1200 m | 2 | Central Plateau | |
| | 3 | > 1200 m | 3 | Pre-Alps | |
| | | | 4 | Alps | |
| | | | 5 | Southern Alps | |

## 6.1.5. Uncertainty estimates

Table 6-5 gives an overview of uncertainty estimates of activity data (AD), carbon stock change factors (CSCF; $CO_2$ emissions and removals in 4A–4G), and emission factors (EF; $CH_4$ and $N_2O$ emissions in 4(II)–4(V)).

For categories 4A–4F, the uncertainties of AD mainly depend on the uncertainty of the AREA survey data (cells highlighted in orange in Table 6-5; see chp. 6.3.3 and Table 6-10). For categories 4D1, 4(II)–4(V), and 4G other data sources are relevant, e.g. for 4D1 the uncertainty of the area of organic soils. They are presented in detail in the respective chapters (6.X.3), along with the uncertainty estimates for EF.

In general, AD uncertainty is lower than CSCF/EF uncertainty, because AD are mostly based on a systematic survey with high spatial resolution (such as AREA), while CSCFs/EFs include parameters that are difficult to measure or to model such as carbon stocks in biomass, growth rates and biogeochemical processes.

Very large relative uncertainties for CSCFs in categories 4B and 4C are due to the calculation approach, in which absolute uncertainties (in t C $ha^{-1}$ $yr^{-1}$) of the carbon stock changes in categories 4B1, 4B2, 4C1 and 4C2 were divided by the associated net carbon stock changes (chp. 6.5.3 and chp. 6.6.3).

For the emission factors of $N_2O$ in categories 4(III) and 4(IV2), the uncertainty is modelled by an (asymmetrical) gamma distribution.

The detailed input parameters used for uncertainty computation, approaches 1 and 2, are documented in Annex A2.1.

Table 6-5 Uncertainty estimates in the LULUCF sector, expressed as half of the 95% confidence intervals. Highlighted activity data (AD) uncertainties depend mainly on the uncertainty of the AREA survey. CSCF/EF = carbon stock change factor and emission factor, respectively.

| IPCC category | | Gas | AD uncertainty | CSCF/EF uncertainty 1990 | CSCF/EF uncertainty 2020 |
|---|---|---|---|---|---|
| | | | % | % | % |
| 4A1 | Forest land remaining forest land | $CO_2$ | 1.1 | 46.7 | 46.7 |
| 4A2 | Land converted to forest land | $CO_2$ | 1.5 | 46.7 | 46.7 |
| 4B1 | Cropland remaining cropland | $CO_2$ | 4.9 | 188.8 | 5615.2 |
| 4B2 | Land converted to cropland | $CO_2$ | 5.1 | 89.6 | 148.9 |
| 4C1 | Grassland remaining grassland | $CO_2$ | 5.2 | 1227.8 | 292.7 |
| 4C2 | Land converted to grassland | $CO_2$ | 5.3 | 52.5 | 43.1 |
| 4D1 | Wetlands remaining wetlands | $CO_2$ | 90.8 | 72.2 | 72.2 |
| 4D2 | Land converted to wetlands | $CO_2$ | 3.8 | 23.9 | 20.4 |
| 4E1 | Settlements remaining settlements | $CO_2$ | 4.4 | 50.0 | 50.0 |
| 4E2 | Land converted to settlements | $CO_2$ | 4.6 | 50.0 | 50.0 |
| 4F1 | Other land remaining other land | $CO_2$ | NA | NA | NA |
| 4F2 | Land converted to other land | $CO_2$ | 3.2 | 50.0 | 50.0 |
| 4(II) | Drained organic soils | $N_2O$ | 48.9 | 66.9 | 66.9 |
| 4(II)D2 | Flooded land | $CH_4$ | 10.0 | 70.0 | 70.0 |
| 4(III) | N mineralization | $N_2O$ | 83.5 | -91.4, +200.8 | -91.4, +200.8 |
| 4(IV)2 | N leaching and runoff | $N_2O$ | 85.8 | -95.1, +233.7 | -95.1, +233.7 |
| 4(V) | Biomass burning | $CH_4$ | 30.0 | 70.0 | 70.0 |
| 4(V) | Biomass burning | $CO_2$ | NA | NA | NA |
| 4(V) | Biomass burning | $N_2O$ | 30.0 | 70.0 | 70.0 |
| 4G | Harvested wood products | $CO_2$ | 11.2 | 54.8 | 54.8 |

## 6.2. Land-use definitions and classification systems

### 6.2.1. Combination Categories (CC) as derived from AREA Land Use Statistics

The nomenclature of the Swiss Land Use Statistics (AREA) processed by the Swiss Federal Statistical Office (SFSO 2006a) is the basis for the land-use categories used for land area representation in the LULUCF sector. In the course of an AREA survey (see chp. 6.3.1), every sample point on a hectare-mesh in Switzerland is assigned to a land-use category (NOLU04) and to a land-cover category (NOLC04) (SFSO nomenclature version 2004). The interpretation is backed by a large set of geodata (e.g. forest boundary layer from the NFI; for just a public subset of geodata available to the SFSO interpreters see https://map.geo.admin.ch; English version available) that can be superimposed if required. These geodata also include data sets indicating the legal status of land use (e.g. residential zones, crop rotation areas, nature reserves). Ambiguous sample points are visited by the AREA staff to verify the on-screen classification of land use (ground control).

The AREA survey is a highly sophisticated and well-established land use statistic (see the links to visualization examples in chp. 6.3.1). It allows for the identification of country-specific categories that are more detailed than those defined in IPCC (2006) (see Table 6-2). Thus, the 46 NOLU04 categories and 27 NOLC04 categories of AREA were aggregated to 18 combination categories (CC) following the assignment shown in Table 6-6 (The first digit of the CC code represents the IPCC (2006) main land-use category, whereas the second digit stands for the respective sub-division). This approach enables more precise estimates of carbon stocks and carbon stock changes in the LULUCF sector than on the basis of the IPCC (2006) main categories alone because each CC can be fed with individual carbon data and distinctive carbon dynamics can be assumed (see below).

The CCs were defined in 2006 in an evaluation process involving experts from the FOEN, the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), the Swiss Federal Statistical Office and Agroscope as well as private consultants. The evaluation process resulted in the elaboration of Table 6-6.

With regard to carbon content in living biomass, there is a strong relation to the vegetation type (i.e. to land cover in most cases). This is exemplarily reflected by the mainly horizontal arrangement of the individual CCs in Table 6-6. With regard to carbon changes in living biomass, dead organic matter, and in soils the CC definition was driven by the consideration that frequently individual vegetation units – like e.g. orchards – are subject to a similar management all over Switzerland leading to comparable carbon fluxes in living biomass, dead organic matter, and in soils.

For individual CCs (especially for Forest land, i.e. CC11, CC12, CC13) further spatial stratifications were introduced (cf. chp. 6.2.2) with the intent to approximate the real/natural differences in carbon stock, carbon stock changes and soil conditions as good as possible.

The underlying criteria to include land use sub-divisions such as shrub vegetation, vineyards, low-stem orchards, tree nurseries, copse and orchards under Grassland with woody biomass are: (1) They do not fulfil the criteria for forests; (2) There is an agricultural management in general; (3) They all have woody biomass (i.e. perennial vegetation) with grass understory. Under Cropland, in contrast, there are no perennial crops, but annual crops and leys in arable rotations. All perennial crops are included in the Grassland sub-divisions.

All sub-divisions of Forest land, Grassland and Wetlands are defined as managed and reported under managed land in CRF Table4.1. Cropland and Settlements are regarded to be managed by default. Other land is regarded to be unmanaged by default. In a nutshell, the entire land area of Switzerland – except for 4F Other land – is reported to be managed.

Table 6-6 Derivation of 18 combination categories (CC) from AREA NOLU04 and NOLC04 categories.

**18 Combination Categories (CC)**

Land Use (NOLU04) acc. to AREA – Settlement and urban areas

| Land Cover (NOLC04) acc. to AREA | Building areas | | | | | | | | Transport surfaces | | | | | Special urban areas | | | | | | | Recreational areas and cemeteries | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 101 Industrial and commercial areas > 1 ha | 102 Industrial and commercial areas < 1 ha | 103 Residential areas (one and two-family house | 104 Residential areas (terraced houses) | 105 Residential areas (blocks of flats) | 106 Public buildings and surroundings | 107 Agricultural buildings and surroundings | 108 Unspecified buildings and surroundings | 121 Motorways | 122 Roads | 123 Parking areas | 124 Railway surface | 125 Airports and airfields | 141 Energy supply plants | 142 Waste treatment plants | 143 Other supply or waste treatment plants | 144 Dumps | 145 Quarries, mines | 146 Construction sites | 147 Unexploited urban areas | 161 Public parks | 162 Sport facilities | 163 Golf courses | 164 Camping areas | 165 Garden allotments | 166 Cemeteries |
| **10 Artificial areas** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 11 Sealed surfaces | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 |
| 12 Buildings | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 |
| 13 Greenhouses | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | | | 52 | 52 | 52 | | | | | | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 |
| 14 Gardens with border and patch structures | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | | | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 |
| 15 Lawns | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | | | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 |
| 16 Trees in artificial areas | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | | | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 |
| 17 Mix of small structures | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | | | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 |
| **20 Grass and herb vegetation** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 21 Grass and herb vegetation | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 |
| **30 Brush vegetation** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 31 Shrub | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 |
| 32 Brush meadows | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 |
| 33 Short-stem fruit trees | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | | | | | | | | 53 | 53 | | | | 53 | 53 |
| 34 Vines | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | | | | | | | | 53 | 53 | | | | 53 | 53 |
| 35 Permanent garden plants and brush crops | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | | | | | | | | 52 | 52 | | | | 52 | 52 |
| **40 Tree vegetation** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 41 Closed forest | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | | 54 | | | | | | | | | 54 | 54 | 54 | | 54 | 54 | 54 |
| 42 Forest edges | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | | 54 | | | 54 | 54 | 54 | | | | 54 | 54 | 54 | 54 | 54 | 54 | 54 |
| 43 Forest strips | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | | 54 | | | 54 | 54 | 54 | | | | 54 | 54 | 54 | | 54 | 54 | 54 |
| 44 Open forest | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | | 54 | | | 54 | 54 | 54 | | | | 54 | 54 | 54 | | 54 | 54 | 54 |
| 45 Brush forest | | | | | | | | | | | | | | | | | | | | | 53 | | | 53 | | |
| 46 Linear woods | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 |
| 47 Clusters of trees | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 |
| **50 Bare land** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 51 Solid rock | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 |
| 52 Granular soil | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 |
| 53 Rocky areas | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 |
| **60 Watery areas** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 61 Water | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 |
| 62 Glacier, perpetual snow | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 63 Wetlands | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 |
| 64 Reedy marshes | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 |

Land Use (NOLU04) acc. to AREA – Agricultural areas, Forest areas, Unproductive areas

| Land Cover (NOLC04) acc. to AREA | Agricultural areas: Orchards, vineyards, horticulture | | | Arable and grassland | | | Alpine grazing areas | | | Forest areas: Forest (not used for agriculture) | | | | Unproductive areas: Lakes and rivers | | | Unproductive land | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 201 Orchards | 202 Vineyards | 203 Horticulture | 221 Arable land, in general | 222 Semi-natural grassland, in general | 223 Farm pastures, in general | 241 Alpine meadows, in general | 242 Alpine pastures, in general | 243 Alpine sheep grazing pastures, in general | 301 Forest | 302 Afforestation | 303 Lumbering areas | 304 Damaged forest | 401 Lakes | 402 Streams, rivers | 403 Flood protection structures | 421 Unused | 422 Avalanche and rockfall protection structures | 423 Alpine sports facilities | 424 Landscape intervention |
| **10 Artificial areas** | | | | | | | | | | | | | | | | | | | | |
| 11 Sealed surfaces | | 51 | 51 | | | | | | | | | | | 51 | 51 | 51 | | 51 | 51 | 51 |
| 12 Buildings | | | | | | | | | | | | | | | | | | | | |
| 13 Greenhouses | | | 21 | | | | | | | | | | | | | | | | | |
| 14 Gardens with border and patch structures | | 21 | 21 | 21 | 21 | | 21 | | | 12 | | | | | | | | | | |
| 15 Lawns | | 31 | 31 | | | | | | | | | | | | | | | | | |
| 16 Trees in artificial areas | | | | | | | | | | | | | | | | | | | | |
| 17 Mix of small structures | | 21 | 21 | | | | | | | | | | | | | | | | | |
| **20 Grass and herb vegetation** | | | | | | | | | | | | | | | | | | | | |
| 21 Grass and herb vegetation | 31 | 31 | 31 | 21 | 31 | 31 | 31 | 31 | 31 | | 11 | 12 | 12 | 37 | 37 | 37 | 37 | 37 | 37 | 31 |
| **30 Brush vegetation** | | | | | | | | | | | | | | | | | | | | |
| 31 Shrub | | 32 | 32 | | | | | | | | 11 | 12 | 12 | 32 | 32 | 32 | 32 | 32 | 32 | 32 |
| 32 Brush meadows | | 32 | 32 | | 32 | 32 | 32 | 32 | | | 11 | 12 | 12 | 32 | 32 | 32 | 32 | 32 | 32 | 32 |
| 33 Short-stem fruit trees | 33 | | 33 | | | | | | | | | | | | | | | | | |
| 34 Vines | | 33 | 33 | | | | | | | | | | | | | | | | | |
| 35 Permanent garden plants and brush crops | | | 33 | | | | | | | 12 | | | | | | | | | | |
| **40 Tree vegetation** | | | | | | | | | | | | | | | | | | | | |
| 41 Closed forest | 35 | | | | | | | | | 12 | 11 | | | | | 12 | | 12 | | |
| 42 Forest edges | 35 | | | | | | | | | 12 | 11 | 12 | 12 | | | 12 | | 12 | | |
| 43 Forest strips | 35 | | | | | | | | | 12 | 11 | | | | | 12 | | 12 | | |
| 44 Open forest | 35 | | | | 12 | 12 | 12 | 12 | 13 | 12 | 11 | 12 | 12 | | | 12 | | 12 | 12 | 12 |
| 45 Brush forest | | | | | | | | | | 13 | | | | | | 13 | | 13 | | |
| 46 Linear woods | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | | 11 | 12 | 12 | 34 | 34 | 34 | 34 | 34 | 34 | 34 |
| 47 Clusters of trees | 34 | 34 | 34 | 34 | 13 | 13 | 34 | 13 | 34 | | 11 | 12 | 12 | 34 | 34 | 34 | 34 | 34 | 34 | 34 |
| **50 Bare land** | | | | | | | | | | | | | | | | | | | | |
| 51 Solid rock | | | | | | | | | | | | 13 | 13 | 61 | 61 | 61 | 61 | 61 | 61 | 61 |
| 52 Granular soil | | 61 | 61 | | | | | | | | | 12 | 12 | 61 | 61 | 61 | 61 | 61 | 61 | 61 |
| 53 Rocky areas | | 36 | 36 | | | 36 | 36 | 36 | | | 11 | 13 | 13 | 36 | 36 | 36 | 36 | 36 | 36 | 36 |
| **60 Watery areas** | | | | | | | | | | | | | | | | | | | | |
| 61 Water | | | | | | | | | | | | | | 41 | 41 | 41 | | | | 41 |
| 62 Glacier, perpetual snow | | | | | | | | | | | | | | | | | 61 | | 61 | |
| 63 Wetlands | | | | | 42 | 42 | 42 | 42 | 42 | | | 12 | 13 | 42 | 42 | 42 | 42 | 42 | 42 | 42 |
| 64 Reedy marshes | | | | 21 | 42 | 42 | 42 | 42 | 42 | | | | | 42 | 42 | 42 | 42 | | | |

**Combination Categories (CC):**

- 11 Afforestations
- 12 Productive forest
- 13 Unproductive forest
- 21 Cropland
- 31 Permanent grassland
- 32 Shrub vegetation
- 33 Vineyards, Low-stem Orchards, Tree nurseries
- 34 Copse
- 35 Orchards
- 36 Stony grassland
- 37 Unproductive grassland
- 41 Surface waters
- 42 Unproductive wetland
- 51 Buildings and constructions
- 52 Herbaceous biomass in settlements
- 53 Shrubs in settlements
- 54 Trees in settlements
- 61 Other land

## 6.2.2. Spatial stratification

In order to quantify carbon stocks and GHG emissions and removals in the LULUCF sector as accurately as possible, Switzerland's territory was stratified by means of three site criteria: soil type (mineral or organic), elevation and forest production region.

### 6.2.2.1. Soil Type

Most soils in Switzerland are mineral soil types. A digital map showing estimates of the surface of organic soils in Switzerland was elaborated by Wüst-Galley et al. (2015). As there is no single data set from which the location of organic soils across the country could be adequately deduced, the authors evaluated numerous spatial and non-spatial data sets providing information on geology, soils, forest habitats and vegetation. According to Wüst-Galley et al. (2015) the total area of organic soils is 28 kha (0.8% of the total area covered by soils).

The definition of organic soils in the GHG inventory is as follows:

Intact or degraded peaty soils are considered organic soils. Where information on soil organic carbon (SOC) is known, the definition of organic soils from the IPCC (IPCC 2006, Volume 4, chp. 3, Annex 3A.5) was used to classify soils as mineral / organic (see Wüst-Galley et al. 2015: 11). Thus, this definition was used for the ground-truthing of forest habitat maps and fen inventories. This definition also formed the basis of the classification of soil types from the soils maps, as organic or mineral. Here however, two soils types ("anmoorig" and "antorfig" soils) could not be classified; these have ranges of SOC and peat depth that are wider than those given in the IPCC (2006) definition, meaning they cannot be classified as either mineral or organic soils. Due to lack of information regarding their distribution, they were not explicitly considered in the estimate of organic soils (see Wüst-Galley et al. 2015: 14–15 and 61); including these additional soil types would lead to inconsistency of the definition of organic soils across the country, because their distribution is only known for a small area in Switzerland.

For the other data sets used in the construction of the organic soils map (geology maps, hydrogeology maps and other habitat maps), no information on SOC is available, and the presence of peat was used as evidence of organic soils. The carbon content of peat meets the IPCC (2006) definition of organic soils.

Consistency: A single map of organic soils is applied to all years (1990 to present), meaning the classifications used are consistent through time. The same definition of organic soils was used across the whole country.

### 6.2.2.2. Elevation

For Forest land (CC11-CC13), Cropland (CC21), and permanent grassland (CC31) three elevation zones were differentiated: <601 m a.s.l. (meters above sea level), 601–1200 m a.s.l., and >1200 m a.s.l. (Figure 6-4). Elevation data from the Federal Office of Topography (swisstopo.ch) on a 25x25 m raster (product DHM25) were used to map the three zones.

#### 6.2.2.3. Forest production region

Forest land was furthermore differentiated into the five production regions of the National Forest Inventory (Brändli and Hägeli 2019: chp. 1.5.2) as shown in Figure 6-4 (see also https://s.geo.admin.ch/8d972b5708):

1. Jura, 2. Central Plateau, 3. Pre-Alps, 4. Alps, 5. Southern Alps.

Applying all spatial stratifications, 30 different strata (referred to as subscript i in chp. 6.1.3.2) would be theoretically possible. Not all of them, but altogether 29 have been actually realised and applied for the calculation of LULUCF-associated $CO_2$ emissions and removals.

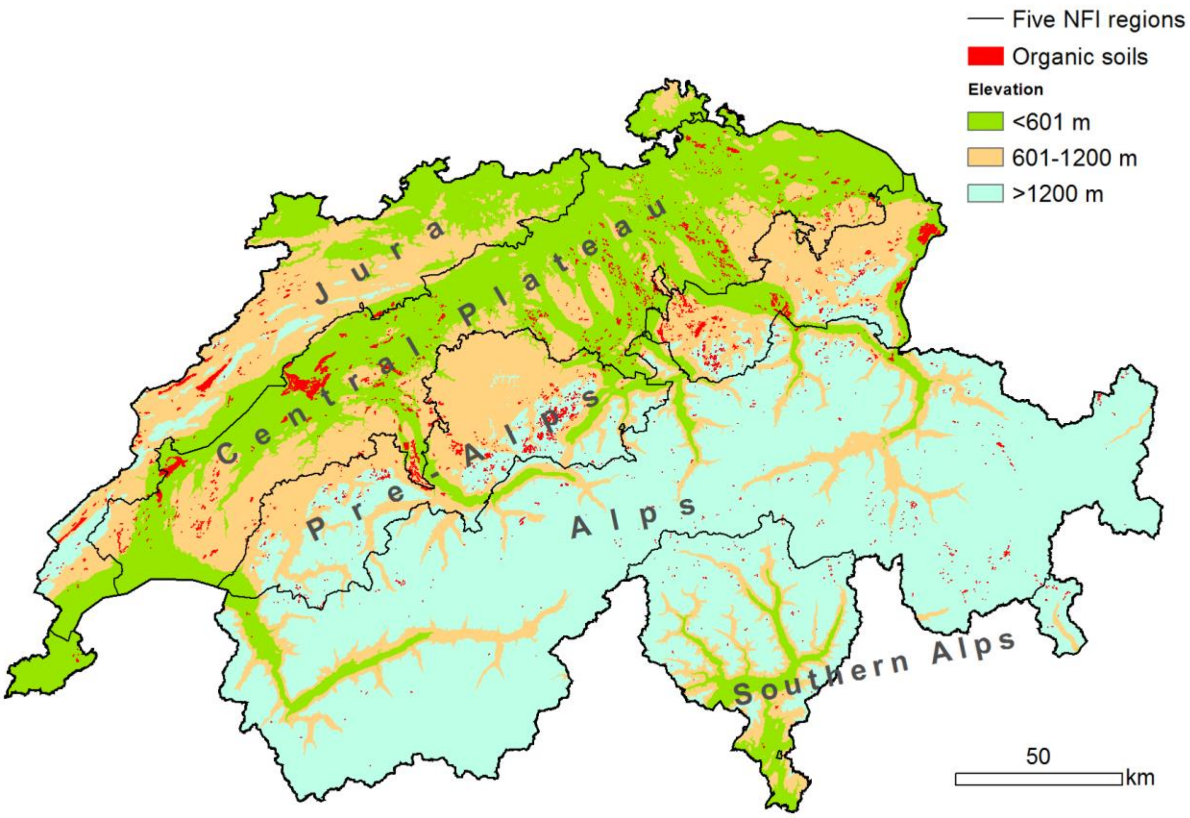



Figure 6-4 Map showing the spatial stratification according to NFI production region, elevation zone, and soil type.

### 6.2.3. The land-use tables and change matrices

In Table 6-7 the land-use statistics resulting from spatial stratification (chp. 6.2.2) and interpolation in time (chp. 6.3.2) are exemplarily shown for the year 1990. The table gives also the size of the individual spatial strata.

Table 6-7 Land use projection by the end of 1990 (in terms of combination categories CC), stratified separately for elevation (3 zones), soil type (mineral or organic) and NFI production region (1-5), in kha, rounded values. The country's total area is 4'129'073 ha (SFSO 2021).

| CC: | 11 | 12 | 13 | 21 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 41 | 42 | 51 | 52 | 53 | 54 | 61 | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Altitude** | | | | | | | | | | | | | | | | | | | |
| <601 m | 1.1 | 224.8 | 6.2 | 299.8 | 153.8 | 2.6 | 22.5 | 32.4 | 1.2 | 0.5 | 2.9 | 138.6 | 5.2 | 116.7 | 47.5 | 2.8 | 18.6 | 2.0 | 1079.1 |
| 601-1200 m | 1.4 | 504.2 | 18.1 | 131.7 | 358.2 | 8.7 | 3.9 | 29.9 | 0.3 | 2.5 | 1.5 | 9.7 | 5.7 | 46.4 | 17.0 | 0.9 | 5.3 | 8.1 | 1153.9 |
| >1200 m | 1.4 | 377.8 | 79.9 | 0.4 | 425.4 | 144.4 | 0.0 | 27.1 | 0.0 | 148.7 | 61.9 | 13.3 | 14.3 | 11.4 | 3.7 | 0.2 | 1.0 | 585.2 | 1896.1 |
| | 3.9 | 1106.9 | 104.2 | 432.0 | 937.4 | 155.7 | 26.5 | 89.3 | 1.6 | 151.6 | 66.3 | 161.6 | 25.1 | 174.6 | 68.2 | 3.9 | 24.9 | 595.3 | 4129.1 |
| **Soil** | | | | | | | | | | | | | | | | | | | |
| mineral | 3.9 | 1103.3 | 104.1 | 420.3 | 931.8 | 155.6 | 26.4 | 89.0 | 1.6 | 151.6 | 66.1 | 161.3 | 21.4 | 173.4 | 67.7 | 3.9 | 24.8 | 595.3 | 4101.3 |
| organic | 0.0 | 3.6 | 0.2 | 11.7 | 5.6 | 0.1 | 0.0 | 0.4 | 0.0 | 0.0 | 0.2 | 0.3 | 3.7 | 1.2 | 0.5 | 0.0 | 0.1 | 0.025 | 27.7 |
| | 3.9 | 1106.9 | 104.2 | 432.0 | 937.4 | 155.7 | 26.5 | 89.3 | 1.6 | 151.6 | 66.3 | 161.6 | 25.1 | 174.6 | 68.2 | 3.9 | 24.9 | 595.3 | 4129.1 |
| **NFI region** | | | | | | | | | | | | | | | | | | | |
| 1 | 0.7 | 197.2 | 8.3 | 78.0 | 122.6 | 0.9 | 4.7 | 11.9 | 0.3 | 0.2 | 0.6 | 23.6 | 1.2 | 26.8 | 10.9 | 0.5 | 4.7 | 0.5 | 493.5 |
| 2 | 0.8 | 227.2 | 4.1 | 307.0 | 152.4 | 0.9 | 9.9 | 27.4 | 1.0 | 0.2 | 1.6 | 70.4 | 4.1 | 84.9 | 34.7 | 1.6 | 12.6 | 0.7 | 941.5 |
| 3 | 1.0 | 214.3 | 13.0 | 30.2 | 261.3 | 10.4 | 0.8 | 17.8 | 0.1 | 8.5 | 6.8 | 30.6 | 12.0 | 26.8 | 9.2 | 0.5 | 2.9 | 15.0 | 661.2 |
| 4 | 1.1 | 331.6 | 56.1 | 13.8 | 365.4 | 110.2 | 9.5 | 24.5 | 0.2 | 118.1 | 49.2 | 26.2 | 7.2 | 26.9 | 9.8 | 0.8 | 3.0 | 524.8 | 1678.2 |
| 5 | 0.3 | 136.6 | 22.6 | 3.0 | 35.7 | 33.3 | 1.5 | 7.8 | 0.0 | 24.6 | 8.1 | 10.7 | 0.7 | 9.2 | 3.7 | 0.6 | 1.9 | 54.3 | 354.6 |
| | 3.9 | 1106.9 | 104.2 | 432.0 | 937.4 | 155.7 | 26.5 | 89.3 | 1.6 | 151.6 | 66.3 | 161.6 | 25.1 | 174.6 | 68.2 | 3.9 | 24.9 | 595.3 | 4129.1 |

Table 6-8 shows the overall trends of land-use changes between 1990 and 2020. For example, the area of afforestations (CC11) decreased by 90% during this period, while the area of productive forests (CC12) increased by 5%. Afforestation area is decreasing because afforestation activities slowed down over the inventory period (see Table 6-9) and because most of the afforestations turn into productive forests after a certain time.

Table 6-8 Statistics of land use (in terms of combination categories CC) and relative change (%) between 1990 and 2020, in kha, rounded values. The country's total area is 4'129'073 ha (SFSO 2021).

| CC: | 11 | 12 | 13 | 21 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 41 | 42 | 51 | 52 | 53 | 54 | 61 | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year:** | | | | | | | | | | | | | | | | | | | |
| 1990 | 3.9 | 1106.9 | 104.2 | 432.0 | 937.4 | 155.7 | 26.5 | 89.3 | 1.6 | 151.6 | 66.3 | 161.6 | 25.1 | 174.6 | 68.2 | 3.9 | 24.9 | 595.3 | 4129.1 |
| 1991 | 3.8 | 1109.1 | 104.4 | 431.2 | 935.6 | 155.2 | 26.5 | 88.3 | 1.5 | 151.4 | 66.2 | 161.6 | 25.1 | 176.2 | 68.7 | 4.0 | 25.3 | 595.0 | 4129.1 |
| 1992 | 3.7 | 1111.3 | 104.7 | 430.4 | 933.8 | 154.7 | 26.6 | 87.3 | 1.4 | 151.1 | 66.0 | 161.6 | 25.1 | 177.9 | 69.3 | 4.0 | 25.6 | 594.6 | 4129.1 |
| 1993 | 3.5 | 1113.4 | 104.9 | 429.4 | 932.3 | 154.2 | 26.5 | 86.2 | 1.4 | 150.9 | 65.8 | 161.6 | 25.1 | 179.5 | 69.9 | 4.1 | 25.9 | 594.2 | 4129.1 |
| 1994 | 3.4 | 1115.3 | 105.1 | 428.0 | 931.7 | 153.7 | 26.5 | 85.2 | 1.3 | 150.8 | 65.7 | 161.6 | 25.1 | 181.1 | 70.4 | 4.2 | 26.2 | 593.8 | 4129.1 |
| 1995 | 3.2 | 1117.1 | 105.3 | 426.1 | 931.6 | 153.2 | 26.5 | 84.3 | 1.3 | 150.6 | 65.5 | 161.6 | 25.2 | 182.7 | 71.2 | 4.2 | 26.2 | 593.4 | 4129.1 |
| 1996 | 3.0 | 1118.7 | 105.4 | 424.2 | 931.8 | 152.7 | 26.4 | 83.3 | 1.3 | 150.5 | 65.3 | 161.6 | 25.2 | 184.2 | 71.9 | 4.2 | 26.2 | 592.9 | 4129.1 |
| 1997 | 2.8 | 1120.2 | 105.6 | 422.1 | 932.3 | 152.3 | 26.3 | 82.4 | 1.2 | 150.4 | 65.2 | 161.7 | 25.2 | 185.8 | 72.7 | 4.2 | 26.2 | 592.5 | 4129.1 |
| 1998 | 2.6 | 1121.5 | 105.6 | 420.0 | 932.7 | 152.1 | 26.3 | 81.5 | 1.2 | 150.5 | 65.0 | 161.7 | 25.2 | 187.3 | 73.6 | 4.2 | 26.1 | 592.0 | 4129.1 |
| 1999 | 2.4 | 1122.9 | 105.7 | 418.0 | 933.2 | 151.9 | 26.2 | 80.5 | 1.2 | 150.5 | 64.8 | 161.8 | 25.3 | 188.8 | 74.4 | 4.2 | 26.0 | 591.5 | 4129.1 |
| 2000 | 2.2 | 1124.2 | 105.7 | 415.9 | 933.6 | 151.7 | 26.1 | 79.6 | 1.2 | 150.6 | 64.6 | 161.8 | 25.3 | 190.3 | 75.2 | 4.2 | 25.9 | 591.0 | 4129.1 |
| 2001 | 2.0 | 1125.5 | 105.8 | 413.8 | 934.0 | 151.5 | 26.0 | 78.6 | 1.1 | 150.7 | 64.3 | 161.9 | 25.4 | 191.9 | 76.1 | 4.2 | 25.8 | 590.6 | 4129.1 |
| 2002 | 1.7 | 1126.8 | 105.8 | 411.8 | 934.5 | 151.3 | 25.9 | 77.7 | 1.1 | 150.7 | 64.1 | 161.9 | 25.4 | 193.4 | 76.9 | 4.2 | 25.7 | 590.1 | 4129.1 |
| 2003 | 1.5 | 1128.1 | 105.9 | 409.7 | 934.9 | 151.1 | 25.8 | 76.7 | 1.1 | 150.8 | 63.9 | 162.0 | 25.4 | 194.9 | 77.7 | 4.2 | 25.6 | 589.6 | 4129.1 |
| 2004 | 1.3 | 1129.5 | 106.0 | 407.6 | 935.4 | 150.9 | 25.7 | 75.8 | 1.1 | 150.8 | 63.7 | 162.0 | 25.5 | 196.4 | 78.6 | 4.2 | 25.5 | 589.1 | 4129.1 |
| 2005 | 1.2 | 1130.9 | 105.9 | 406.0 | 935.1 | 150.7 | 25.6 | 74.9 | 1.1 | 150.9 | 63.5 | 162.1 | 25.5 | 198.1 | 79.4 | 4.2 | 25.4 | 588.7 | 4129.1 |
| 2006 | 1.0 | 1132.3 | 106.0 | 404.1 | 934.9 | 150.6 | 25.5 | 74.1 | 1.0 | 151.1 | 63.3 | 162.1 | 25.5 | 199.7 | 80.0 | 4.2 | 25.4 | 588.2 | 4129.1 |
| 2007 | 0.9 | 1134.0 | 105.8 | 402.3 | 934.3 | 150.7 | 25.5 | 73.5 | 1.0 | 151.2 | 63.0 | 162.2 | 25.6 | 201.4 | 80.5 | 4.2 | 25.5 | 587.5 | 4129.1 |
| 2008 | 0.8 | 1135.9 | 105.6 | 400.6 | 933.2 | 151.1 | 25.4 | 73.2 | 1.0 | 151.6 | 62.7 | 162.3 | 25.6 | 203.0 | 80.6 | 4.1 | 25.8 | 586.4 | 4129.1 |
| 2009 | 0.8 | 1138.0 | 105.4 | 398.9 | 931.9 | 151.4 | 25.3 | 73.1 | 1.1 | 152.0 | 62.5 | 162.3 | 25.6 | 204.6 | 80.7 | 4.1 | 26.2 | 585.3 | 4129.1 |
| 2010 | 0.7 | 1140.1 | 105.3 | 397.2 | 930.4 | 151.6 | 25.3 | 73.1 | 1.1 | 152.4 | 62.2 | 162.3 | 25.6 | 206.2 | 80.7 | 4.1 | 26.7 | 584.1 | 4129.1 |
| 2011 | 0.7 | 1142.3 | 105.1 | 395.5 | 929.0 | 151.8 | 25.3 | 73.1 | 1.1 | 152.8 | 61.9 | 162.4 | 25.6 | 207.8 | 80.7 | 4.0 | 27.1 | 582.8 | 4129.1 |
| 2012 | 0.6 | 1144.4 | 105.0 | 393.9 | 927.6 | 152.0 | 25.2 | 73.1 | 1.2 | 153.2 | 61.6 | 162.4 | 25.6 | 209.5 | 80.7 | 4.0 | 27.5 | 581.5 | 4129.1 |
| 2013 | 0.6 | 1146.6 | 104.8 | 392.2 | 926.3 | 152.2 | 25.2 | 73.1 | 1.2 | 153.6 | 61.3 | 162.5 | 25.7 | 211.1 | 80.6 | 4.0 | 28.0 | 580.3 | 4129.1 |
| 2014 | 0.5 | 1148.6 | 104.8 | 390.4 | 925.1 | 152.5 | 25.1 | 73.2 | 1.3 | 154.0 | 61.1 | 162.5 | 25.7 | 212.6 | 80.5 | 3.9 | 28.4 | 579.1 | 4129.1 |
| 2015 | 0.5 | 1150.6 | 104.7 | 388.7 | 923.8 | 152.8 | 25.0 | 73.2 | 1.3 | 154.4 | 60.8 | 162.5 | 25.7 | 214.1 | 80.4 | 3.9 | 28.9 | 577.8 | 4129.1 |
| 2016 | 0.5 | 1152.6 | 104.7 | 386.9 | 922.6 | 153.1 | 25.0 | 73.2 | 1.4 | 154.8 | 60.6 | 162.6 | 25.7 | 215.6 | 80.3 | 3.9 | 29.3 | 576.5 | 4129.1 |
| 2017 | 0.4 | 1154.5 | 104.6 | 385.4 | 921.2 | 153.1 | 25.0 | 73.2 | 1.5 | 155.1 | 60.3 | 162.6 | 25.7 | 217.1 | 80.3 | 3.9 | 29.6 | 575.3 | 4129.1 |
| 2018 | 0.4 | 1156.5 | 104.7 | 383.9 | 919.7 | 153.1 | 25.0 | 73.3 | 1.5 | 155.6 | 60.1 | 162.6 | 25.7 | 218.6 | 80.3 | 3.8 | 30.0 | 574.0 | 4129.1 |
| 2019 | 0.4 | 1158.5 | 104.7 | 382.4 | 918.2 | 153.2 | 24.9 | 73.4 | 1.5 | 156.0 | 59.9 | 162.6 | 25.7 | 220.2 | 80.4 | 3.8 | 30.4 | 572.8 | 4129.1 |
| 2020 | 0.4 | 1160.6 | 104.6 | 380.9 | 916.7 | 153.3 | 24.9 | 73.4 | 1.5 | 156.4 | 59.6 | 162.7 | 25.8 | 221.7 | 80.4 | 3.8 | 30.7 | 571.5 | 4129.1 |
| **Change:** | -90 | 5 | 0 | -12 | -2 | -2 | -6 | -18 | -1 | 3 | -10 | 1 | 3 | 27 | 18 | -2 | 23 | -4 | 0 |

The annual land-use changes across the entire territory of Switzerland (change-matrices, see examples for 1990 and 2020 in Table 6-9) were obtained by adding up the annual changes on a hectare basis per combination category (CC). For calculating the carbon stock changes, fully stratified (cf. chp. 6.2.2) land-use change tables were used for each year (Meteotest 2022). More aggregated change-matrices are reported in CRF Table4.1 for each year of the inventory period.

It is worth noting that in general the numbers given in the change-matrices (Table 6-9) cannot be directly compared with the figures of category 2 in CRF Table4.A, Table4.B, Table4.C, Table4.D, Table4.E, and Table4.F (Land converted to X), where the cumulative area remaining in the respective category in the reporting year is recorded (cf. the description of conversion time of 20 years in chp. 6.1.3.3). In contrast, the change matrices present the land-use changes occurring in the specified year only.

Table 6-9 Annual land-use changes in 1990 and in 2020 (change matrices). Units: ha/year, rounded values. Empty cells indicate that no change occurred.

| 1990 | change to CC | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| change from CC | 11 | 12 | 13 | 21 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 41 | 42 | 51 | 52 | 53 | 54 | 61 | decrease |
| 11 | | 369 | 1 | 0 | 0 | 1 | | 0 | | | | | | 0 | 0 | 0 | | 0 | 372 |
| 12 | | | 158 | 5 | 125 | 86 | 6 | 59 | | 12 | 19 | 11 | 7 | 117 | 27 | 11 | 17 | 49 | 709 |
| 13 | | 678 | | 8 | 354 | 48 | 5 | 89 | 0 | 3 | 3 | 1 | 3 | 41 | 20 | 3 | 15 | 10 | 1280 |
| 21 | 8 | 1 | 5 | | 663 | 6 | 181 | 35 | 1 | 4 | 4 | 4 | 4 | 632 | 317 | 21 | 18 | 22 | 1926 |
| 31 | 136 | 166 | 480 | 717 | | 1007 | 123 | 311 | 4 | 46 | 43 | 9 | 11 | 870 | 490 | 27 | 44 | 67 | 4554 |
| 32 | 24 | 1022 | 715 | 2 | 126 | | 9 | 309 | | 14 | 15 | 6 | 0 | 24 | 8 | 5 | 3 | 30 | 2313 |
| 33 | 1 | 2 | 4 | 126 | 65 | 4 | | 28 | 2 | 0 | 1 | 0 | | 50 | 26 | 4 | 3 | 5 | 323 |
| 34 | 20 | 536 | 63 | 143 | 866 | 49 | 35 | | 11 | 9 | 23 | 4 | 3 | 171 | 94 | 6 | 41 | 14 | 2087 |
| 35 | | 0 | 0 | 8 | 13 | 0 | 4 | 46 | | | | | | 4 | 2 | 0 | 1 | 0 | 80 |
| 36 | 3 | 27 | 26 | 2 | 162 | 243 | 1 | 41 | | | 89 | 4 | 0 | 8 | 1 | 0 | | 45 | 652 |
| 37 | 7 | 26 | 6 | 1 | 8 | 234 | 1 | 68 | | 10 | | 3 | 0 | 6 | 2 | | 0 | 13 | 384 |
| 41 | 0 | 4 | 1 | 2 | 2 | 6 | 0 | 4 | | 4 | 1 | | 17 | 11 | 2 | 1 | 0 | 99 | 156 |
| 42 | 5 | 27 | 6 | 1 | 3 | 2 | 0 | 2 | | 0 | 0 | 6 | | 4 | 1 | 0 | 0 | 1 | 59 |
| 51 | 38 | 18 | 4 | 86 | 158 | 11 | 5 | 7 | | 3 | 5 | 6 | 4 | | 271 | 58 | 46 | 5 | 726 |
| 52 | 7 | 4 | 1 | 16 | 32 | 3 | 1 | 1 | | 0 | 1 | 1 | 2 | 349 | | 68 | 387 | 0 | 874 |
| 53 | 5 | 9 | 0 | 6 | 7 | 2 | 0 | 2 | | | | 0 | 2 | 45 | 28 | | 46 | 0 | 150 |
| 54 | 2 | 6 | 0 | 1 | 2 | 0 | 0 | 3 | | | 0 | 0 | 1 | 78 | 152 | 8 | | 0 | 253 |
| 61 | 4 | 41 | 17 | 16 | 67 | 93 | 8 | 31 | | 287 | 33 | 96 | 2 | 13 | 1 | 0 | 1 | | 709 |
| increase | 261 | 2936 | 1489 | 1140 | 2653 | 1794 | 381 | 1036 | 18 | 394 | 236 | 152 | 55 | 2425 | 1443 | 211 | 621 | 361 | 17607 |

| 2020 | change to CC | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| change from CC | 11 | 12 | 13 | 21 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 41 | 42 | 51 | 52 | 53 | 54 | 61 | decrease |
| 11 | | 43 | 0 | | | 0 | | | | | | | | 0 | | 0 | | | 43 |
| 12 | | | 427 | 1 | 294 | 130 | 4 | 105 | 6 | 38 | 17 | 24 | 21 | 95 | 29 | 10 | 16 | 72 | 1290 |
| 13 | | 1225 | | 2 | 418 | 184 | 2 | 109 | 0 | 14 | 4 | 1 | 3 | 25 | 15 | 2 | 13 | 22 | 2040 |
| 21 | 1 | 1 | 3 | | 2553 | 6 | 163 | 46 | 9 | 4 | 7 | 4 | 7 | 462 | 190 | 8 | 5 | 14 | 3482 |
| 31 | 7 | 175 | 606 | 1747 | | 1514 | 89 | 464 | 13 | 138 | 77 | 12 | 23 | 809 | 428 | 17 | 20 | 83 | 6223 |
| 32 | 1 | 912 | 762 | 1 | 227 | | 2 | 686 | | 37 | 21 | 8 | 1 | 10 | 3 | 2 | 1 | 45 | 2720 |
| 33 | | 6 | 2 | 103 | 93 | 5 | | 35 | 4 | 0 | 1 | 0 | 0 | 36 | 27 | 2 | 2 | 2 | 318 |
| 34 | 1 | 776 | 89 | 32 | 533 | 54 | 8 | | 27 | 12 | 25 | 8 | 1 | 76 | 50 | 2 | 30 | 18 | 1741 |
| 35 | | 0 | | 1 | 11 | | 1 | 17 | | | | | | 1 | | | | | 31 |
| 36 | | 51 | 40 | 1 | 226 | 453 | 0 | 102 | | | 138 | 7 | 1 | 7 | 1 | | | 92 | 1121 |
| 37 | 0 | 29 | 4 | | 20 | 370 | | 82 | | 56 | | 6 | 1 | 4 | 1 | | | 18 | 589 |
| 41 | 0 | 6 | 1 | 0 | 2 | 10 | | 4 | | 7 | 6 | | 16 | 5 | 1 | 0 | 0 | 142 | 202 |
| 42 | 0 | 40 | 8 | 1 | 2 | 1 | | 3 | | 1 | 0 | 9 | | 2 | 2 | 0 | 1 | 1 | 72 |
| 51 | 15 | 19 | 2 | 60 | 151 | 9 | 1 | 5 | | 8 | 8 | 7 | 3 | | 382 | 54 | 47 | 11 | 781 |
| 52 | 8 | 7 | 1 | 15 | 59 | 3 | 1 | 3 | | 2 | 3 | 1 | 1 | 586 | | 76 | 672 | 1 | 1439 |
| 53 | 2 | 21 | 1 | 3 | 7 | 4 | | 1 | | 0 | 1 | 0 | 0 | 52 | 48 | | 65 | | 205 |
| 54 | 1 | 12 | 2 | 0 | 3 | 1 | | 5 | | 0 | 0 | 1 | 0 | 150 | 313 | 28 | | 0 | 515 |
| 61 | 0 | 57 | 27 | 9 | 79 | 129 | 6 | 76 | | 1189 | 26 | 139 | 2 | 6 | 0 | 0 | | | 1745 |
| increase | 37 | 3377 | 1975 | 1978 | 4678 | 2873 | 278 | 1742 | 59 | 1505 | 334 | 228 | 82 | 2327 | 1488 | 200 | 872 | 523 | 24557 |

# 6.3. Approaches used for representing land areas, land-use databases

## 6.3.1. Swiss Land Use Statistics (AREA)

Data of the Swiss Land Use Statistics (AREA) processed by the Swiss Federal Statistical Office (SFSO 2021) form the basis of activity data. In the course of an AREA survey, every hectare of Switzerland's territory (4'129'073 ha) is assigned to one of 46 land-use categories and to one of 27 land-cover categories by means of stereographic interpretation of aerial photos (SFSO 2006a).

For the reconstruction of the land use conditions in Switzerland during the inventory period data from four surveys were available:

- Land Use Statistics “1979/85” (AREA1), status: completed
- Land Use Statistics “1992/97” (AREA2), status: completed
- Land Use Statistics “2004/09” (AREA3), status: completed
- Land Use Statistics "2013/18" (AREA4), status: completed (in 2021, cf. https://www.bfs.admin.ch/bfs/en/home.gnpdetail.2021-0316.html).

The aerial photos for AREA1, AREA2, AREA3 and AREA4 were taken 1979–1985, 1990–1998, 2004–2009 and 2012–2019, respectively. In the course of AREA3 all photos (including those from AREA1 and AREA2) were simultaneously (re-) interpreted according to the newly designed AREA set of land-use and land-cover categories based on the nomenclature 'NOAS04' (SFSO 2006a).

The federal geoportal geo.admin.ch provides digital access to the maps, aerial photographs and geographic information of the federal administration covering the entire territory of Switzerland. The map viewer https://map.geo.admin.ch allows a visualization of the completed AREA surveys. See the example https://s.geo.admin.ch/96e44254c8 for the change in direct neighbourhood of a FOEN building in Bern-Ittigen. Legend: yellow crosses represent sample points; circles represent land cover, triangles (they appear when clicking on “Land use statistics standard”) represent land use statistics based on the SFSO standard nomenclature; both data sets are retrievable for all four AREA surveys. (At the time of going to press, the incorporation of the results for land use had not yet been completed). Click circles and triangles for object information. To get a clue on the situation prior to the construction of the FOEN building check the box “Journey through time – Maps” (preset 1986, but year is freely selectable) and look out for the former course of the stream nowadays bound to the south of the rail tracks. Please note: The background aerial photograph is of recent age. Examples of characteristic landscape changes in Switzerland across the four survey phases can be found under "Documentation of landscape change".

The inter-survey period is not identical throughout the Swiss territory, but varies regionally (see flyover periods shown above). It averages approximately 12 years for AREA1, AREA2 and AREA3; for AREA4 it was shortened to approximately 9 years. This methodic characteristic needs to be considered when reconstructing the annual country-wide status of land use or when calculating annual rates of land-use change.

### 6.3.2. Interpolation of the status for each year

The exact dates of aerial photo shootings are known for each hectare. However, the exact occurrence date (year) of a land-use change on a specific hectare is unknown. The actual change can have taken place in any year between two AREA surveys. In this study, it was assumed that the probability of a land-use change from AREA1 to AREA2, from AREA2 to AREA3 and from AREA3 to AREA4 is uniformly distributed over the respective interim period between two surveys. Therefore, the land-use change of each hectare has to be equally distributed over its specific interim period.

Thus, the land-use status for the years between two data collection dates can be calculated by linear interpolation. Dates of aerial photo shootings (i.e. starting and ending year of the inter-survey period) and the land-use categories of AREA1, AREA2, AREA3 and AREA4 for every hectare were used for these calculations. An example is shown in Figure 6-5: A hectare had been assigned to the land-use category Cropland in AREA1 (aerial photo in 1980). A land-use change to 'Surrounding of Buildings' was discovered 10 years later (1990) in AREA2.

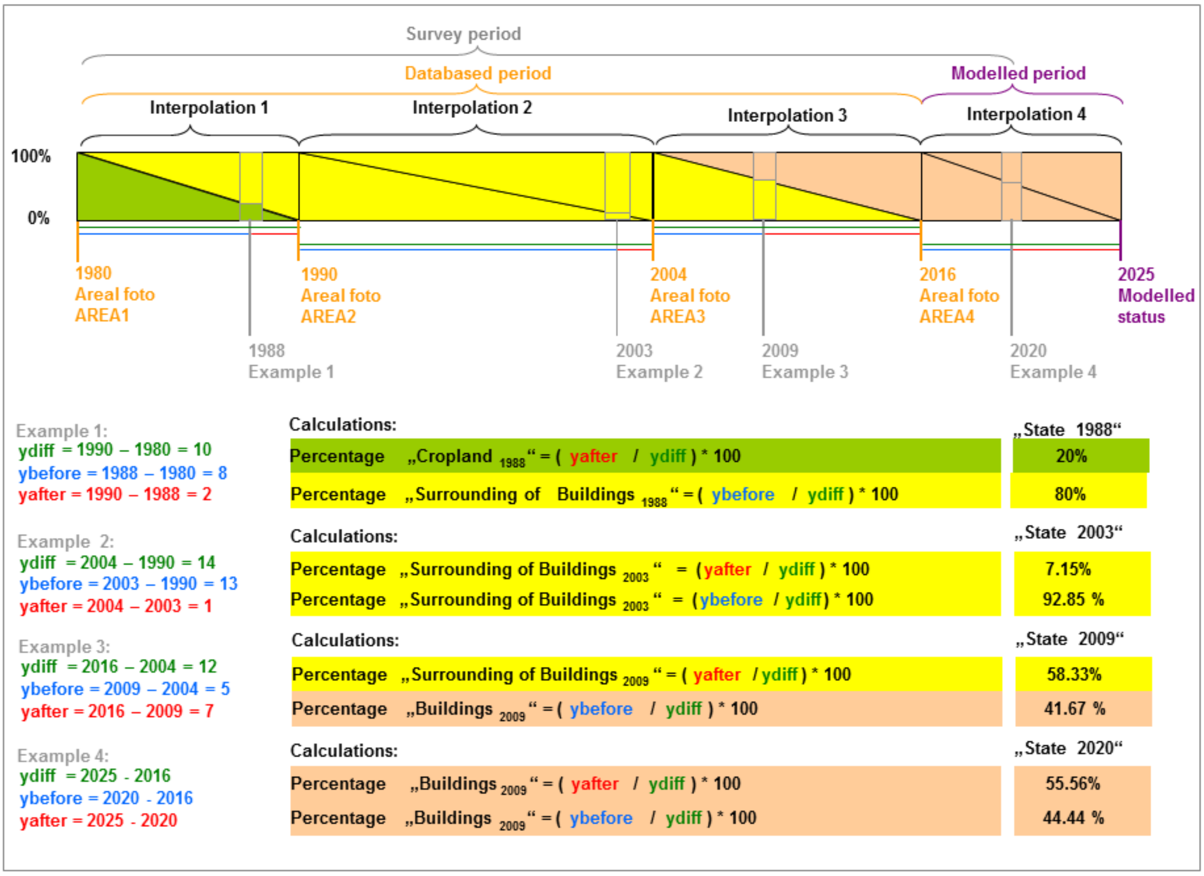



Figure 6-5 Hypothetical development of land use for a supposed survey period 1980–2020. The linear land-use changes between AREA1, AREA2, AREA3 and AREA4 considering as example a hectare changing from “Cropland” to “Surrounding of Buildings” and later from "Surrounding of Buildings" to "Buildings". For 2020, a linear interpolation has been carried out between AREA4 and a virtual fifth survey (AREA5v) that was modelled for the year 2025 (here resulting in no change of land use).

The “state 1988” of that hectare is determined by calculating the fractions of the two land-use categories for the year 1988. A linear development from “Cropland” to “Surrounding of Buildings” during the whole interim period was assumed. Thus, in 1988 the hectare was split up in two fractions: 80% is “Surrounding of Buildings” and 20% is “Cropland”. The same procedure can be applied for two survey dates between AREA2 and AREA3 (here exemplarily shown for the period 1990–2004, highlighting “state 2003”) or between AREA3 and AREA4 (here exemplarily shown for the period 2004–2016, highlighting “state 2009”).

To obtain consistent and complete nationwide data for each year, the land-use states after the flight year of AREA4 were interpolated between AREA4 and a "virtual" 5$^{th}$ survey (AREA5v). AREA5v was modelled for each sample point using a Markov-chain approach, where transition probabilities between AREA4 and AREA5v were assessed based on the transition distribution between AREA3 and AREA4 within each spatial stratum (Sigmaplan 2022). Therefore, the land-use changes occurring after the flight year of AREA4 were calculated from the linear development detected between AREA4 and the virtual 5$^{th}$ survey AREA5v for this type of hectare (regarding CC and spatial strata) (see Figure 6-5: example “state 2020”).

The wall-to-wall land-use status within Switzerland for each individual year in the inventory period results from the summation of the fractions of all hectares per combination category CC, additionally considering the spatial strata where appropriate.

### 6.3.3. Uncertainties and time-series consistency of activity data

An overview of uncertainty estimates of activity data (AD), carbon stock change factors, and emission factors is shown in Table 6-5. Details related to uncertainties of AREA data are presented in this chapter, while the remaining uncertainties of other activity data (such as consumption of Harvested wood products) and of carbon stock change factors and emission factors are presented in the respective LULUCF chapters (6.X.3).

In most cases, the uncertainty of AD for categories 4A–4F depends on the quality of the AREA survey data. For categories with relevant emissions from drained organic soils, also the uncertainty of the spatial allocation of organic soils (see chp. 6.2.2.1 and below) was considered.

The uncertainty of AREA-based activity data has two main sources (Table 6-10). They were quantified on the basis of the AREA data (SFSO 2021) as follows:

1) Interpretation error: In the AREA survey, the first classification of the aerial photos is checked by a second independent interpreter. The portion of sampling points with a mismatch of the first and the second interpretation was used as the uncertainty of the interpretation. This uncertainty of interpretation integrates all errors related to the manual interpretation of land-use and land-cover classes on aerial photographs. While it is clear that this is rather an estimate of the maximum potential interpretation error than of the actual interpretation error, it is reported hereafter unless better information is available.

2) Statistical sampling error: In the AREA survey, the land-use types are interpreted on points situated on a regular 100x100 m grid. Thus, the uncertainty of the measured surface area covered by a certain land-use type or land-use change decreases with increasing

numbers of sampling points that are used for the measurement. Assuming a binomial distribution of the errors, this uncertainty was calculated as

$U_{sampling} = 100 * 1.96 * (\text{number of points})^{-0.5}$

The number of sampling points lies between 2'787 (for 4D2) and 1'334'376 (for 4C1) leading to values of $U_{sampling}$ between 3.7% and 0.2%.

The overall uncertainty was calculated as:

$U_{overall} = (U_{interpret}^2 + U_{sampling}^2)^{0.5}$

Table 6-10 Sources of AD uncertainty and overall uncertainties in the allocation of land-use categories, expressed as half of the 95% confidence intervals. Calculations are based only on AREA data from SFSO (2021); uncertainties with respect to other data sources (organic soils, wildfires) are not included, see main text.

| Category | Description | Interpretation uncertainty | Sampling uncertainty | Overall uncertainty |
|---|---|---|---|---|
| 4A1 | Forest land remaining forest land | 1.1 | 0.2 | 1.1 |
| 4A2 | Land converted to forest land | 1.1 | 1.1 | 1.5 |
| 4B1 | Cropland remaining cropland | 4.9 | 0.3 | 4.9 |
| 4B2 | Land converted to cropland | 4.9 | 1.5 | 5.1 |
| 4C1 | Grassland remaining grassland | 5.2 | 0.2 | 5.2 |
| 4C2 | Land converted to grassland | 5.2 | 0.8 | 5.3 |
| 4D1 | Wetlands remaining wetlands | 0.9 | 0.5 | 1.0 |
| 4D2 | Land converted to wetlands | 0.9 | 3.7 | 3.8 |
| 4E1 | Settlements remaining settlements | 4.4 | 0.4 | 4.4 |
| 4E2 | Land converted to settlements | 4.4 | 1.3 | 4.6 |
| 4F1 | Other land remaining other land | 1.4 | 0.3 | 1.4 |
| 4F2 | Land converted to other land | 1.4 | 2.8 | 3.2 |

An update of the uncertainty analysis of the spatial allocation of organic soils published by Wüst-Galley et al. (2015) (Wüst-Galley 2019) resulted in 35.3% for Forest land, 37.3% for Cropland, 68.6% for Grassland and 90.8% for Wetlands. For Forest land (chp. 6.4.3) and Settlements (chp. 6.8.3) $CO_2$ emissions from organic soils were not considered in the calculation of the overall uncertainty (Meteotest 2022).

Activity data for wildfires were taken from the Swissfire database (see chp. 6.4.2.11 and chp. 6.6.2.4). The uncertainty for areas affected by wildfires was estimated between 10% (NFI production region 5) and 30% (other NFI production regions) for Forest land by expert judgment (Pezzatti 2017). For Grassland the mean uncertainty is probably higher than for Forest land. As a consequence, a value of 30% was agreed on for both land uses.

Consistency: Time series for activity data are all considered consistent; they were calculated based on consistent methods for interpolation and extrapolation and homogenous databases.

## 6.3.4. QA/QC and verification of activity data

The general QA/QC measures are described in chp. 1.2.3.

### 6.3.4.1. QA/QC measures

The AREA survey is a well-defined and controlled, long-term process in the responsibility of the Swiss Federal Statistical Office (SFSO 2006a). The data supplied by SFSO (2021) were checked for consistency (Sigmaplan 2022).

The temporal interpolation and extrapolation of the AREA sample is quite a complex procedure, whose internal consistency was checked systematically as described in Sigmaplan (2022). Further checks (interannual comparisons, plausibility) were carried out after producing the land-use change tables presented in chp. 6.2.3.

### 6.3.4.2. Country area

The total country area remains constant over the inventory period.

### 6.3.4.3. Completion of AREA4 survey and impact on activity data

The inclusion of newly available data from the AREA4 survey led to recalculations of areas for all land-use combination categories for either the entire period 1990–2019 or later time periods thereof (as the more recent years are generally most affected by the changes). With the latest submission AREA4 data completely replaced the virtual (extrapolated) 4$^{th}$ survey (AREA4v, see FOEN 2021: chp. 6.3.2), thus improving the overall quality of the activity data.

The last tranche of AREA4 data covered the easternmost part of the canton of Glarus, the southern part of the canton of St. Gallen and essentially a large part of the canton of the Grisons (cf. Sigmaplan 2021: Figure 1). It is a mountainous and, with the exception of the Rhine valley, sparsely populated region; there are few larger settlements. The recalculation (see chp. 6.3.5) caused deviations in the areas allocated to all CC for the period 1990–2019 between the latest and the previous submissions (Meteotest 2022: lulucf_area_1990_ 2020.xlsx). In accordance with the findings from recalculations of activity data in previous years, there are increases in the areas of copse (CC34), orchard (CC35), stony grassland (CC36) and trees in settlements (CC54) as well as the reduction in area of Other Land (CC61). The latest recalculation thus confirms these nationwide trends. In contrast, sealing (land-use change to CC51) in the sparsely populated region is significantly below domestic average. Also contrary to the nationwide trend of previous recalculations, there are a below-expected (AREA4v) forest area since 2014, a general below-average scrub encroachment on grasslands (CC32) and a higher-than-expected (AREA4v) proportion of unproductive grassland (CC37) in the last five years. Very striking is an adjustment between the Cropland

(CC21) area, which is clearly below and the Grassland (CC31) area, which is clearly above the AREA4v prediction. This type of area exchange can be interpreted as a regional feature of the of the eastern Swiss mountain zone where cropping is less common.

#### 6.3.4.4. Area comparison

A systematic cross-check between the activity data reported under LULUCF category 4A Forest land and under the Kyoto Protocol activity Forest management was carried out (see chp. 11.3.2.2).

### 6.3.5. Recalculations of activity data

The whole time series 1990–2019 was updated as a result of the following activities:

- 4: Land use areas: The most recent land-use data from the now completed fourth area survey (AREA4) were included (SFSO 2021). They are based on aerial photographs from 2015, 2016 and predominantly 2019. The interpolation and projection procedures were adapted accordingly (see chp. 6.3.2 and Sigmaplan 2022).
- 4: Land use areas: Along with the AREA4 survey the SFSO continuously performed consistency checks and, where appropriate, corrections in the data of AREA3 (2004–2009). Due to temporal interpolation (see chp. 6.3.2) the years 1990–2003 were affected.
- 4: Land use areas: The total area of the country recorded by the AREA survey increased by 67 ha to 4'129'073 ha (SFSO 2021). This modification is due to the inclusion of the most recent land survey data elaborated at the Federal Office of Topography (changes caused e.g. by glacial melting), defining the country's frontiers.

### 6.3.6. Planned improvements for activity data

Switzerland’s activity data for land areas are currently based on the surveys AREA1 to AREA4. Interpretation and processing of AREA4 were completed in 2021. The fifth survey (AREA5) will be included in future submissions. It will be based on aerial photographs from 2020 to 2025, reducing the interval between successive surveys in the future to six years.

An update of the study “Locating organic soils for the Swiss Greenhouse Gas Inventory” by Wüst-Galley et al. (2015), incorporating any newly available or updated data sources, is planned for the next two years.

The FOEN is currently evaluating the suitability of newly available satellite data (e.g. Sentinel 2) in the field of environmental reporting. Several feasibility studies were commissioned. Depending on the results (and on the future availability of EU satellite data in Switzerland) it is intended to refine the spatio-temporal pattern of land use dynamics in Switzerland provided by the Land Use Statistics AREA by the use of satellite data in the medium term. In the course of this evaluation the design of the land-use categories used in the GHG inventory (i.e. the combination categories CC) will be scrutinised. The establishment of a geo-referenced LULUCF reporting system is being pursued.

# 6.4. Category 4A – Forest land

## 6.4.1. Description

Table 6-11 Key categories in category 4A. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 4A1 | Forest Land Remaining Forest Land | CO2 | L1, T1, L2, T2 |
| 4A2 | Land Converted to Forest Land | CO2 | L1, L2 |

Only temperate forests occur in Switzerland. Forest is defined as a minimum area of land of 0.0625 ha with crown cover of at least 20% and a minimum width of 25 m. The minimum height of the dominant trees must be 3 m or have the potential to reach 3 m at maturity in situ (FOEN 2006h). The following forest areas are not subject to the criteria of minimum stand height and minimum crown cover, but must have the potential to achieve it: afforested, regenerated, as well as burnt, cut or damaged areas. Although orchards, parks, camping grounds, open tree formations in settlements, gardens, cemeteries, sports and parking fields may fulfil the (quantitative) forest definition, they were not considered as forests (FOEN 2006h).

According to the Federal Act on Forest, it is one objective to "conserve the forest in its area and spatial distribution" (Swiss Confederation 1991: Art. 1a). Any change of the forest area has to be authorized. Therefore, all forests in Switzerland are considered to be under management.

For reporting purposes, the different forest types were allocated to afforestations (CC11), productive forest (CC12) and unproductive forest (CC13) based on AREA categories (see Table 6-2 and Table 6-6; SFSO 2006a; Didion and Thürig 2013).

Note for afforested areas: The diction *afforestation* is consistently used for reporting under the UNFCCC, and the diction *Afforestation* (with uppercase letter) for reporting the activity under the Kyoto Protocol (see chp. 6.1.3.1 and chp. 11.1.3).

A detailed description of the category unproductive forest CC13 can be found in chp. 6.4.2.7.

In the period 1990–2020, the total net emissions and removals of category 4A1 Forest land remaining forest land varied between 4'971 kt $CO_2$ in 2000 and -5'764 kt $CO_2$ in 1996 (average -2'583 kt $CO_2$). Fluctuations are mainly due carbon losses from the pools living biomass, dead wood and litter. The exceptionally high net emissions in 2000 and the small net removals in the following year 2001 originate from winter storm "Lothar" at the end of 1999, which caused large-scale damages in forest stands and increased losses of living biomass due to salvage logging.

Category 4A2 Land converted to forest land was a net sink in all years 1990–2020 (average -588 kt $CO_2$) with relatively small fluctuations mainly due to slight variations in land use change rates over the inventory period and the associated living biomasses on these areas.

## 6.4.2. Methodological issues

### 6.4.2.1. Choice of method and National Forest Inventories

The Swiss National Forest Inventory (NFI) is the primary source for estimating carbon stock change factors for forest land. Growing stock, cut and mortality are estimated based on tally trees with a diameter at breast height (DBH) ≥12 cm. For tally trees allometric relationships were developed to obtain accurate data on whole tree volume and biomass (Lanz et al. 2019). These data are further used to estimate the annual production of dead wood and litter that drive carbon stocks and carbon stock changes in the dead organic matter and soil carbon pools calculated with Yasso07.

For all carbon pools, the calculation approach and the applied conversion time periods for different land-use changes within, from and to Forest land are shown in Table 6-3. FOEN (2022c) contains a schematic overview and Didion et al. (2019: Fig. 14.1) a detailed description of all tree biomass elements which are included in the estimation of reported carbon stocks and carbon stock changes in above- and belowground biomass. The tree elements comprise stemwood including tree top and stump, large and small branches, foliage, and coarse roots. For estimating the carbon stock changes in litter, dead wood and in mineral soil also fine roots and seeds are considered (Didion and Zell 2019).

Data from four completed Swiss National Forest Inventories (NFI1, NFI2, NFI3, NFI4) and from the the first two years of the ongoing NFI5; Table 6-12) are currently available. Descriptions of NFI1, NFI2, and NFI3 results can be found in EAFV/BFL (1988), in Brassel and Brändli (1999), and in Brändli (2010), respectively. These inventories were based on full surveys that were repeated in intervals of approximately 10 years. Starting with the NFI4 (Brändli et al. 2020) a continuous survey approach is used where annually a nationally representative subsample of approximately 12% of the Swiss forests is surveyed and evaluated. Otherwise, the methodology remained consistent with previous inventories. The NFI5 has started in 2018. A detailed description of the current methods to estimate volume, biomass, and carbon for the GHG inventory can be found in Herold et al. (2019) and Didion et al. (2019).

Table 6-12 Characteristics of the National Forest Inventories NFI1, NFI2, NFI3, NFI4 and NFI5 (2018–2019), accessible forest plots without brush forest.

| | NFI1 | NFI2 | NFI3 | NFI4 | NFI5 |
|---|---|---|---|---|---|
| Inventory cycle | 1983-1985 | 1993-1995 | 2004-2006 | 2009-2017 | 2018-2019 |
| Grid size | 1 x 1 km | 1.4 x 1.4 km | 1.4 x 1.4 km | 1.4 x 1.4 km | 1.4 x 1.4 km |
| Terrestrial sample plots | 10'981 | 5'679 | 5'920 | 6'042 | 1'358 |
| Tally trees | 128'441 | 67'297 | 69'960 | 71'906 | 16'343 |

Data for growing stock (carbon stock of total living biomass) were estimated for a particular inventory. Gross growth (gain in carbon stock of living biomass), cut and mortality (loss in carbon stock of living biomass; Didion et al. 2020: chp. 2.3), and dead wood and litter production (Didion 2020a: chp. 2.3.2) were based on the observed changes between two consecutive inventories (see chp. 6.4.2.4 and chp. 6.4.2.5). Carbon stock changes between two inventories were obtained based on data from the common plots (Table 6-13). The total number of common plots can differ for inter-survey periods as a result of land-use changes from or to Forest land (Didion et al. 2020: Table 4).

For assembling the results for the latest GHG inventory, NFI5 data for the years 2018–2019 were used in addition to the data from NFI1, NFI2, NFI3 and NFI4, and the respective inventory periods NFI1-2, NFI2-3, and NFI34-5 (2015–2019). Results on growing stock based on data collected in the five years 2015–2017 (NFI4) and 2018–2019 (NFI5) and for growth and cut and mortality based on the inventory period NFI34-5 (2015–2019) were summarised in the data release NFI34-5 (2015–2019; see Table 6-13 and Didion et al. 2020).

Table 6-13 Number of NFI sample plots in each NFI inter-survey period: number of plots which were forest also in the previous NFI inter-survey period and the number of plots newly converted to forest (Didion et al. 2020). Data from the total number of plots is used to calculated carbon stock changes between two inventories. Footnote 1: not applicable in this first NFI period; footnote 2: for the period NFI34-5 only sample plots common to NFI3 and the sample plots in NFI4 visited in the years 2015 to 2017 and common to NFI4 and NFI5 visited in the years 2018 and 2019 were considered.

| NFI period | NFI interservey-period | Forest in previous period | Converted to forest since previous period | Total for period |
|---|---|---|---|---|
| | | Number of sample plots | | |
| NFI1-2 | 1985-1995 | NA[1] | NA[1] | 5456 |
| NFI2-3 | 1996-2005 | 5'370 | 211 | 5581 |
| NFI34-5 (2015-2019)[2] | 2006-2019 | 3'022 | 199 | 3'221 |

**Updating NFI data**

In general, new NFI data have an influence on the time series of carbon stock changes (gains and losses in living biomass, dead wood, litter and mineral soil) because they are calculated based on observed changes between two forest inventories.

The change from periodic sampling (NFIs 1 to 3) to a continuous sampling starting with the NFI4 required a modification of the estimation of carbon stock changes affecting estimates from 2005 onwards only. The adapted method requires NFI data from a shifting five-year window to ensure accuracy and consistency of the estimates of carbon stock changes. The method based on a shifting five-year window of NFI data will also be used in future submissions and thus, recalculations will be performed when new NFI data become available (see chp. 1.1 and chp. 2.3 in Didion et al. 2020). The continuous survey approach allows regular updates of data to obtain the most current and accurate estimates for stocks, gains, and losses of living biomass. The differences in the results arising by an update of the five-year period reflect the uncertainty in the data as the sample plots used for the estimation are exchanged, but time series remain consistent as carbon stock change estimates are still based on representative subsamples of the NFI sample plots.

**Data available in the NFI for estimating biomass**

In the field surveys standing and lying stems are measured on two nested circular sample plots with 200 $m^2$ and 500 $m^2$ in area, respectively. On the smaller plot, trees and shrubs with DBH ≥12 cm are measured, whereas all trees with DBH ≥36 cm are measured on the larger plot. In order to assess the regeneration of the forest, young trees and the main shrub species with a minimum height of 10 cm and DBH <12 cm are assessed on a separate set of four circular sample plots with radii between 0.9 and 4 m (Brändli and Hägeli 2019).

For estimating carbon stocks and carbon stock changes in the GHG Inventory, currently, (1) trees with DBH <12 cm with branches, foliage, and roots, and (2) non-tree understory vegetation including shrubs, ferns, grasses, sedges, and herbs are not considered because Switzerland's country-specific allometric functions only apply to trees ≥12 cm DBH.

The omission of trees <12 cm DBH and of non-tree understory vegetation is justified, in response to UNFCCC (2022, ID#L.4), because of their negligible effect on the carbon stock and carbon stock change estimates of living biomass, dead wood, litter, and soil in productive forests in Switzerland:

- Trees with DBH <12 cm contribute only little to total forest biomass and carbon stock (Peichl and Arain 2006). Dunger et al. (2012) estimated this contribution to 1–2% for forests with similar forest structure as common in Switzerland. Their contribution to annual litter production and hence to C stock changes in dead wood, litter, and soil is small compared to mature trees with larger diameters (He et al. 2012).
- Carbon gains in biomass of trees <12 cm are implicitly accounted for in the trees above this threshold as the cumulative carbon uptake. This is a statistically valid and accurate approach, particularly for the gain/loss approach applied by Switzerland ensuring that carbon stock change factors are neither over- nor underestimated.
- Biomass of non-tree understory vegetation presents <1% of the above ground biomass carbon pool in the Swiss NFI (Didion 2020b), and thus has a negligible contribution to annual litter production. Consistent with the inventory guidelines (IPCC 2006, Volume 4, Annex 4A.1), it can therefore be excluded from the inventory.

#### 6.4.2.2. Stratification

**Definition of strata**

Forests in Switzerland reveal a high heterogeneity in terms of elevation, growth conditions, tree species composition, and interannual growth variability. To find explanatory variables that significantly reduce the variance of gross growth, an analysis of variance was done (see Table 2b in Thürig et al. 2005 and Table 3 in Didion et al. 2020). The analysis indicated that tree species type, production, region and elevation all significantly explain differences in gross growth. Therefore, Forest land is classified into the following strata:

- two tree species types: coniferous and broadleaved species
- five NFI production regions (L):
  L1 Jura, L2 Central Plateau, L3 Pre-Alps, L4 Alps, L5 Southern Alps
- three elevation zones (Z):
  Z1 <601 m, Z2 601–1200 m, Z3 >1200 m.

Values for growing stock, gross growth, harvesting and mortality were calculated for each of the resulting 30 strata.

**Aggregation of strata**

The continuous survey approach since the NFI4 and the use of a five-year shifting window to regularly update estimates of carbon stocks, gains, and losses (see chp. 6.4.2.1) result in a reduced number of sample plots that are simultaneously available for estimating the forest carbon balance (Table 6-13; see Table 4 in Didion et al. 2020), and several spatial strata are represented by a low number of plots. Due to the large variability of the forest structure and composition between sample plots a minimum number of sample plots is needed to obtain reliable estimates of means and sampling errors. Smaller strata are thus merged with neighbouring strata and treated as single strata:

- NFI production region 2 Central Plateau 601-1200 m and >1200 m:
  new stratum NFI production region 2 Central Plateau >600 m
- NFI production region 3 Pre-Alps ≤600 m and 601-1200 m:
  new stratum NFI production region 3 Pre-Alps ≤1200 m
- NFI production region 4 Alps ≤600 m and 601-1200 m:
  new stratum NFI production region 4 Alps ≤1200 m

### 6.4.2.3. Carbon content

A mean carbon content of 50% was used to convert the biomass of alive trees to carbon stocks. The carbon content estimate represents an approximation which was based on carbon fractions for coniferous and broadleaved trees in temperate forests provided in Table 4.3 in Volume 4 of IPCC (2006), and on the fact that in Switzerland coniferous trees are more abundant than broadleaved trees (see Brändli et al. 2020: Table 056).

### 6.4.2.4. Productive forests (CC12): carbon stock, carbon gains and losses in living biomass

The estimates of carbon stocks in living biomass (growing stock) were based on measurements of individual tally trees in the second of two consecutive NFIs, considering all measured living trees on the common sample plots. Estimates for carbon gains in living biomass (gross growth) and carbon losses in living biomass (cut and mortality) for productive forests were derived from two consecutive NFIs (see Table 6-13). All values derived from the national forest inventories refer to above- and below ground biomass in mass units (t $ha^{-1}$) per spatial stratum. The estimates used for the latest submission are displayed in the supplement to Didion et al. (2020).

**Carbon stock in biomass – growing stock**

Carbon stock in living biomass was defined as the biomass of all tree elements (stemwood over bark including stump, large (coarse) and small branches, needles/leaves, and roots) of trees with DBH ≥12 cm. It was estimated based on established allometries to tree dimensions and wood densities. Biomass estimates for stemwood over bark including stump and for all branches are derived based on volume models and conversion to biomass. Foliage and coarse root biomass are derived directly from tree DBH. Fine roots are reported under litter (see chp. 6.4.2.5). Except for coarse roots, the biomass functions were empirically derived from a large number of single-tree data from Swiss forest sites. A detailed overview of the applied allometric biomass functions and the corresponding scientific references per tree element is given in Didion et al. (2020: Table 2).

#### Carbon gains in living biomass – gross growth

Carbon gains in living biomass were derived from two consecutive NFIs and were assumed to remain constant within the intersurvey periods (see Table 6-13).

#### Carbon losses in living biomass – cut and mortality

Carbon losses in living biomass were derived from two consecutive NFIs (see Table 6-13). To obtain annual values of cut and mortality (CMy) for each individual NFI intersurvey period, i.e. the years 1985 to 1995, 1996 to 2005 and 2006 to 2020, respectively, the average amount of cut and mortality from NFI was weighted by the percentage of the relative harvesting amounts derived from the forest statistics (Table 6-14; FOEN 2022f and previous editions; Federal Statistical Office: Wood production in Switzerland 1975–2020, https://www.pxweb.bfs.admin.ch). These relative harvesting amounts, used as weighting factors, were calculated for each year per NFI intersurvey period.

Harvesting rates in Swiss forests increased since the start of the statistics until 2007 (Table 6-14). Harvesting rates were exceptionally high in 1990 after the storm Vivian (February 1990) and in 2000 after the storm Lothar (December 1999), which resulted in higher losses of living biomass compared to other years. In 2008 harvesting rates dropped due to the international and domestic economic framework conditions and remained relatively constant thereafter with interannual fluctuation of ca. 2 to 8%.

Table 6-14 Annual harvesting amount in m$^3$ merchantable wood specified for five NFI production region as well as for coniferous and broadleaved tree species (FOEN 2022f and previous editions; https://www.pxweb.bfs.admin.ch).

| Year | 1. Jura | | 2. Central plateau | | 3. Pre-Alps | | 4. Alps | | 5. Southern Alps | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Conif. | Broadl. | Conif. | Broadl. | Conif. | Broadl. | Conif. | Broadl. | Conif. | Broadl. | |
| | [m$^3$] | [m$^3$] | [m$^3$] | [m$^3$] | [m$^3$] | [m$^3$] | [m$^3$] | [m$^3$] | [m$^3$] | [m$^3$] | [m$^3$] |
| 1990 | 687'327 | 358'647 | 1'769'813 | 606'718 | 1'285'639 | 138'126 | 1'301'313 | 70'064 | 21'575 | 22'456 | 6'261'678 |
| 1991 | 476'956 | 354'002 | 1'017'232 | 489'742 | 877'851 | 133'155 | 1'064'650 | 72'229 | 24'356 | 26'736 | 4'536'909 |
| 1992 | 555'523 | 372'249 | 1'199'596 | 571'610 | 735'680 | 128'934 | 736'230 | 70'706 | 47'388 | 28'637 | 4'446'553 |
| 1993 | 550'536 | 373'298 | 1'206'294 | 562'232 | 723'565 | 132'676 | 649'938 | 63'940 | 42'511 | 32'785 | 4'337'775 |
| 1994 | 621'726 | 392'967 | 1'270'296 | 530'906 | 798'449 | 136'103 | 717'840 | 66'896 | 40'986 | 33'746 | 4'609'915 |
| 1995 | 650'572 | 407'119 | 1'388'932 | 570'552 | 774'040 | 154'108 | 590'859 | 56'714 | 51'643 | 33'869 | 4'678'408 |
| 1996 | 520'335 | 381'365 | 1'066'770 | 567'769 | 654'554 | 151'164 | 506'107 | 59'674 | 48'288 | 38'889 | 3'994'915 |
| 1997 | 599'981 | 394'846 | 1'176'333 | 576'415 | 742'830 | 153'719 | 574'152 | 63'650 | 61'043 | 40'189 | 4'383'158 |
| 1998 | 604'703 | 422'216 | 1'330'973 | 627'633 | 836'806 | 164'348 | 657'409 | 108'848 | 50'626 | 41'485 | 4'845'047 |
| 1999 | 602'652 | 398'648 | 1'342'905 | 639'150 | 824'142 | 173'845 | 593'844 | 68'786 | 44'556 | 39'181 | 4'727'709 |
| 2000 | 994'262 | 387'183 | 3'916'680 | 934'372 | 2'241'486 | 213'858 | 436'743 | 57'105 | 21'236 | 35'049 | 9'237'974 |
| 2001 | 443'612 | 338'751 | 2'020'561 | 594'616 | 1'477'489 | 157'710 | 510'730 | 60'152 | 22'237 | 35'722 | 5'661'580 |
| 2002 | 442'519 | 329'480 | 1'406'758 | 493'905 | 1'090'875 | 134'603 | 528'144 | 63'303 | 31'236 | 35'794 | 4'556'617 |
| 2003 | 557'454 | 315'096 | 1'669'605 | 518'273 | 1'195'090 | 142'055 | 588'062 | 62'739 | 37'111 | 35'486 | 5'120'971 |
| 2004 | 655'757 | 305'681 | 1'774'841 | 515'877 | 1'119'243 | 164'745 | 488'722 | 70'090 | 29'995 | 35'571 | 5'160'522 |
| 2005 | 653049 | 359808 | 1810839 | 614845 | 1010979 | 180546 | 514905 | 70603 | 35462 | 33614 | 5'284'650 |
| 2006 | 735'256 | 405'850 | 1'779'973 | 687'428 | 1'116'868 | 229'781 | 569'673 | 84'656 | 43'443 | 48'599 | 5'701'527 |
| 2007 | 793'459 | 425'790 | 1'587'494 | 699'076 | 1'144'370 | 230'284 | 621'234 | 82'414 | 62'799 | 43'638 | 5'690'558 |
| 2008 | 705'815 | 459'994 | 1'281'782 | 727'581 | 1'018'497 | 224'634 | 664'086 | 82'623 | 53'064 | 44'123 | 5'262'199 |
| 2009 | 598'292 | 461'055 | 1'149'202 | 701'188 | 878'565 | 224'490 | 678'212 | 90'001 | 56'375 | 42'316 | 4'879'696 |
| 2010 | 647'176 | 494'739 | 1'090'994 | 722'644 | 992'435 | 248'151 | 720'659 | 99'773 | 60'391 | 52'037 | 5'128'999 |
| 2011 | 617'887 | 513'720 | 1'061'986 | 741'587 | 983'040 | 253'300 | 686'797 | 101'644 | 61'822 | 53'305 | 5'075'088 |
| 2012 | 566'782 | 488'626 | 970'748 | 719'003 | 825'019 | 225'988 | 665'506 | 94'480 | 51'475 | 50'757 | 4'658'384 |
| 2013 | 576'744 | 521'122 | 948'706 | 739'180 | 834'166 | 254'726 | 670'170 | 117'841 | 64'745 | 50'928 | 4'778'328 |
| 2014 | 619'002 | 539'721 | 945'695 | 777'852 | 863'150 | 259'888 | 654'300 | 110'816 | 95'192 | 47'603 | 4'913'219 |
| 2015 | 528'202 | 505'431 | 916'020 | 766'645 | 753'783 | 244'149 | 625'555 | 96'230 | 62'233 | 53'649 | 4'551'897 |
| 2016 | 549'561 | 509'699 | 859'677 | 737'207 | 766'647 | 236'279 | 570'415 | 103'416 | 65'254 | 60'836 | 4'458'991 |
| 2017 | 545'998 | 514'176 | 993'430 | 765'711 | 806'033 | 242'423 | 596'105 | 96'622 | 72'298 | 54'746 | 4'687'542 |
| 2018 | 564'468 | 492'343 | 1'421'416 | 719'879 | 910'871 | 216'813 | 649'759 | 94'766 | 61'417 | 66'470 | 5'198'202 |
| 2019 | 537'886 | 478'869 | 1'181'674 | 630'237 | 787'296 | 214'837 | 530'476 | 94'646 | 92'495 | 65'622 | 4'614'038 |
| 2020 | 604'675 | 457'399 | 1'360'224 | 633'451 | 814'466 | 205'946 | 543'583 | 74'541 | 45'401 | 62'539 | 4'802'225 |

### Carbon stock in living biomass: calculation of time series

In order to develop a consistent time series, annual carbon stocks of living biomass (growing stocks) per species type (stockC$_l$) were calculated per spatial strata (i) for productive forests (CC12) backward or forward starting from the growing stock 2005, determined from common plots from NFI2-3 (Brändli 2010; abbreviations are explained in chp. 6.1.3.2):

$$stockC_{l,i,CC12,iy} = stockC_{l,i,CC12,2005} - \sum_{n=2005}^{iy} [gainC_{l,i,CC12,n}] + \sum_{n=2005}^{iy} [lossC_{l,i,CC12,n}] \text{ for iy < 2005}$$

$$stockC_{l,i,CC12,iy} = stockC_{l,i,CC12,2005} \qquad \text{for iy = 2005}$$

$$stockC_{l,i,CC12,iy} = stockC_{l,i,CC12,2005} + \sum_{n=2006}^{iy} [gainC_{l,i,CC12,n}] - \sum_{n=2006}^{iy} [lossC_{l,i,CC12,n}] \text{ for iy > 2005}$$

where “iy” indicates the inventory year (here: 1985–2020), “n” the years between 2005 and the inventory year iy.

The backward calculation was used for the time period 1985–2004 (iy <2005), where the annual carbon stock in living biomass equals the carbon stock in living biomass 2005 minus the net change based on the carbon gains in living biomass due gross growth ($gainC_{l,i,CC12,iy}$) and the carbon losses in living biomass due to the annual amounts of cut and mortality ($lossC_{l,i,CC12,iy}$).

The forward calculation was used for the time period after 2005 (iy >2005), where the annual growing stock equals the growing stock 2005 plus the net change based on the gains due to the annual gross growth ($gainC_{l,i,CC12,iy}$) and the losses due the annual amounts of cut and mortality ($lossC_{l,i,CC12,iy}$).

Annual gross growth (carbon gains in living biomass), cut and mortality (carbon losses in living biomass) and growing stocks (carbon stocks in living biomass) specified for all spatial strata are displayed in Table 6-15.

Background information on the NFI data delivery as well as a description of all working steps and data required to reproduce the calculation of emission factors for productive forests (CC12) in the period 1990 until the inventory year are summarised in Didion et al. (2020) and FOEN (2022c).

Table 6-15 Carbon stocks in living biomass (stockC$_l$), carbon gains in living biomass (gross growth, gainC$_l$), and carbon losses in living biomass (cut and mortality, lossC$_l$) for productive forest (CC12) stratified for NFI production region (NFI) and elevation zone (Elev.). Highlighted data for 1990 are displayed in Table 6-4.

| NFI | Elev. | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: carbon stock in living biomass (stockCl,i) [t C $ha^{-1}$] | | | | | | | | | |
| 1 | 1 | 128.65 | 130.14 | 131.45 | 132.77 | 133.91 | 134.96 | 134.44 | 133.64 | 132.63 | 131.80 |
| 1 | 2 | 125.27 | 126.64 | 127.81 | 128.99 | 129.98 | 130.87 | 131.58 | 132.08 | 132.48 | 132.96 |
| 1 | 3 | 84.74 | 85.71 | 86.53 | 87.36 | 88.06 | 88.69 | 89.46 | 90.11 | 90.73 | 91.37 |
| 2 | 1 | 134.51 | 135.97 | 136.89 | 137.82 | 138.74 | 139.34 | 140.14 | 140.70 | 140.83 | 140.90 |
| 2 | 2 | 147.20 | 148.86 | 149.99 | 151.13 | 152.23 | 153.02 | 154.09 | 154.91 | 155.30 | 155.63 |
| 2 | 3 | 102.11 | 103.09 | 103.95 | 104.81 | 105.64 | 106.40 | 106.82 | 107.17 | 107.41 | 107.64 |
| 3 | 1 | 135.07 | 136.81 | 138.76 | 140.67 | 142.46 | 144.02 | 146.17 | 148.18 | 149.97 | 151.71 |
| 3 | 2 | 147.49 | 148.86 | 150.59 | 152.32 | 153.87 | 155.38 | 156.92 | 158.20 | 159.16 | 160.12 |
| 3 | 3 | 118.79 | 119.37 | 120.26 | 121.17 | 121.92 | 122.71 | 123.80 | 124.70 | 125.41 | 126.14 |
| 4 | 1 | 92.97 | 93.11 | 93.52 | 94.22 | 94.77 | 95.74 | 97.85 | 99.66 | 100.68 | 102.39 |
| 4 | 2 | 103.37 | 103.65 | 104.48 | 105.50 | 106.38 | 107.54 | 108.53 | 109.44 | 109.85 | 110.69 |
| 4 | 3 | 94.98 | 94.76 | 95.15 | 95.71 | 96.14 | 96.81 | 97.56 | 98.15 | 98.54 | 99.09 |
| 5 | 1 | 72.68 | 74.33 | 75.88 | 77.27 | 78.63 | 79.97 | 80.57 | 81.13 | 81.63 | 82.23 |
| 5 | 2 | 76.85 | 78.33 | 79.69 | 80.96 | 82.22 | 83.44 | 84.94 | 86.40 | 87.86 | 89.37 |
| 5 | 3 | 76.43 | 77.69 | 78.73 | 79.79 | 80.87 | 81.85 | 83.06 | 84.13 | 85.31 | 86.56 |

| NFI | Elev. | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: carbon stock in living biomass (stockCl,i) [t C $ha^{-1}$] | | | | | | | | | |
| 1 | 1 | 130.14 | 130.09 | 130.12 | 129.97 | 129.67 | 128.99 | 129.58 | 129.98 | 130.47 | 131.18 |
| 1 | 2 | 132.57 | 133.59 | 134.64 | 135.47 | 136.09 | 136.57 | 136.90 | 137.04 | 137.30 | 137.84 |
| 1 | 3 | 91.47 | 92.38 | 93.30 | 94.06 | 94.70 | 95.30 | 95.04 | 94.60 | 94.39 | 94.47 |
| 2 | 1 | 135.39 | 134.39 | 134.81 | 134.68 | 134.37 | 133.68 | 132.14 | 130.97 | 130.35 | 130.09 |
| 2 | 2 | 150.00 | 149.04 | 149.58 | 149.52 | 149.25 | 148.67 | 146.45 | 145.61 | 145.35 | 145.47 |
| 2 | 3 | 106.15 | 105.96 | 106.20 | 106.26 | 106.25 | 106.19 | 146.45 | 145.61 | 145.35 | 145.47 |
| 3 | 1 | 151.23 | 152.21 | 153.91 | 155.40 | 156.81 | 158.25 | 156.56 | 155.99 | 155.83 | 156.08 |
| 3 | 2 | 156.83 | 156.00 | 156.38 | 156.43 | 156.59 | 156.97 | 156.56 | 155.99 | 155.83 | 156.08 |
| 3 | 3 | 123.92 | 123.30 | 123.49 | 123.46 | 123.58 | 123.92 | 124.21 | 124.44 | 124.89 | 125.58 |
| 4 | 1 | 104.45 | 106.39 | 108.26 | 110.07 | 111.88 | 113.65 | 117.52 | 118.28 | 118.97 | 119.56 |
| 4 | 2 | 111.91 | 112.98 | 113.98 | 114.88 | 115.91 | 116.88 | 117.52 | 118.28 | 118.97 | 119.56 |
| 4 | 3 | 99.99 | 100.73 | 101.42 | 101.99 | 102.77 | 103.49 | 104.61 | 105.65 | 106.62 | 107.55 |
| 5 | 1 | 82.98 | 83.71 | 84.43 | 85.17 | 85.90 | 86.70 | 87.96 | 89.37 | 90.77 | 92.22 |
| 5 | 2 | 90.98 | 92.58 | 94.16 | 95.74 | 97.33 | 98.93 | 100.03 | 101.11 | 102.22 | 103.34 |
| 5 | 3 | 88.06 | 89.54 | 90.93 | 92.26 | 93.67 | 95.02 | 96.45 | 97.70 | 99.05 | 100.37 |

| NFI | Elev. | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: carbon stock in living biomass (stockCl,i) [t C $ha^{-1}$] | | | | | | | | | |
| 1 | 1 | 131.69 | 132.21 | 132.91 | 133.50 | 133.94 | 134.67 | 135.35 | 136.02 | 136.71 | 137.50 |
| 1 | 2 | 138.16 | 138.51 | 139.05 | 139.48 | 139.76 | 140.36 | 140.89 | 141.41 | 141.95 | 142.59 |
| 1 | 3 | 94.40 | 94.39 | 94.54 | 94.64 | 94.62 | 94.86 | 95.05 | 95.24 | 95.40 | 95.63 |
| 2 | 1 | 129.89 | 129.68 | 129.74 | 129.78 | 129.71 | 129.74 | 129.98 | 129.84 | 128.96 | 128.85 |
| 2 | 2 | 145.64 | 145.81 | 146.26 | 146.69 | 147.00 | 147.41 | 148.04 | 148.28 | 147.74 | 148.02 |
| 2 | 3 | 145.64 | 145.81 | 146.26 | 146.69 | 147.00 | 147.41 | 148.04 | 148.28 | 147.74 | 148.02 |
| 3 | 1 | 155.88 | 155.68 | 156.09 | 156.33 | 156.46 | 156.99 | 157.53 | 157.91 | 158.11 | 158.69 |
| 3 | 2 | 155.88 | 155.68 | 156.09 | 156.33 | 156.46 | 156.99 | 157.53 | 157.91 | 158.11 | 158.69 |
| 3 | 3 | 126.07 | 126.57 | 127.35 | 128.11 | 128.81 | 129.71 | 130.59 | 131.39 | 132.03 | 132.89 |
| 4 | 1 | 120.00 | 120.48 | 121.06 | 121.42 | 121.88 | 122.52 | 123.19 | 123.88 | 124.48 | 125.31 |
| 4 | 2 | 120.00 | 120.48 | 121.06 | 121.42 | 121.88 | 122.52 | 123.19 | 123.88 | 124.48 | 125.31 |
| 4 | 3 | 108.42 | 109.33 | 110.28 | 111.21 | 112.17 | 113.19 | 114.29 | 115.36 | 116.34 | 117.51 |
| 5 | 1 | 93.38 | 94.50 | 95.70 | 96.89 | 98.18 | 99.29 | 100.18 | 101.26 | 101.98 | 102.73 |
| 5 | 2 | 104.32 | 105.28 | 106.32 | 107.29 | 108.17 | 109.12 | 109.97 | 110.86 | 111.65 | 112.31 |
| 5 | 3 | 101.63 | 102.86 | 104.21 | 105.42 | 106.35 | 107.58 | 108.76 | 109.89 | 111.10 | 112.00 |

| NFI | Elev. | 2020 |
|---|---|---|
| | | CC12: carbon stock in living biomass (stockCl,i) [t C $ha^{-1}$] |
| 1 | 1 | 138.21 |
| 1 | 2 | 143.12 |
| 1 | 3 | 95.70 |
| 2 | 1 | 128.35 |
| 2 | 2 | 147.89 |
| 2 | 3 | 147.89 |
| 3 | 1 | 159.23 |
| 3 | 2 | 159.23 |
| 3 | 3 | 133.69 |
| 4 | 1 | 126.28 |
| 4 | 2 | 126.28 |
| 4 | 3 | 118.68 |
| 5 | 1 | 103.57 |
| 5 | 2 | 113.23 |
| 5 | 3 | 113.37 |

(Table 6-15 continued)

| NFI | Elev. | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: gain in living biomass (gainCl,i) [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| 1 | 1 | 3.60 | 3.60 | 3.60 | 3.60 | 3.60 | 3.60 | 3.37 | 3.37 | 3.37 | 3.37 |
| 1 | 2 | 3.21 | 3.21 | 3.21 | 3.21 | 3.21 | 3.21 | 3.04 | 3.04 | 3.04 | 3.04 |
| 1 | 3 | 1.95 | 1.95 | 1.95 | 1.95 | 1.95 | 1.95 | 1.80 | 1.80 | 1.80 | 1.80 |
| 2 | 1 | 4.63 | 4.63 | 4.63 | 4.63 | 4.63 | 4.63 | 4.54 | 4.54 | 4.54 | 4.54 |
| 2 | 2 | 4.63 | 4.63 | 4.63 | 4.63 | 4.63 | 4.63 | 4.56 | 4.56 | 4.56 | 4.56 |
| 2 | 3 | 1.60 | 1.60 | 1.60 | 1.60 | 1.60 | 1.60 | 1.28 | 1.28 | 1.28 | 1.28 |
| 3 | 1 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.23 | 4.23 | 4.23 | 4.23 |
| 3 | 2 | 4.15 | 4.15 | 4.15 | 4.15 | 4.15 | 4.15 | 4.15 | 4.15 | 4.15 | 4.15 |
| 3 | 3 | 2.48 | 2.48 | 2.48 | 2.48 | 2.48 | 2.48 | 2.50 | 2.50 | 2.50 | 2.50 |
| 4 | 1 | 3.24 | 3.24 | 3.24 | 3.24 | 3.24 | 3.24 | 3.44 | 3.44 | 3.44 | 3.44 |
| 4 | 2 | 2.49 | 2.49 | 2.49 | 2.49 | 2.49 | 2.49 | 2.50 | 2.50 | 2.50 | 2.50 |
| 4 | 3 | 1.81 | 1.81 | 1.81 | 1.81 | 1.81 | 1.81 | 1.90 | 1.90 | 1.90 | 1.90 |
| 5 | 1 | 2.74 | 2.74 | 2.74 | 2.74 | 2.74 | 2.74 | 2.04 | 2.04 | 2.04 | 2.04 |
| 5 | 2 | 2.20 | 2.20 | 2.20 | 2.20 | 2.20 | 2.20 | 2.18 | 2.18 | 2.18 | 2.18 |
| 5 | 3 | 1.61 | 1.61 | 1.61 | 1.61 | 1.61 | 1.61 | 1.79 | 1.79 | 1.79 | 1.79 |

| NFI | Elev. | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: gain in living biomass (gainCl,i) [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| 1 | 1 | 3.37 | 3.37 | 3.37 | 3.37 | 3.37 | 3.37 | 3.31 | 3.31 | 3.31 | 3.31 |
| 1 | 2 | 3.04 | 3.04 | 3.04 | 3.04 | 3.04 | 3.04 | 3.20 | 3.20 | 3.20 | 3.20 |
| 1 | 3 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 2.04 | 2.04 | 2.04 | 2.04 |
| 2 | 1 | 4.54 | 4.54 | 4.54 | 4.54 | 4.54 | 4.54 | 4.29 | 4.29 | 4.29 | 4.29 |
| 2 | 2 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.89 | 4.89 | 4.89 | 4.89 |
| 2 | 3 | 1.28 | 1.28 | 1.28 | 1.28 | 1.28 | 1.28 | 4.89 | 4.89 | 4.89 | 4.89 |
| 3 | 1 | 4.23 | 4.23 | 4.23 | 4.23 | 4.23 | 4.23 | 4.00 | 4.00 | 4.00 | 4.00 |
| 3 | 2 | 4.15 | 4.15 | 4.15 | 4.15 | 4.15 | 4.15 | 4.00 | 4.00 | 4.00 | 4.00 |
| 3 | 3 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.29 | 2.29 | 2.29 | 2.29 |
| 4 | 1 | 3.44 | 3.44 | 3.44 | 3.44 | 3.44 | 3.44 | 2.62 | 2.62 | 2.62 | 2.62 |
| 4 | 2 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.62 | 2.62 | 2.62 | 2.62 |
| 4 | 3 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 2.12 | 2.12 | 2.12 | 2.12 |
| 5 | 1 | 2.04 | 2.04 | 2.04 | 2.04 | 2.04 | 2.04 | 2.73 | 2.73 | 2.73 | 2.73 |
| 5 | 2 | 2.18 | 2.18 | 2.18 | 2.18 | 2.18 | 2.18 | 1.92 | 1.92 | 1.92 | 1.92 |
| 5 | 3 | 1.79 | 1.79 | 1.79 | 1.79 | 1.79 | 1.79 | 1.99 | 1.99 | 1.99 | 1.99 |

| NFI | Elev. | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: gain in living biomass (gainCl,i) [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| 1 | 1 | 3.31 | 3.31 | 3.31 | 3.31 | 3.31 | 3.31 | 3.31 | 3.31 | 3.31 | 3.31 |
| 1 | 2 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 |
| 1 | 3 | 2.04 | 2.04 | 2.04 | 2.04 | 2.04 | 2.04 | 2.04 | 2.04 | 2.04 | 2.04 |
| 2 | 1 | 4.29 | 4.29 | 4.29 | 4.29 | 4.29 | 4.29 | 4.29 | 4.29 | 4.29 | 4.29 |
| 2 | 2 | 4.89 | 4.89 | 4.89 | 4.89 | 4.89 | 4.89 | 4.89 | 4.89 | 4.89 | 4.89 |
| 2 | 3 | 4.89 | 4.89 | 4.89 | 4.89 | 4.89 | 4.89 | 4.89 | 4.89 | 4.89 | 4.89 |
| 3 | 1 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 |
| 3 | 2 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 |
| 3 | 3 | 2.29 | 2.29 | 2.29 | 2.29 | 2.29 | 2.29 | 2.29 | 2.29 | 2.29 | 2.29 |
| 4 | 1 | 2.62 | 2.62 | 2.62 | 2.62 | 2.62 | 2.62 | 2.62 | 2.62 | 2.62 | 2.62 |
| 4 | 2 | 2.62 | 2.62 | 2.62 | 2.62 | 2.62 | 2.62 | 2.62 | 2.62 | 2.62 | 2.62 |
| 4 | 3 | 2.12 | 2.12 | 2.12 | 2.12 | 2.12 | 2.12 | 2.12 | 2.12 | 2.12 | 2.12 |
| 5 | 1 | 2.73 | 2.73 | 2.73 | 2.73 | 2.73 | 2.73 | 2.73 | 2.73 | 2.73 | 2.73 |
| 5 | 2 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 |
| 5 | 3 | 1.99 | 1.99 | 1.99 | 1.99 | 1.99 | 1.99 | 1.99 | 1.99 | 1.99 | 1.99 |

| NFI | Elev. | 2020 |
|---|---|---|
| | | CC12: gain in living biomass (gainCl,i) [t C ha$^{-1}$ yr$^{-1}$] |
| 1 | 1 | 3.31 |
| 1 | 2 | 3.20 |
| 1 | 3 | 2.04 |
| 2 | 1 | 4.29 |
| 2 | 2 | 4.89 |
| 2 | 3 | 4.89 |
| 3 | 1 | 4.00 |
| 3 | 2 | 4.00 |
| 3 | 3 | 2.29 |
| 4 | 1 | 2.62 |
| 4 | 2 | 2.62 |
| 4 | 3 | 2.12 |
| 5 | 1 | 2.73 |
| 5 | 2 | 1.92 |
| 5 | 3 | 1.99 |

(Table 6-15 continued)

| NFI | Elev. | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: loss in living biomass (lossCl,i) [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| 1 | 1 | -2.38 | -2.12 | -2.29 | -2.29 | -2.46 | -2.55 | -3.89 | -4.17 | -4.37 | -4.20 |
| 1 | 2 | -2.28 | -1.83 | -2.04 | -2.03 | -2.23 | -2.32 | -2.32 | -2.54 | -2.63 | -2.56 |
| 1 | 3 | -1.36 | -0.99 | -1.13 | -1.12 | -1.26 | -1.32 | -1.03 | -1.15 | -1.18 | -1.16 |
| 2 | 1 | -4.77 | -3.17 | -3.72 | -3.70 | -3.71 | -4.03 | -3.75 | -3.97 | -4.41 | -4.47 |
| 2 | 2 | -4.61 | -2.98 | -3.50 | -3.49 | -3.53 | -3.84 | -3.50 | -3.74 | -4.18 | -4.23 |
| 2 | 3 | -1.05 | -0.62 | -0.74 | -0.74 | -0.77 | -0.84 | -0.86 | -0.93 | -1.04 | -1.05 |
| 3 | 1 | -3.35 | -2.82 | -2.60 | -2.64 | -2.77 | -2.99 | -2.09 | -2.22 | -2.44 | -2.49 |
| 3 | 2 | -3.78 | -2.78 | -2.42 | -2.41 | -2.60 | -2.63 | -2.61 | -2.87 | -3.19 | -3.20 |
| 3 | 3 | -2.75 | -1.90 | -1.60 | -1.57 | -1.73 | -1.69 | -1.41 | -1.59 | -1.79 | -1.77 |
| 4 | 1 | -3.19 | -3.10 | -2.83 | -2.55 | -2.69 | -2.27 | -1.49 | -1.62 | -2.42 | -1.72 |
| 4 | 2 | -2.59 | -2.21 | -1.66 | -1.48 | -1.61 | -1.33 | -1.43 | -1.59 | -2.10 | -1.67 |
| 4 | 3 | -2.47 | -2.03 | -1.41 | -1.25 | -1.38 | -1.14 | -1.15 | -1.30 | -1.51 | -1.35 |
| 5 | 1 | -0.92 | -1.09 | -1.18 | -1.35 | -1.38 | -1.40 | -1.44 | -1.49 | -1.54 | -1.45 |
| 5 | 2 | -0.61 | -0.72 | -0.84 | -0.92 | -0.94 | -0.98 | -0.67 | -0.72 | -0.72 | -0.67 |
| 5 | 3 | -0.30 | -0.35 | -0.57 | -0.54 | -0.53 | -0.63 | -0.58 | -0.71 | -0.61 | -0.54 |

| NFI | Elev. | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: loss in living biomass (lossCl,i) [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| 1 | 1 | -5.03 | -3.41 | -3.35 | -3.51 | -3.67 | -4.05 | -2.73 | -2.91 | -2.82 | -2.60 |
| 1 | 2 | -3.43 | -2.02 | -1.99 | -2.21 | -2.41 | -2.56 | -2.87 | -3.07 | -2.93 | -2.67 |
| 1 | 3 | -1.70 | -0.89 | -0.88 | -1.03 | -1.16 | -1.20 | -2.30 | -2.47 | -2.25 | -1.96 |
| 2 | 1 | -10.04 | -5.54 | -4.12 | -4.67 | -4.85 | -5.23 | -5.82 | -5.46 | -4.91 | -4.55 |
| 2 | 2 | -10.20 | -5.52 | -4.03 | -4.62 | -4.83 | -5.14 | -6.10 | -5.72 | -5.15 | -4.77 |
| 2 | 3 | -2.77 | -1.47 | -1.05 | -1.22 | -1.29 | -1.34 | -6.10 | -5.72 | -5.15 | -4.77 |
| 3 | 1 | -4.72 | -3.24 | -2.54 | -2.74 | -2.82 | -2.80 | -4.49 | -4.57 | -4.17 | -3.75 |
| 3 | 2 | -7.44 | -4.99 | -3.77 | -4.10 | -4.00 | -3.77 | -4.49 | -4.57 | -4.17 | -3.75 |
| 3 | 3 | -4.72 | -3.12 | -2.31 | -2.53 | -2.38 | -2.16 | -2.01 | -2.06 | -1.84 | -1.60 |
| 4 | 1 | -1.37 | -1.50 | -1.57 | -1.62 | -1.63 | -1.67 | -1.78 | -1.85 | -1.93 | -2.02 |
| 4 | 2 | -1.28 | -1.44 | -1.50 | -1.61 | -1.48 | -1.53 | -1.78 | -1.85 | -1.93 | -2.02 |
| 4 | 3 | -1.00 | -1.16 | -1.20 | -1.33 | -1.12 | -1.18 | -1.00 | -1.09 | -1.16 | -1.19 |
| 5 | 1 | -1.29 | -1.32 | -1.32 | -1.31 | -1.31 | -1.24 | -1.47 | -1.32 | -1.33 | -1.28 |
| 5 | 2 | -0.56 | -0.58 | -0.59 | -0.60 | -0.59 | -0.57 | -0.81 | -0.84 | -0.80 | -0.80 |
| 5 | 3 | -0.29 | -0.31 | -0.40 | -0.46 | -0.38 | -0.44 | -0.56 | -0.73 | -0.64 | -0.67 |

| NFI | Elev. | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: loss in living biomass (lossCl,i) [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| 1 | 1 | -2.80 | -2.79 | -2.61 | -2.72 | -2.87 | -2.58 | -2.63 | -2.64 | -2.61 | -2.52 |
| 1 | 2 | -2.88 | -2.85 | -2.66 | -2.77 | -2.92 | -2.61 | -2.67 | -2.67 | -2.66 | -2.56 |
| 1 | 3 | -2.11 | -2.04 | -1.89 | -1.93 | -2.06 | -1.79 | -1.85 | -1.84 | -1.88 | -1.80 |
| 2 | 1 | -4.49 | -4.49 | -4.23 | -4.24 | -4.36 | -4.26 | -4.05 | -4.42 | -5.17 | -4.40 |
| 2 | 2 | -4.72 | -4.71 | -4.44 | -4.46 | -4.58 | -4.48 | -4.26 | -4.64 | -5.43 | -4.61 |
| 2 | 3 | -4.72 | -4.71 | -4.44 | -4.46 | -4.58 | -4.48 | -4.26 | -4.64 | -5.43 | -4.61 |
| 3 | 1 | -4.21 | -4.20 | -3.59 | -3.77 | -3.88 | -3.47 | -3.47 | -3.62 | -3.81 | -3.43 |
| 3 | 2 | -4.21 | -4.20 | -3.59 | -3.77 | -3.88 | -3.47 | -3.47 | -3.62 | -3.81 | -3.43 |
| 3 | 3 | -1.81 | -1.79 | -1.51 | -1.54 | -1.59 | -1.40 | -1.41 | -1.48 | -1.65 | -1.44 |
| 4 | 1 | -2.18 | -2.14 | -2.04 | -2.25 | -2.16 | -1.98 | -1.94 | -1.93 | -2.01 | -1.79 |
| 4 | 2 | -2.18 | -2.14 | -2.04 | -2.25 | -2.16 | -1.98 | -1.94 | -1.93 | -2.01 | -1.79 |
| 4 | 3 | -1.26 | -1.21 | -1.17 | -1.20 | -1.17 | -1.11 | -1.02 | -1.06 | -1.14 | -0.95 |
| 5 | 1 | -1.57 | -1.61 | -1.53 | -1.54 | -1.44 | -1.62 | -1.84 | -1.66 | -2.01 | -1.98 |
| 5 | 2 | -0.94 | -0.96 | -0.88 | -0.94 | -1.04 | -0.97 | -1.07 | -1.03 | -1.12 | -1.26 |
| 5 | 3 | -0.74 | -0.75 | -0.64 | -0.77 | -1.06 | -0.76 | -0.81 | -0.86 | -0.79 | -1.09 |

| NFI | Elev. | 2020 |
|---|---|---|
| | | CC12: loss in living biomass (lossCl,i) [t C ha$^{-1}$ yr$^{-1}$] |
| 1 | 1 | -2.60 |
| 1 | 2 | -2.68 |
| 1 | 3 | -1.97 |
| 2 | 1 | -4.78 |
| 2 | 2 | -5.01 |
| 2 | 3 | -5.01 |
| 3 | 1 | -3.46 |
| 3 | 2 | -3.46 |
| 3 | 3 | -1.48 |
| 4 | 1 | -1.64 |
| 4 | 2 | -1.64 |
| 4 | 3 | -0.95 |
| 5 | 1 | -1.89 |
| 5 | 2 | -1.00 |
| 5 | 3 | -0.62 |

### 6.4.2.5. Productive forests (CC12): carbon stocks in dead wood, in litter and in mineral soil

**Method**

Switzerland uses the soil carbon model Yasso07 to estimate temporal changes in carbon stocks in dead wood, organic soil horizons (LFH; litter) and mineral forest soil (0–100 cm depth) for productive forests. The implementation of Yasso07 (Tuomi et al. 2009, 2011) in the Swiss GHG inventory is described in detail in Didion (2020a). Didion et al. (2014a) demonstrated the validity of the model for application in Swiss forests. Consistently with the estimation procedure for living biomass, the model is applied on the common plots between two NFIs (chp. 6.4.2.4; Table 6-13). The estimates used for the latest submission are displayed in the supplement to Didion (2020a).

Yasso07 is a model of carbon cycling in mineral soil, litter and dead wood. For estimating stocks of organic carbon in mineral soil up to a depth of ca. 100 cm and the temporal dynamics of the carbon stocks, Yasso07 requires information on carbon inputs (see below) and climate (annual monthly temperature and precipitation).

The Swiss NFI is the source of carbon inputs and of the state change of each sample tree between two consecutive inventories (i.e. survivor, cut, mortality, ingrowth and nongrowth trees; Didion et al. 2020). The tree state in two consecutive NFIs determines the type and quantity of carbon inputs. Turnover rates reflecting the longevity of leaves and needles, seeds and fruits, fine roots, and small branches are used to estimate carbon inputs that are produced annually. Stemwood, incl. tree top and stump, large branches, and coarse roots are assumed to accrue only as the result of mortality. Depending on the cause of mortality, i.e. natural or timber harvesting, either the total mass of these tree elements or only the non-merchantable fraction (coarse root, stump, top, and small branches) is considered for carbon inputs.

By default, Yasso07 does not provide separate estimates of carbon pool sizes for dead wood, litter and mineral soil. In order to report estimates for each pool, the model structure of Yasso07 was examined to obtain separate estimates. Dead wood, litter and soil pools could be correlated with modelled data based on the category of carbon input, i.e., non-woody and woody material, and the five carbon compartments in Yasso07, i.e. four chemical partitions (insoluble, soluble in ethanol, soluble in water or in acid) and humus. The approach was validated using independent, measured data (Didion et al. 2012).

**Carbon stocks in dead wood, litter and mineral soil**

Carbon stocks in dead wood were simulated and estimated based on source of carbon inputs, including (1) stemwood of trees ≥12 cm (diameter at breast height; DBH), (2) large branches ≥ ca. 7 cm in diameter, and (3) dead coarse roots > ca. 5 mm in diameter. These tree elements were estimated according to Table 2 in Didion et al. (2020).

Carbon stocks in litter were derived from simulations of carbon inputs of the tree elements small branches and twigs < ca. 7 cm in diameter, bark of the tree bole, foliage (Didion et al. 2020: Table 2), seeds and fruits (based on published allometries, see Didion and Zell 2019), and fine roots < ca. 5 mm (estimated as fraction of coarse roots; Perruchoud et al. 1999).

Carbon stocks in mineral soil were not taken from Yasso07 simulations. Due to the incomplete knowledge of the origin of the high carbon stocks in mineral soils, particularly pyrogenic carbon in the mountainous soils of Southern Switzerland (Eckmeier et al. 2010; Nussbaum et al. 2014; Zanelli et al. 2006), they cannot be reproduced by models yet. Hence, soil carbon stocks were taken from Nussbaum and Burgos (2021), a spatial statistical analysis of soil profile data using the machine learning approach “random forest”. The sample material was taken from the soil sample archive (pedothek) maintained at the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) (n = 1033 sites). Additional 1060 sites either sampled by WSL or in the course of cantonal projects were used. The soil samples were collected over the past 50 years, by far the most between 1990 and 2015, and distributed over different forest types throughout Switzerland. Because of the distribution of sampling over a long time span, it is not possible to attribute the carbon stocks estimates in mineral forest soils to one single year. A combination of these carbon stocks and the carbon stock changes derived from the Yasso07 model (Didion 2020a; see chp. 6.4.2.6) would not result in a consistent time series for soil carbon stocks. Thus, it was assumed that the values from Nussbaum and Burgos (2021) are represenative of conditions of Swiss forests soils for the whole inventory period and were considered constant. This assumption is supported by the trend of a very minor increase in soil carbon stocks since 1990 based on the Yasso07 simulations (see chpt. 6.4.2.6).

All data were stratified by the five NFI production regions and three elevation levels (see Table 6-16 for dead wood and litter and Table 6-4 for mineral soil).

Table 6-16 Carbon stocks in dead wood ($stockC_d$) and in litter ($stockC_h$) for productive forest (CC12) stratified for NFI production region (NFI) and elevation zone (Elev.). Highlighted data for 1990 are displayed in Table 6-4.

| NFI | Elev. | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: carbon stock in dead wood (stockCd,i) [t C $ha^{-1}$] | | | | | | | | | |
| 1 | 1 | 4.89 | 4.95 | 4.98 | 5.01 | 5.01 | 5.03 | 5.35 | 5.70 | 5.99 | 6.24 |
| 1 | 2 | 5.26 | 5.32 | 5.36 | 5.39 | 5.40 | 5.43 | 5.46 | 5.53 | 5.60 | 5.66 |
| 1 | 3 | 4.65 | 4.65 | 4.63 | 4.62 | 4.59 | 4.58 | 4.36 | 4.26 | 4.19 | 4.12 |
| 2 | 1 | 8.10 | 8.18 | 8.23 | 8.27 | 8.26 | 8.29 | 8.60 | 8.93 | 9.20 | 9.43 |
| 2 | 2 | 7.86 | 7.94 | 7.98 | 8.02 | 8.02 | 8.05 | 8.38 | 8.73 | 9.05 | 9.31 |
| 2 | 3 | 7.86 | 7.94 | 7.98 | 8.02 | 8.02 | 8.05 | 8.38 | 8.73 | 9.05 | 9.31 |
| 3 | 1 | 7.54 | 7.66 | 7.75 | 7.84 | 7.88 | 7.96 | 8.38 | 8.76 | 9.11 | 9.42 |
| 3 | 2 | 7.54 | 7.66 | 7.75 | 7.84 | 7.88 | 7.96 | 8.38 | 8.76 | 9.11 | 9.42 |
| 3 | 3 | 6.03 | 6.08 | 6.10 | 6.13 | 6.13 | 6.17 | 5.99 | 6.04 | 6.11 | 6.18 |
| 4 | 1 | 5.39 | 5.50 | 5.57 | 5.65 | 5.70 | 5.78 | 5.64 | 5.63 | 5.63 | 5.63 |
| 4 | 2 | 5.39 | 5.50 | 5.57 | 5.65 | 5.70 | 5.78 | 5.64 | 5.63 | 5.63 | 5.63 |
| 4 | 3 | 4.98 | 5.10 | 5.19 | 5.29 | 5.36 | 5.45 | 5.22 | 5.20 | 5.20 | 5.19 |
| 5 | 1 | 2.15 | 2.20 | 2.24 | 2.28 | 2.32 | 2.36 | 2.34 | 2.38 | 2.42 | 2.45 |
| 5 | 2 | 2.09 | 2.16 | 2.21 | 2.26 | 2.31 | 2.36 | 2.16 | 2.06 | 1.97 | 1.89 |
| 5 | 3 | 1.77 | 1.80 | 1.81 | 1.84 | 1.85 | 1.87 | 1.74 | 1.72 | 1.71 | 1.69 |

| NFI | Elev. | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: carbon stock in dead wood (stockCd,i) [t C $ha^{-1}$] | | | | | | | | | |
| 1 | 1 | 6.47 | 6.68 | 6.86 | 7.10 | 7.27 | 7.45 | 7.23 | 7.17 | 7.15 | 7.16 |
| 1 | 2 | 5.70 | 5.75 | 5.78 | 5.85 | 5.89 | 5.95 | 5.95 | 6.15 | 6.35 | 6.54 |
| 1 | 3 | 4.05 | 3.99 | 3.92 | 3.87 | 3.83 | 3.80 | 3.90 | 4.14 | 4.38 | 4.59 |
| 2 | 1 | 9.63 | 9.81 | 9.96 | 10.21 | 10.37 | 10.55 | 10.16 | 10.17 | 10.23 | 10.30 |
| 2 | 2 | 9.54 | 9.76 | 9.95 | 10.20 | 10.38 | 10.59 | 10.42 | 10.44 | 10.50 | 10.57 |
| 2 | 3 | 9.54 | 9.76 | 9.95 | 10.20 | 10.38 | 10.59 | 10.42 | 10.44 | 10.50 | 10.57 |
| 3 | 1 | 9.70 | 9.96 | 10.18 | 10.43 | 10.65 | 10.87 | 11.03 | 11.13 | 11.25 | 11.37 |
| 3 | 2 | 9.70 | 9.96 | 10.18 | 10.43 | 10.65 | 10.87 | 11.03 | 11.13 | 11.25 | 11.37 |
| 3 | 3 | 6.23 | 6.28 | 6.32 | 6.36 | 6.41 | 6.47 | 5.93 | 5.96 | 6.00 | 6.04 |
| 4 | 1 | 5.61 | 5.61 | 5.59 | 5.61 | 5.62 | 5.65 | 5.14 | 5.35 | 5.55 | 5.74 |
| 4 | 2 | 5.61 | 5.61 | 5.59 | 5.61 | 5.62 | 5.65 | 5.14 | 5.35 | 5.55 | 5.74 |
| 4 | 3 | 5.17 | 5.17 | 5.15 | 5.16 | 5.17 | 5.20 | 4.65 | 4.68 | 4.71 | 4.75 |
| 5 | 1 | 2.48 | 2.51 | 2.54 | 2.58 | 2.60 | 2.64 | 3.15 | 3.23 | 3.31 | 3.38 |
| 5 | 2 | 1.82 | 1.76 | 1.70 | 1.66 | 1.61 | 1.58 | 1.22 | 1.31 | 1.39 | 1.46 |
| 5 | 3 | 1.68 | 1.67 | 1.66 | 1.65 | 1.64 | 1.65 | 1.32 | 1.43 | 1.52 | 1.61 |

| NFI | Elev. | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: carbon stock in dead wood (stockCd,i) [t C $ha^{-1}$] | | | | | | | | | |
| 1 | 1 | 7.18 | 7.18 | 7.17 | 7.18 | 7.15 | 7.18 | 7.16 | 7.18 | 7.19 | 7.19 |
| 1 | 2 | 6.74 | 6.87 | 7.00 | 7.15 | 7.23 | 7.33 | 7.42 | 7.52 | 7.59 | 7.66 |
| 1 | 3 | 4.82 | 4.97 | 5.14 | 5.30 | 5.42 | 5.53 | 5.64 | 5.76 | 5.84 | 5.93 |
| 2 | 1 | 10.40 | 10.44 | 10.49 | 10.55 | 10.53 | 10.60 | 10.60 | 10.65 | 10.68 | 10.69 |
| 2 | 2 | 10.68 | 10.72 | 10.77 | 10.83 | 10.81 | 10.86 | 10.86 | 10.90 | 10.93 | 10.94 |
| 2 | 3 | 10.68 | 10.72 | 10.77 | 10.83 | 10.81 | 10.86 | 10.86 | 10.90 | 10.93 | 10.94 |
| 3 | 1 | 11.53 | 11.59 | 11.69 | 11.81 | 11.82 | 11.88 | 11.92 | 11.98 | 12.03 | 12.07 |
| 3 | 2 | 11.53 | 11.59 | 11.69 | 11.81 | 11.82 | 11.88 | 11.92 | 11.98 | 12.03 | 12.07 |
| 3 | 3 | 6.10 | 6.10 | 6.13 | 6.17 | 6.17 | 6.17 | 6.18 | 6.19 | 6.19 | 6.20 |
| 4 | 1 | 5.93 | 6.07 | 6.21 | 6.35 | 6.44 | 6.54 | 6.63 | 6.73 | 6.80 | 6.87 |
| 4 | 2 | 5.93 | 6.07 | 6.21 | 6.35 | 6.44 | 6.54 | 6.63 | 6.73 | 6.80 | 6.87 |
| 4 | 3 | 4.80 | 4.81 | 4.83 | 4.86 | 4.86 | 4.87 | 4.89 | 4.90 | 4.91 | 4.91 |
| 5 | 1 | 3.46 | 3.52 | 3.58 | 3.64 | 3.67 | 3.72 | 3.76 | 3.80 | 3.84 | 3.86 |
| 5 | 2 | 1.54 | 1.59 | 1.65 | 1.70 | 1.74 | 1.78 | 1.82 | 1.86 | 1.90 | 1.92 |
| 5 | 3 | 1.69 | 1.76 | 1.83 | 1.89 | 1.95 | 2.00 | 2.05 | 2.09 | 2.14 | 2.18 |

| NFI | Elev. | 2020 |
|---|---|---|
| | | CC12: carbon stock in dead wood (stockCd,i) [t C $ha^{-1}$] |
| 1 | 1 | 7.18 |
| 1 | 2 | 7.71 |
| 1 | 3 | 5.99 |
| 2 | 1 | 10.69 |
| 2 | 2 | 10.92 |
| 2 | 3 | 10.92 |
| 3 | 1 | 12.07 |
| 3 | 2 | 12.07 |
| 3 | 3 | 6.19 |
| 4 | 1 | 6.92 |
| 4 | 2 | 6.92 |
| 4 | 3 | 4.91 |
| 5 | 1 | 3.89 |
| 5 | 2 | 1.95 |
| 5 | 3 | 2.21 |

(Table 6-16 continued)

| NFI | Elev. | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: carbon stock in litter (stockCh,i) [t C ha$^{-1}$] | | | | | | | | | |
| 1 | 1 | 11.97 | 12.10 | 12.04 | 12.02 | 11.85 | 11.81 | 11.99 | 12.16 | 12.19 | 12.15 |
| 1 | 2 | 12.16 | 12.29 | 12.26 | 12.27 | 12.12 | 12.13 | 12.34 | 12.48 | 12.60 | 12.65 |
| 1 | 3 | 10.35 | 10.32 | 10.20 | 10.15 | 9.99 | 9.99 | 9.76 | 9.81 | 9.93 | 10.01 |
| 2 | 1 | 12.35 | 12.48 | 12.44 | 12.40 | 12.21 | 12.18 | 12.33 | 12.47 | 12.49 | 12.43 |
| 2 | 2 | 13.23 | 13.36 | 13.33 | 13.31 | 13.13 | 13.14 | 13.31 | 13.42 | 13.49 | 13.48 |
| 2 | 3 | 13.23 | 13.36 | 13.33 | 13.31 | 13.13 | 13.14 | 13.31 | 13.42 | 13.49 | 13.48 |
| 3 | 1 | 14.09 | 14.25 | 14.25 | 14.27 | 14.12 | 14.18 | 14.38 | 14.46 | 14.58 | 14.65 |
| 3 | 2 | 14.09 | 14.25 | 14.25 | 14.27 | 14.12 | 14.18 | 14.38 | 14.46 | 14.58 | 14.65 |
| 3 | 3 | 13.63 | 13.73 | 13.67 | 13.70 | 13.57 | 13.64 | 13.34 | 13.40 | 13.58 | 13.71 |
| 4 | 1 | 11.14 | 11.26 | 11.26 | 11.27 | 11.18 | 11.24 | 11.23 | 11.37 | 11.54 | 11.62 |
| 4 | 2 | 11.14 | 11.26 | 11.26 | 11.27 | 11.18 | 11.24 | 11.23 | 11.37 | 11.54 | 11.62 |
| 4 | 3 | 14.06 | 14.27 | 14.30 | 14.41 | 14.33 | 14.48 | 14.20 | 14.37 | 14.62 | 14.71 |
| 5 | 1 | 8.14 | 8.17 | 8.16 | 8.14 | 8.10 | 8.15 | 8.36 | 8.50 | 8.65 | 8.76 |
| 5 | 2 | 9.62 | 9.76 | 9.80 | 9.86 | 9.84 | 9.96 | 10.22 | 10.53 | 10.82 | 11.06 |
| 5 | 3 | 11.17 | 11.38 | 11.43 | 11.55 | 11.53 | 11.69 | 11.48 | 11.77 | 12.08 | 12.35 |

| NFI | Elev. | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: carbon stock in litter (stockCh,i) [t C ha$^{-1}$] | | | | | | | | | |
| 1 | 1 | 12.14 | 12.12 | 12.05 | 12.35 | 12.35 | 12.44 | 12.26 | 12.09 | 12.06 | 12.10 |
| 1 | 2 | 12.68 | 12.73 | 12.68 | 12.87 | 12.91 | 13.05 | 13.08 | 13.07 | 13.16 | 13.28 |
| 1 | 3 | 10.02 | 10.08 | 10.05 | 10.10 | 10.16 | 10.27 | 10.08 | 10.33 | 10.61 | 10.83 |
| 2 | 1 | 12.38 | 12.33 | 12.26 | 12.52 | 12.51 | 12.61 | 12.06 | 11.84 | 11.77 | 11.78 |
| 2 | 2 | 13.45 | 13.45 | 13.39 | 13.60 | 13.62 | 13.74 | 12.88 | 12.69 | 12.65 | 12.67 |
| 2 | 3 | 13.45 | 13.45 | 13.39 | 13.60 | 13.62 | 13.74 | 12.88 | 12.69 | 12.65 | 12.67 |
| 3 | 1 | 14.65 | 14.72 | 14.65 | 14.77 | 14.83 | 14.96 | 14.73 | 14.67 | 14.72 | 14.79 |
| 3 | 2 | 14.65 | 14.72 | 14.65 | 14.77 | 14.83 | 14.96 | 14.73 | 14.67 | 14.72 | 14.79 |
| 3 | 3 | 13.75 | 13.86 | 13.82 | 13.86 | 13.97 | 14.13 | 13.31 | 13.31 | 13.39 | 13.45 |
| 4 | 1 | 11.65 | 11.73 | 11.68 | 11.86 | 11.95 | 12.13 | 11.94 | 12.05 | 12.19 | 12.39 |
| 4 | 2 | 11.65 | 11.73 | 11.68 | 11.86 | 11.95 | 12.13 | 11.94 | 12.05 | 12.19 | 12.39 |
| 4 | 3 | 14.73 | 14.86 | 14.81 | 15.00 | 15.18 | 15.43 | 14.14 | 14.37 | 14.59 | 14.86 |
| 5 | 1 | 8.80 | 8.90 | 8.92 | 9.07 | 9.09 | 9.26 | 8.57 | 8.66 | 8.74 | 8.82 |
| 5 | 2 | 11.19 | 11.37 | 11.42 | 11.62 | 11.69 | 11.93 | 11.35 | 11.59 | 11.82 | 12.02 |
| 5 | 3 | 12.50 | 12.70 | 12.75 | 12.94 | 13.07 | 13.40 | 11.86 | 12.15 | 12.44 | 12.68 |

| NFI | Elev. | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: carbon stock in litter (stockCh,i) [t C ha$^{-1}$] | | | | | | | | | |
| 1 | 1 | 12.21 | 12.16 | 12.12 | 12.15 | 11.97 | 12.09 | 12.00 | 12.07 | 12.06 | 12.03 |
| 1 | 2 | 13.52 | 13.44 | 13.47 | 13.56 | 13.40 | 13.44 | 13.39 | 13.46 | 13.41 | 13.38 |
| 1 | 3 | 11.16 | 11.15 | 11.27 | 11.43 | 11.37 | 11.37 | 11.38 | 11.43 | 11.39 | 11.39 |
| 2 | 1 | 11.87 | 11.81 | 11.77 | 11.79 | 11.59 | 11.68 | 11.57 | 11.62 | 11.62 | 11.55 |
| 2 | 2 | 12.80 | 12.70 | 12.69 | 12.72 | 12.50 | 12.55 | 12.45 | 12.49 | 12.47 | 12.42 |
| 2 | 3 | 12.80 | 12.70 | 12.69 | 12.72 | 12.50 | 12.55 | 12.45 | 12.49 | 12.47 | 12.42 |
| 3 | 1 | 14.98 | 14.84 | 14.89 | 15.00 | 14.77 | 14.75 | 14.68 | 14.70 | 14.67 | 14.64 |
| 3 | 2 | 14.98 | 14.84 | 14.89 | 15.00 | 14.77 | 14.75 | 14.68 | 14.70 | 14.67 | 14.64 |
| 3 | 3 | 13.66 | 13.48 | 13.52 | 13.61 | 13.45 | 13.37 | 13.33 | 13.33 | 13.26 | 13.22 |
| 4 | 1 | 12.66 | 12.64 | 12.72 | 12.86 | 12.72 | 12.75 | 12.73 | 12.78 | 12.74 | 12.72 |
| 4 | 2 | 12.66 | 12.64 | 12.72 | 12.86 | 12.72 | 12.75 | 12.73 | 12.78 | 12.74 | 12.72 |
| 4 | 3 | 15.24 | 15.22 | 15.29 | 15.46 | 15.38 | 15.37 | 15.43 | 15.47 | 15.39 | 15.36 |
| 5 | 1 | 8.98 | 8.99 | 9.02 | 9.05 | 8.96 | 9.00 | 9.00 | 9.04 | 9.03 | 8.99 |
| 5 | 2 | 12.33 | 12.36 | 12.43 | 12.53 | 12.47 | 12.51 | 12.53 | 12.57 | 12.58 | 12.54 |
| 5 | 3 | 13.04 | 13.04 | 13.13 | 13.27 | 13.26 | 13.25 | 13.30 | 13.34 | 13.35 | 13.32 |

| NFI | Elev. | 2020 |
|---|---|---|
| | | CC12: carbon stock in litter (stockCh,i) [t C ha$^{-1}$] |
| 1 | 1 | 11.96 |
| 1 | 2 | 13.28 |
| 1 | 3 | 11.30 |
| 2 | 1 | 11.46 |
| 2 | 2 | 12.30 |
| 2 | 3 | 12.30 |
| 3 | 1 | 14.51 |
| 3 | 2 | 14.51 |
| 3 | 3 | 13.10 |
| 4 | 1 | 12.65 |
| 4 | 2 | 12.65 |
| 4 | 3 | 15.30 |
| 5 | 1 | 8.97 |
| 5 | 2 | 12.52 |
| 5 | 3 | 13.31 |

### 6.4.2.6. Productive forests (CC12): changes in carbon stocks of dead wood, of litter and of mineral soils

Annual stratified values of carbon stock changes for dead wood, litter and mineral soils are calculated from the simulated annual stocks (chp. 6.4.2.5). Results are given in Table 6-17. Despite limitations to reproduce the comparably high carbon stocks in mineral soils in Swiss forests (chp. 6.4.2.5), the carbon stock changes derived from simulated stocks can be expected to be accurate because (1) the pyrogenic carbon which is found particularly in the soils of the Southern Alps is very stable (Eckmeier et al. 2010), and (2) the simulated carbon stock changes including standard error are less than the minimum detection limit of repeated soil carbon stock measurements (see chp. 6.4.4). Furthermore, carbon stock changes were validated as described in Didion (2020a).

Carbon stock changes in the soil pool are small (Table 6-17). Carbon stock changes in litter are higher and more erratic than changes in the dead wood and soil pools (Figure 6-6). This is expected since non-woody material decomposes faster than dead wood (Tuomi et al. 2011) and its decomposition is more sensitive to interannual changes in temperature and precipitation (Liski et al. 2003). Furthermore there is a high interannual variability in the production of foliage (Etzold et al. 2011). The carbon stock change in the dead wood pool is to a large extend driven by the increase in dead wood volume in Swiss forests since the mid-1990s (Brändli 2010). Dead wood accumulation as a consequence of the two storms Vivian (1990) and, in particular, Lothar (1999), strongly affects the results of the change analysis for dead wood volume in the period NFI2 to NFI3. Although the majority of the wind thrown trees were removed from the forest, the dead wood stock increased significantly. As particularly the larger-sized felled trees decay slowly (Didion et al. 2014a), the increased dead wood stock acts as a sustained carbon sink (Figure 6-6). The trend of decreasing harvesting rates for several years after NFI3 (see Table 6-14) further sustained the carbon sink of dead wood as mature trees, which could be harvested, remain in the forest and potentially contribute to the dead wood pool. Large-scale disturbance events like Lothar occurring between two consecutive NFIs can strongly affect the estimates of annually accumulating mass of dead wood that drives the Yasso07 simulation. Results of the NFI4 indicate that dead wood volume is still increasing (Brändli et al. 2020).

Table 6-17 Net carbon stock change in dead wood (changeC$_d$), in litter (changeC$_h$) and in mineral soil (changeC$_s$) for productive forest (CC12) stratified for NFI production region (NFI) and elevation zone (Elev.). Highlighted data for 1990 are displayed in Table 6-4. Positive values refer to gains in carbon stock, negative values refer to losses in carbon stock.

| NFI | Elev. | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: net change in dead wood (changeCd,i) [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| 1 | 1 | 0.03 | 0.06 | 0.03 | 0.03 | 0.00 | 0.02 | 0.40 | 0.35 | 0.29 | 0.25 |
| 1 | 2 | 0.03 | 0.06 | 0.03 | 0.04 | 0.01 | 0.03 | 0.11 | 0.07 | 0.07 | 0.05 |
| 1 | 3 | -0.03 | -0.01 | -0.02 | -0.01 | -0.03 | -0.01 | -0.07 | -0.09 | -0.07 | -0.07 |
| 2 | 1 | 0.03 | 0.09 | 0.04 | 0.04 | -0.01 | 0.03 | 0.38 | 0.33 | 0.27 | 0.22 |
| 2 | 2 | 0.03 | 0.08 | 0.04 | 0.04 | 0.00 | 0.03 | 0.41 | 0.35 | 0.31 | 0.26 |
| 2 | 3 | 0.03 | 0.08 | 0.04 | 0.04 | 0.00 | 0.03 | 0.41 | 0.35 | 0.31 | 0.26 |
| 3 | 1 | 0.09 | 0.12 | 0.09 | 0.09 | 0.04 | 0.08 | 0.45 | 0.37 | 0.35 | 0.31 |
| 3 | 2 | 0.09 | 0.12 | 0.09 | 0.09 | 0.04 | 0.08 | 0.45 | 0.37 | 0.35 | 0.31 |
| 3 | 3 | 0.02 | 0.04 | 0.02 | 0.03 | 0.00 | 0.03 | 0.10 | 0.06 | 0.07 | 0.07 |
| 4 | 1 | 0.09 | 0.10 | 0.08 | 0.08 | 0.05 | 0.07 | 0.01 | -0.01 | 0.00 | -0.01 |
| 4 | 2 | 0.09 | 0.10 | 0.08 | 0.08 | 0.05 | 0.07 | 0.01 | -0.01 | 0.00 | -0.01 |
| 4 | 3 | 0.11 | 0.12 | 0.09 | 0.10 | 0.07 | 0.09 | 0.00 | -0.02 | 0.00 | -0.01 |
| 5 | 1 | 0.05 | 0.05 | 0.04 | 0.04 | 0.03 | 0.04 | 0.05 | 0.04 | 0.04 | 0.03 |
| 5 | 2 | 0.07 | 0.07 | 0.06 | 0.05 | 0.04 | 0.05 | -0.10 | -0.10 | -0.09 | -0.08 |
| 5 | 3 | 0.02 | 0.03 | 0.02 | 0.02 | 0.01 | 0.02 | -0.01 | -0.02 | -0.01 | -0.01 |

| NFI | Elev. | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: net change in dead wood (changeCd,i) [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| 1 | 1 | 0.23 | 0.21 | 0.18 | 0.25 | 0.17 | 0.18 | -0.03 | -0.05 | -0.02 | 0.00 |
| 1 | 2 | 0.05 | 0.05 | 0.03 | 0.07 | 0.04 | 0.06 | 0.24 | 0.20 | 0.20 | 0.19 |
| 1 | 3 | -0.07 | -0.06 | -0.07 | -0.05 | -0.04 | -0.03 | 0.27 | 0.25 | 0.23 | 0.22 |
| 2 | 1 | 0.20 | 0.18 | 0.15 | 0.25 | 0.16 | 0.18 | 0.07 | 0.02 | 0.05 | 0.07 |
| 2 | 2 | 0.23 | 0.22 | 0.18 | 0.25 | 0.19 | 0.20 | 0.07 | 0.02 | 0.06 | 0.07 |
| 2 | 3 | 0.23 | 0.22 | 0.18 | 0.25 | 0.19 | 0.20 | 0.07 | 0.02 | 0.06 | 0.07 |
| 3 | 1 | 0.27 | 0.27 | 0.22 | 0.25 | 0.22 | 0.23 | 0.14 | 0.10 | 0.12 | 0.12 |
| 3 | 2 | 0.27 | 0.27 | 0.22 | 0.25 | 0.22 | 0.23 | 0.14 | 0.10 | 0.12 | 0.12 |
| 3 | 3 | 0.05 | 0.06 | 0.03 | 0.04 | 0.05 | 0.06 | 0.04 | 0.03 | 0.04 | 0.04 |
| 4 | 1 | -0.01 | 0.00 | -0.02 | 0.02 | 0.01 | 0.03 | 0.26 | 0.21 | 0.20 | 0.19 |
| 4 | 2 | -0.01 | 0.00 | -0.02 | 0.02 | 0.01 | 0.03 | 0.26 | 0.21 | 0.20 | 0.19 |
| 4 | 3 | -0.02 | 0.00 | -0.02 | 0.01 | 0.01 | 0.02 | 0.04 | 0.03 | 0.03 | 0.04 |
| 5 | 1 | 0.03 | 0.03 | 0.03 | 0.04 | 0.02 | 0.04 | 0.10 | 0.08 | 0.08 | 0.07 |
| 5 | 2 | -0.07 | -0.06 | -0.06 | -0.05 | -0.05 | -0.03 | 0.10 | 0.09 | 0.08 | 0.07 |
| 5 | 3 | -0.01 | -0.01 | -0.01 | -0.01 | -0.01 | 0.01 | 0.11 | 0.10 | 0.09 | 0.09 |

| NFI | Elev. | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: net change in dead wood (changeCd,i) [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| 1 | 1 | 0.03 | -0.01 | -0.01 | 0.01 | -0.04 | 0.03 | -0.01 | 0.02 | 0.00 | 0.00 |
| 1 | 2 | 0.20 | 0.13 | 0.14 | 0.14 | 0.08 | 0.11 | 0.08 | 0.10 | 0.07 | 0.07 |
| 1 | 3 | 0.22 | 0.16 | 0.16 | 0.17 | 0.12 | 0.11 | 0.11 | 0.11 | 0.09 | 0.09 |
| 2 | 1 | 0.10 | 0.05 | 0.05 | 0.06 | -0.02 | 0.07 | 0.01 | 0.05 | 0.03 | 0.01 |
| 2 | 2 | 0.11 | 0.04 | 0.05 | 0.06 | -0.02 | 0.05 | 0.00 | 0.04 | 0.03 | 0.01 |
| 2 | 3 | 0.11 | 0.04 | 0.05 | 0.06 | -0.02 | 0.05 | 0.00 | 0.04 | 0.03 | 0.01 |
| 3 | 1 | 0.16 | 0.06 | 0.10 | 0.12 | 0.01 | 0.06 | 0.04 | 0.06 | 0.05 | 0.04 |
| 3 | 2 | 0.16 | 0.06 | 0.10 | 0.12 | 0.01 | 0.06 | 0.04 | 0.06 | 0.05 | 0.04 |
| 3 | 3 | 0.06 | 0.00 | 0.03 | 0.04 | -0.01 | 0.00 | 0.01 | 0.01 | 0.00 | 0.00 |
| 4 | 1 | 0.19 | 0.13 | 0.14 | 0.14 | 0.08 | 0.11 | 0.09 | 0.10 | 0.07 | 0.07 |
| 4 | 2 | 0.19 | 0.13 | 0.14 | 0.14 | 0.08 | 0.11 | 0.09 | 0.10 | 0.07 | 0.07 |
| 4 | 3 | 0.05 | 0.01 | 0.02 | 0.03 | 0.00 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 |
| 5 | 1 | 0.08 | 0.06 | 0.06 | 0.05 | 0.03 | 0.05 | 0.04 | 0.04 | 0.03 | 0.03 |
| 5 | 2 | 0.07 | 0.06 | 0.05 | 0.05 | 0.04 | 0.04 | 0.04 | 0.04 | 0.03 | 0.03 |
| 5 | 3 | 0.09 | 0.07 | 0.07 | 0.06 | 0.05 | 0.05 | 0.05 | 0.05 | 0.04 | 0.04 |

| NFI | Elev. | 2020 |
|---|---|---|
| | | CC12: net change in dead wood (changeCd,i) [t C ha$^{-1}$ yr$^{-1}$] |
| 1 | 1 | -0.01 |
| 1 | 2 | 0.05 |
| 1 | 3 | 0.06 |
| 2 | 1 | -0.01 |
| 2 | 2 | -0.02 |
| 2 | 3 | -0.02 |
| 3 | 1 | 0.00 |
| 3 | 2 | 0.00 |
| 3 | 3 | -0.01 |
| 4 | 1 | 0.05 |
| 4 | 2 | 0.05 |
| 4 | 3 | 0.00 |
| 5 | 1 | 0.03 |
| 5 | 2 | 0.03 |
| 5 | 3 | 0.04 |

(Table 6-17 continued)

| NFI | Elev. | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: net change in litter (changeCh,i) [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| 1 | 1 | -0.12 | 0.13 | -0.06 | -0.01 | -0.17 | -0.04 | 0.31 | 0.17 | 0.03 | -0.04 |
| 1 | 2 | -0.06 | 0.13 | -0.03 | 0.01 | -0.14 | 0.01 | 0.35 | 0.14 | 0.12 | 0.05 |
| 1 | 3 | -0.16 | -0.03 | -0.12 | -0.05 | -0.16 | -0.01 | 0.26 | 0.05 | 0.12 | 0.07 |
| 2 | 1 | -0.13 | 0.13 | -0.04 | -0.04 | -0.19 | -0.03 | 0.24 | 0.13 | 0.03 | -0.06 |
| 2 | 2 | -0.09 | 0.13 | -0.03 | -0.02 | -0.18 | 0.01 | 0.27 | 0.11 | 0.07 | 0.00 |
| 2 | 3 | -0.09 | 0.13 | -0.03 | -0.02 | -0.18 | 0.01 | 0.27 | 0.11 | 0.07 | 0.00 |
| 3 | 1 | -0.01 | 0.16 | 0.00 | 0.02 | -0.15 | 0.06 | 0.33 | 0.08 | 0.12 | 0.07 |
| 3 | 2 | -0.01 | 0.16 | 0.00 | 0.02 | -0.15 | 0.06 | 0.33 | 0.08 | 0.12 | 0.07 |
| 3 | 3 | -0.04 | 0.10 | -0.06 | 0.03 | -0.14 | 0.07 | 0.34 | 0.05 | 0.18 | 0.13 |
| 4 | 1 | 0.01 | 0.12 | -0.01 | 0.02 | -0.09 | 0.06 | 0.33 | 0.14 | 0.17 | 0.07 |
| 4 | 2 | 0.01 | 0.12 | -0.01 | 0.02 | -0.09 | 0.06 | 0.33 | 0.14 | 0.17 | 0.07 |
| 4 | 3 | 0.10 | 0.21 | 0.03 | 0.11 | -0.07 | 0.14 | 0.39 | 0.17 | 0.24 | 0.10 |
| 5 | 1 | 0.01 | 0.04 | -0.01 | -0.02 | -0.04 | 0.05 | 0.26 | 0.14 | 0.15 | 0.11 |
| 5 | 2 | 0.12 | 0.14 | 0.04 | 0.06 | -0.01 | 0.11 | 0.57 | 0.31 | 0.29 | 0.24 |
| 5 | 3 | 0.16 | 0.21 | 0.05 | 0.12 | -0.03 | 0.17 | 0.63 | 0.30 | 0.31 | 0.26 |

| NFI | Elev. | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: net change in litter (changeCh,i) [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| 1 | 1 | -0.01 | -0.02 | -0.07 | 0.30 | 0.00 | 0.09 | -0.06 | -0.17 | -0.03 | 0.04 |
| 1 | 2 | 0.03 | 0.05 | -0.05 | 0.20 | 0.04 | 0.13 | 0.10 | -0.01 | 0.09 | 0.12 |
| 1 | 3 | 0.01 | 0.06 | -0.03 | 0.05 | 0.06 | 0.11 | 0.36 | 0.25 | 0.28 | 0.23 |
| 2 | 1 | -0.05 | -0.05 | -0.07 | 0.26 | -0.01 | 0.10 | -0.10 | -0.22 | -0.07 | 0.01 |
| 2 | 2 | -0.03 | 0.00 | -0.06 | 0.21 | 0.02 | 0.12 | -0.08 | -0.18 | -0.04 | 0.02 |
| 2 | 3 | -0.03 | 0.00 | -0.06 | 0.21 | 0.02 | 0.12 | -0.08 | -0.18 | -0.04 | 0.02 |
| 3 | 1 | 0.00 | 0.07 | -0.06 | 0.12 | 0.06 | 0.12 | 0.07 | -0.06 | 0.05 | 0.06 |
| 3 | 2 | 0.00 | 0.07 | -0.06 | 0.12 | 0.06 | 0.12 | 0.07 | -0.06 | 0.05 | 0.06 |
| 3 | 3 | 0.04 | 0.11 | -0.04 | 0.03 | 0.12 | 0.16 | 0.02 | 0.00 | 0.08 | 0.05 |
| 4 | 1 | 0.03 | 0.08 | -0.05 | 0.18 | 0.09 | 0.17 | 0.32 | 0.11 | 0.14 | 0.20 |
| 4 | 2 | 0.03 | 0.08 | -0.05 | 0.18 | 0.09 | 0.17 | 0.32 | 0.11 | 0.14 | 0.20 |
| 4 | 3 | 0.02 | 0.12 | -0.05 | 0.20 | 0.18 | 0.25 | 0.40 | 0.23 | 0.23 | 0.27 |
| 5 | 1 | 0.04 | 0.10 | 0.03 | 0.14 | 0.02 | 0.18 | 0.24 | 0.09 | 0.08 | 0.08 |
| 5 | 2 | 0.13 | 0.18 | 0.05 | 0.20 | 0.07 | 0.25 | 0.46 | 0.24 | 0.23 | 0.20 |
| 5 | 3 | 0.15 | 0.20 | 0.05 | 0.19 | 0.13 | 0.33 | 0.46 | 0.29 | 0.29 | 0.24 |

| NFI | Elev. | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: net change in litter (changeCh,i) [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| 1 | 1 | 0.12 | -0.05 | -0.04 | 0.03 | -0.18 | 0.12 | -0.09 | 0.07 | -0.01 | -0.03 |
| 1 | 2 | 0.23 | -0.08 | 0.03 | 0.10 | -0.17 | 0.04 | -0.05 | 0.07 | -0.05 | -0.03 |
| 1 | 3 | 0.33 | -0.01 | 0.12 | 0.16 | -0.06 | 0.00 | 0.01 | 0.05 | -0.04 | -0.01 |
| 2 | 1 | 0.09 | -0.06 | -0.04 | 0.02 | -0.19 | 0.08 | -0.10 | 0.05 | -0.01 | -0.06 |
| 2 | 2 | 0.13 | -0.09 | -0.02 | 0.03 | -0.22 | 0.04 | -0.10 | 0.04 | -0.02 | -0.05 |
| 2 | 3 | 0.13 | -0.09 | -0.02 | 0.03 | -0.22 | 0.04 | -0.10 | 0.04 | -0.02 | -0.05 |
| 3 | 1 | 0.19 | -0.13 | 0.05 | 0.10 | -0.23 | -0.02 | -0.07 | 0.03 | -0.03 | -0.04 |
| 3 | 2 | 0.19 | -0.13 | 0.05 | 0.10 | -0.23 | -0.02 | -0.07 | 0.03 | -0.03 | -0.04 |
| 3 | 3 | 0.22 | -0.18 | 0.03 | 0.10 | -0.16 | -0.08 | -0.04 | 0.00 | -0.07 | -0.04 |
| 4 | 1 | 0.27 | -0.02 | 0.09 | 0.14 | -0.15 | 0.04 | -0.02 | 0.05 | -0.04 | -0.02 |
| 4 | 2 | 0.27 | -0.02 | 0.09 | 0.14 | -0.15 | 0.04 | -0.02 | 0.05 | -0.04 | -0.02 |
| 4 | 3 | 0.37 | -0.02 | 0.07 | 0.17 | -0.08 | -0.01 | 0.05 | 0.05 | -0.08 | -0.04 |
| 5 | 1 | 0.16 | 0.01 | 0.03 | 0.03 | -0.09 | 0.04 | 0.00 | 0.04 | -0.01 | -0.04 |
| 5 | 2 | 0.31 | 0.03 | 0.07 | 0.10 | -0.06 | 0.03 | 0.02 | 0.04 | 0.01 | -0.04 |
| 5 | 3 | 0.36 | 0.00 | 0.09 | 0.14 | -0.01 | -0.01 | 0.05 | 0.03 | 0.01 | -0.02 |

| NFI | Elev. | 2020 |
|---|---|---|
| | | CC12: net change in litter (changeCh,i) [t C ha$^{-1}$ yr$^{-1}$] |
| 1 | 1 | -0.07 |
| 1 | 2 | -0.10 |
| 1 | 3 | -0.08 |
| 2 | 1 | -0.09 |
| 2 | 2 | -0.12 |
| 2 | 3 | -0.12 |
| 3 | 1 | -0.13 |
| 3 | 2 | -0.13 |
| 3 | 3 | -0.12 |
| 4 | 1 | -0.07 |
| 4 | 2 | -0.07 |
| 4 | 3 | -0.06 |
| 5 | 1 | -0.02 |
| 5 | 2 | -0.02 |
| 5 | 3 | -0.02 |

(Table 6-17 continued)

| NFI | Elev. | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: net change in mineral soil (changeCs,i) [t C ha-1 yr-1] | | | | | | | | | |
| 1 | 1 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.001 |
| 1 | 2 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| 1 | 3 | -0.001 | -0.001 | -0.001 | -0.001 | -0.001 | -0.001 | -0.002 | -0.002 | -0.002 | -0.002 |
| 2 | 1 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 |
| 2 | 2 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.001 |
| 2 | 3 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.001 |
| 3 | 1 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.002 | 0.002 | 0.002 |
| 3 | 2 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.002 | 0.002 | 0.002 |
| 3 | 3 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4 | 1 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.002 | 0.002 | 0.002 |
| 4 | 2 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.002 | 0.002 | 0.002 |
| 4 | 3 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.003 |
| 5 | 1 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.002 |
| 5 | 2 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.003 | 0.003 | 0.003 | 0.004 |
| 5 | 3 | 0.002 | 0.002 | 0.003 | 0.003 | 0.003 | 0.003 | 0.002 | 0.003 | 0.003 | 0.003 |

| NFI | Elev. | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: net change in mineral soil (changeCs,i) [t C ha-1 yr-1] | | | | | | | | | |
| 1 | 1 | 0.001 | 0.001 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| 1 | 2 | 0.001 | 0.001 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| 1 | 3 | -0.002 | -0.002 | -0.002 | -0.002 | -0.001 | -0.001 | -0.002 | -0.001 | -0.001 | 0.000 |
| 2 | 1 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.000 | 0.000 |
| 2 | 2 | 0.001 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.001 | 0.001 | 0.001 | 0.001 |
| 2 | 3 | 0.001 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.001 | 0.001 | 0.001 | 0.001 |
| 3 | 1 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| 3 | 2 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| 3 | 3 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4 | 1 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.003 | 0.003 | 0.003 |
| 4 | 2 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.003 | 0.003 | 0.003 |
| 4 | 3 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.002 | 0.002 | 0.002 | 0.002 |
| 5 | 1 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| 5 | 2 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.003 | 0.004 | 0.004 | 0.005 |
| 5 | 3 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.003 | 0.003 | 0.003 | 0.004 |

| NFI | Elev. | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC12: net change in mineral soil (changeCs,i) [t C ha-1 yr-1] | | | | | | | | | |
| 1 | 1 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| 1 | 2 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| 1 | 3 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| 2 | 1 | 0.000 | 0.001 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2 | 2 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| 2 | 3 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| 3 | 1 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 |
| 3 | 2 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 |
| 3 | 3 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4 | 1 | 0.003 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 |
| 4 | 2 | 0.003 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 |
| 4 | 3 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| 5 | 1 | 0.002 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| 5 | 2 | 0.005 | 0.005 | 0.005 | 0.005 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 |
| 5 | 3 | 0.004 | 0.005 | 0.004 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 |

| NFI | Elev. | 2020 |
|---|---|---|
| | | CC12: net change in mineral soil (changeCs,i) [t C ha-1 yr-1] |
| 1 | 1 | 0.002 |
| 1 | 2 | 0.003 |
| 1 | 3 | 0.001 |
| 2 | 1 | 0.000 |
| 2 | 2 | 0.001 |
| 2 | 3 | 0.001 |
| 3 | 1 | 0.004 |
| 3 | 2 | 0.004 |
| 3 | 3 | 0.000 |
| 4 | 1 | 0.004 |
| 4 | 2 | 0.004 |
| 4 | 3 | 0.003 |
| 5 | 1 | 0.003 |
| 5 | 2 | 0.006 |
| 5 | 3 | 0.005 |

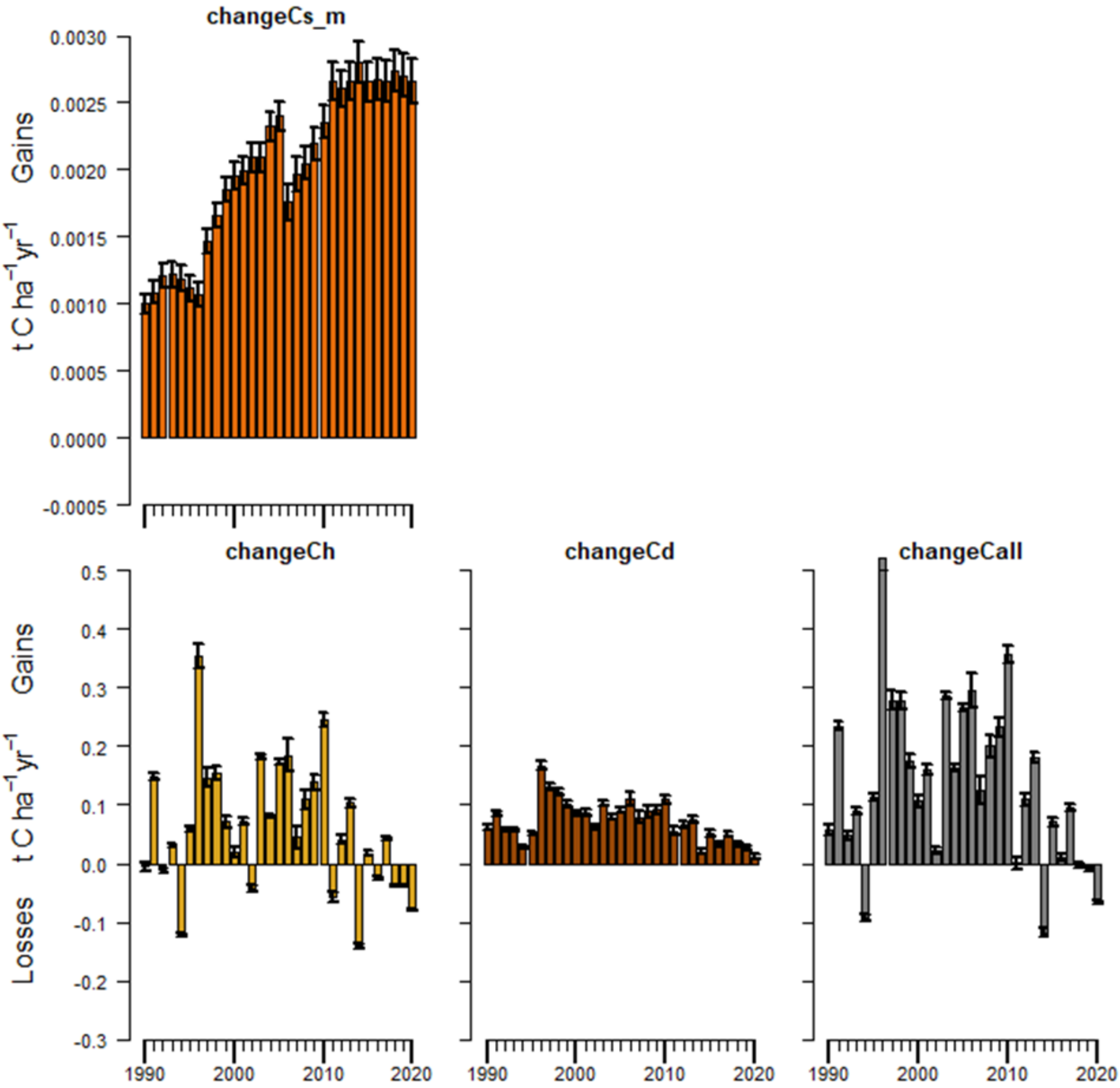



Figure 6-6 Mean carbon stock changes (changeC) for three pools mineral soil (s_m, 0–100 cm), litter (h), dead wood (d) and their sum (all) in t C ha$^{-1}$ yr$^{-1}$. Note the difference of the y-axis scale between changeCs_m and changeCh, changeCd and changeCall, respectively. Negative values indicate losses in carbon stock, positive values gains in carbon stock. The error bars indicate the double standard error.

### 6.4.2.7. Unproductive forests (CC13)

Unproductive forests consist of brush forests, inaccessible stands and unproductive forest not covered by the NFI. Unproductive forests exhibit a high variability (see examples of unproductive forests in Switzerland in FOEN 2014f).

For transparency reasons, productive and unproductive forest areas are reported separately. However, there is only scarce information available on unproductive forests. In unproductive forests, wood is not harvested for economic reasons. Only in exceptional cases there can be an intervention (e.g. moving a wood log that is blocking a hiking trail), but no wood is removed from the stand.

The NFI does not include unproductive stands CC13 in its regular inventory scheme because (1) the plots are not relevant for timber production or it is not possible to carry out precise measurements (brush forests), (2) the plots are inaccessible or (3) the NFI forest definition is not fulfilled (forest not covered by the NFI).

- Brush forests: Since brush forests have no direct economic value in terms of wood harvest, an inventory of these stands has not been attributed high priority. During NFI3, some plots in brush forests were visited for the first time, but only a limited number of attributes such as tree species, stem diameter and crown cover were collected.
- Inaccessible stands: Inaccessible stands are forests which cannot be visited because of safety reasons (see description in Brändli 2010: p. 89). They are mainly located in the Alps and often grow on sites of low productivity, including rocky sites and sites at high elevation near the tree line with a short vegetation period and low biological activity.
- Unproductive forests not covered by NFI: After the review of its first Initial Report (FOEN 2006h), Switzerland had to apply a forest definition for reporting activities under the Kyoto Protocol Art. 3.3 and Art. 3.4, which is different from the definition applied by the Swiss NFI and the Land Use Statistics AREA. The same definition is used for reporting under the UNFCCC and under the Kyoto Protocol. Because the definition of NFI and AREA was not in line with the specific requirements of the Kyoto Protocol forest definition, Switzerland had to develop an approach to classify certain AREA categories as forest. Those areas are not covered by the regular NFI and are situated in the threshold range between forests and alpine pastures with woody biomass of very low productivity. More specifically, it concerns combination categories of “pastures or grasslands with clusters of trees” (NOLC04 47/NOLU04 222, NOLC04 47/NOLU04 223, NOLC04 47/NOLU04 242) and “alpine sheep grazing pastures, in general with open forest” with “clusters of trees”) NOLC04 44/NOLU04 243; cf. Table 6-6).

**Carbon stocks in living biomass**

- Brush forest: Brush forests in Switzerland mainly consist of *Alnus viridis*, horizontal *Pinus mugo var. prostrata* with a percentage cover of 65% and 16%, respectively (Düggelin and Abegg 2011: Table 1). Following the NFI definition, brush forests are dominated by more than two thirds by shrubs. In a case study, Düggelin and Abegg (2011) analysed the carbon stock of living biomass of woody shrub species in Swiss brush forests and found an average value of 20.45 t C $ha^{-1}$.
- Inaccessible stands: Inaccessible stands are considered the same as brush forest regarding biomass and carbon stock. Their area is determined based on land cover ”tree vegetation” in typically remote and high-elevation land uses such as avalanche chutes (NOLU04 403 and 422; Table 6-6).
- Unproductive forests not covered by NFI: These forests are mainly associated with extensively pastured land where sparse tree vegetation (NOLC04 44 and 47; Table 6-6) is found. As those forests are assumed to grow preferably on bad site conditions, an average growing stock (>7 cm diameter) of 150 $m^3$ $ha^{-1}$ was assumed. Multiplied by the mean BCEF of 0.69 (i.e. weighted mean based on the quotient of stemwood volume and total tree biomass of coniferous and broadleaved trees as described in

Thürig and Herold 2013), an average biomass for these forests of 102.75 t $ha^{-1}$ was estimated, which corresponds to 51.38 t C $ha^{-1}$ (using a carbon content of 50%; see chp. 6.4.2.3).

The carbon stock of living biomass ($C_l$) in unproductive forest (CC13) was calculated as a weighted average of brush forest, inaccessible stands and unproductive forest not covered by NFI per spatial stratum:

$$stockC_{l,i,CC13} = F_i * stockC_{l,i,CC13bi} + (1- F_i) * stockC_{l,i,CC13u}$$

where $F_i$ is the fraction of the brush and inaccessible forest per spatial stratum i,

$stockC_{l,i,CC13bi}$ is the carbon stock in brush and inaccessible forest (20.45 t C $ha^{-1}$),

$stockC_{l,i,CC13u}$ is the carbon stock in forest on unproductive areas (51.38 t C $ha^{-1}$).

Table 6-18 shows the resulting carbon stocks in living biomass of unproductive forest per spatial stratum in t C $ha^{-1}$.

Table 6-18 Area of brush forest, inacessesibble forest and unproductive forest not covered by NFI, their areal fractions ($F_i$: fraction of brush and inaccessible forest per stratum i) and the resulting weighted carbon stocks in living biomass in t C $ha^{-1}$ of unproductive forests (CC13) specified for all spatial strata ($stockC_{l,i,CC13}$).

| NFI region | Elevation [m] | Brush forest [ha] | Inacessessible forest [ha] | Forest not covered by NFI [ha] | Fraction of brush and inaccessible forest ($F_i$) | Fraction of forest not covered by NFI ($1-F_i$) | Carbon stock in living biomass ($stockC_{l,i,CC13}$) [t C $ha^{-1}$] |
|---|---|---|---|---|---|---|---|
| 1 | <601 | 49 | 0 | 69 | 0.42 | 0.58 | 38.53 |
| | 601-1200 | 44 | 0 | 4'841 | 0.01 | 0.99 | 51.10 |
| | >1200 | 6 | 0 | 4'648 | 0.00 | 1.00 | 51.34 |
| 2 | <601 | 188 | 0 | 0 | 1.00 | 0.00 | 20.45 |
| | 601-1200 | 94 | 0 | 93 | 0.50 | 0.50 | 35.83 |
| | >1200 | 1 | 0 | 633 | 0.00 | 1.00 | 51.33 |
| 3 | <601 | 11 | 0 | 0 | 1.00 | 0.00 | 20.45 |
| | 601-1200 | 172 | 0 | 1'210 | 0.12 | 0.88 | 47.53 |
| | >1200 | 3'486 | 5 | 8'482 | 0.29 | 0.71 | 42.36 |
| 4 | <601 | 26 | 0 | 1 | 0.96 | 0.04 | 21.60 |
| | 601-1200 | 1'058 | 5 | 589 | 0.64 | 0.36 | 31.48 |
| | >1200 | 42'795 | 50 | 18'808 | 0.69 | 0.31 | 29.88 |
| 5 | <601 | 243 | 1 | 3 | 0.99 | 0.01 | 20.83 |
| | 601-1200 | 2'249 | 0 | 275 | 0.89 | 0.11 | 23.82 |
| | >1200 | 17'776 | 7 | 2'568 | 0.87 | 0.13 | 24.35 |

**Carbon stocks in dead wood, in litter, and in mineral soil**

As stated above, CC13 consists of different types of forests. Carbon stocks in dead wood, litter and in mineral soil under unproductive forests reveal a high spatial heterogeneity, and specific data are not available.

So far, there are no data available for carbon stocks in dead wood in unproductive forests (CC13). Dead wood on CC13 forest stands was assumed to be zero.

Carbon stocks of litter on CC13 were assigned to the mean value of the modelled CC12 litter stocks with Yasso07 for the inventory period (see Table 6-16).

Soil carbon stocks were assumed to be the same as for productive forests (Nussbaum and Burgos 2021; see Table 6-4).

Carbon stocks in dead wood, in litter, and in mineral soil for CC13 are listed in Table 6-4.

**Carbon stocks changes in living biomass**

There are only few case studies on carbon stocks in unproductive forests, but similarly to neighbouring countries with forests in mountainous regions, there are no repeated forest inventory data available for these forests (also known as "mountain forest without harvest"). As no harvesting is conducted in unproductive forests, gross growth and cut and mortality of unproductive forest were assumed to be in equilibrium. This approach is confirmed by three studies in which basal area and crown cover were used as a proxy for the stock of living biomass (Huber and Thürig 2014; Ginzler 2014; Huber and Frehner 2013). An increase in basal area or crown cover, respectively, was positively correlated with an increase in living biomass (e.g. Nowak and Crane 2002). Living biomass in brush forests was increasing during the stage of establishment: the stand developed from a stand with grasses, herbs and some shrubs towards a stand dominated by shrubs and with a denser crown cover. A decrease in crown cover in unproductive forests was observed when natural disturbances like avalanches or rock fall partially damaged the stand. The following studies provide evidence that living biomass in unproductive forests is not a source of carbon:

- Huber and Thürig (2014) analysed the available data on diameters of the terrestrial inventories NFI3 and NFI4 (2009–2012). The authors found that the number of trees had increased over the approximately 6 year period between the two inventories. Since no allometric functions were available for these stands, it was not possible to calculate stocks from these data. The authors estimated an increase in the mean basal area from 4.59 $m^2$ $ha^{-1}$ in 2006 to 5.47 $m^2$ $ha^{-1}$ in 2012. A repetition of this analysis based on data from sample plots visited in the latest three years of the NFI4 and the first 2 years of the NFI5 (2015–2019) shows an identical trend, i.e. an increase in basal area from 6.02 $m^2$ $ha^{-1}$ to 7.99 $m^2$ $ha^{-1.}$
- Ginzler (2014) analysed the crown cover density of 135 aerial photographs between 2006 (NFI3) and 2011 (NFI4) and found no statistical change in crown cover density of well-established, existing brush forests. The terrestrial NFI data, however, showed a slight increase in the basal area of trees in brush forests.
- Huber and Frehner (2013) showed that the expansion of Green Alder (*Alnus viridis*) in eastern Switzerland has doubled in the past 75 years. Especially in the Alps or at unproductive sites, brush forests were expanding as summer pastures were abandoned. At these sites, an increase in crown cover was observed which correlates with an increment in carbon stocks. A literature review by Huber and Frehner (2012; for an overview see FOEN 2014f) showed that Green Alder has in general a strong annual gross growth, not only in very young stands, and that stands of Green Alder can be very vital at an age of over 100 years.

Considering the observed dynamics in Swiss brush forests, it was concluded that living biomass in unproductive forests was not a net source of carbon over the last decades. Applying a Tier 1 approach, living biomass is assumed to be in equilibrium. In Table 6-4, this approach is transcribed into "gains ($gainC_{l,i,13}$) = losses ($lossC_{l,i,13}$) = 0" and reported as "NE" in CRF Table4.A.

**Carbon stocks changes in dead wood, in litter, and in mineral soil**

There are no repeated measurements of carbon stocks in dead wood, in litter, and in mineral soil.

Above, transparent and verifiable information is given that in Switzerland living biomass in brush forest is not decreasing. In principal, an increase in biomass leads to an increase in dead wood and litter production, which in turn can lead to an accumulation in soil carbon. Based on these conceptional considerations, it was concluded that dead wood, litter, and mineral soil in unproductive forests were not a net source of carbon over the last decades. Applying a Tier 1 approach, thus, dead wood, litter, and mineral soil are assumed to be in equilibrium. In Table 6-4, this approach is transcribed into "$changeC_{d,i,11}$= $changeC_{h,i,11}$ = $changeC_{s,I,13}$ = 0" and reported as "NE" in CRF Table4.A.

The Tier 1 approach is supported by the following evidences:

- Unproductive forest stands occur on higher elevation where microbiological processes in soils are slow (Hagedorn et al. 2010; Davidson and Janssens 2006).
- Unproductive forests grow on poor or rocky sites with thin or no organic layer. Brush forest protect the soils; in particular Alder brush is not even destroyed by avalanches or small-to-medium rock fall (Huber and Frehner 2012). By stabilizing soils, brush forests act as a good protection against soil erosion (Richard 1995; Stangl 2004).
- Green Alder has an ameliorative effect on the soil with its nitrogen-fixing root nodules (Huber and Frehner 2012). Amelioration of soils enables an increase in biomass production which on the other hand increases the amount of litter and dead wood and finally leads to accumulation of soil carbon.
- No active logging occurs on unproductive stands and consequently, there is no human impact on the soils, litter and dead wood.

By providing this transparent and verifiable information (survey of peer-reviewed literature and reasoning based on sound knowledge of likely system responses), the requirements for an application of the Tier 1 approach are considered to be fulfilled.

For conversions within Forest land (CC13 to CC12 and CC12 to CC13) no changes in carbon stocks of mineral soil were calculated because carbon stocks of mineral soil are the same for CC12 and CC13. With the exception of brush forests, it is very likely that carbon stocks in mineral soil are smaller under unproductive forests than under productive forests. As the area changing from CC13 to CC12 is larger than from CC12 to CC13 (see Table 6-9), by applying the stock-difference method (see Table 6-3) with the same carbon stocks for mineral soil under productive and unproductive forest, the resulting emissions are not underestimated.

#### 6.4.2.8. Afforestations (CC11)

**Carbon stocks and carbon stock changes in living biomass**

Thürig and Traub (2015: Table 6) estimated the average carbon stock and gains and losses in living biomass of afforestations and young stands in Switzerland. Data are shown in Table 6-4.

In Switzerland, land-use change from non-forest to forest is usually not caused by plantation but by abandonment of agricultural land-use (Rutherford et al. 2008, Rigling and Schaffer 2015, Brändli et al. 2020). Such newly forested areas typically exhibit a large diversity in diameter at breast height (DBH) and tree age. Afforested stands established by plantation or even-aged young forest stands, however, are generally characterized by a large number of trees in small DBH classes and few trees in large DBH classes. Thürig and Traub (2015) selected NFI plots to represent both types of afforestation. Young stands were defined as stands that changed from non-forest to forest between two consecutive NFIs with at least 85% of the trees with a DBH smaller or equal to 20 cm. As there is almost no land-use change from non-forest to forest below 600 m above sea level, results were stratified for below 1200 m above sea level and above 1200 m. As a consequence of the plot selection, small losses caused by natural mortality or cut of single trees occur.

**Carbon stocks and carbon stock changes in dead wood and in litter**

On afforestations, carbon stocks in dead wood and in litter were assumed to be zero (IPCC 2006, Volume 4, chp. 4.3.2). Applying the stock-difference calculation approach (Table 6-3), calculated changes in the dead wood and in the litter pool after an afforestation are zero since the major part of afforestations (CC11) in Switzerland occur on Grasslands and in Settlements (see Table 6-9) where there is no litter and no dead wood (Table 6-4).

**Carbon stocks and carbon stock changes in mineral soil**

The estimates for mineral soil carbon stocks as displayed in Table 6-4 are based on Nussbaum and Burgos (2021), i.e. the same as for productive and unproductive forests. Carbon stock changes in mineral soils of afforestations were calculated with the stock-difference method (see Table 6-3).

### 6.4.2.9. Organic soils

**Carbon stock in organic soils**

The mean soil organic carbon stock (0–30 cm) for organic soils under Forest land is 145.6±24.1 t C $ha^{-1}$ (Wüst-Galley et al. 2016). This value was used for CC11, CC12, and CC13 (Table 6-4).

**Changes in carbon stocks of organic soils**

Drainage of forests is not a permitted practice in Switzerland (Swiss Confederation 1991). However, it is possible that parts of the Swiss forest were drained before 1990 or were established on drained areas. Abegg (2017) estimated the amount of drained organic soils by comparing information on drainage from NFI plots with spatial data of organic soils in Switzerland produced by Wüst-Galley et al. (2015): 3% of organic soils in Forest land appeared to be subject to drainage.

For the calculation of changes in carbon stocks of organic soil, the default emission factor of 2.6 t C $ha^{-1}$ $yr^{-1}$ was applied for all forest stands (CC11, CC12, and CC13; Table 6-4) according to the Wetlands Supplement (IPCC 2014a: Table 2.1).

### 6.4.2.10. $N_2O$ emissions from Forest land

Fertilisation of forests is prohibited by the Federal Act on Forest and the adherent ordinance (Swiss Confederation 1991, 1992). The Federal Act on Forest (Art. 18) states: "The use of environmentally hazardous substances in the forest is prohibited" with a direct reference to the Federal Act on the Protection of the Environment (Swiss Confederation 1983). Details of the Federal Act on Forest Art. 18 had initially been regulated in the Ordinance on Forest (Art. 27). Since 2005, the Chemical Risk Reduction Ordinance (Swiss Confederation 2005: Art. 4) prohibits the application of fertilisers, including liming, in forests. Hence, the application of fertilisers, including liming in forests was prohibited since 1991 in Switzerland. Furthermore, these management practices have never been common practice in Swiss forestry. There is thus considerable evidence to justify the assumption that this situation is valid since 1990. Additionally, the reporting of $N_2O$ emissions from fertiliser application in the agriculture sector encompasses all fertilisers applied in Switzerland. Therefore, no emissions were reported in category A in CRF Table4(I) (notation key "NO").

$N_2O$ emissions from drainage of organic soils was calculated for Forest land with an emission factor of 2.8 kg $N_2O$-N $ha^{-1}$ for 3% of the area of organic soils (see chp. 6.4.2.9) and reported in category A in CRF Table4(II). The emission factor used is the default value given in the Wetlands Supplement (IPCC 2014a: Table 2.5) for temperate forest land.

The calculation of emissions reported in CRF Table4(III) and CRF Table4(IV), i.e. direct $N_2O$ emissions from nitrogen mineralisation in mineral soils and indirect $N_2O$ emissions from managed soils, is described in chp. 6.10.

### 6.4.2.11. Emissions from wildfires

Data on wildfires affecting Forest land were obtained from cantonal authorities and were compiled by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL, Swissfire database). These data are updated regularly based on analysing data from cantonal archives (Pezzatti et al. 2019). Table 6-19 shows the time series 1990 to 2020 of affected areas and associated emissions.

As controlled burning of forest stands is not allowed in Switzerland all fires in forests were considered wildfires. All fires were assigned to productive forests. In this way, emissions are not underestimated, since the available fuel of productive forests is higher than the carbon stocks of afforestations and unproductive forests. Moreover, this approach reflects reality quite well, since fires on afforestations or in unproductive forests are rather unlikely to occur for the following reasons:

- Non-Forest land to Forest land (or Afforestations under the Kyoto Protocol Art. 3.3) and unproductive forest: the available fuel is small, there is very little dead woody material on the surface which can catch fire (Zumbrunnen et al. 2012).

- Unproductive forests: the available fuel is small since tree cover is not very dense (Zumbrunnen et al. 2012). Moreover, in remote areas the cause of fire is restricted to lightning strikes.

$CO_2$ emissions from wildfires were noted “IE” in CRF Table4(V) and are encompassed in the data in CRF Table4.A. Losses in living biomass are reflected in the NFI data set. Carbon changes in dead wood, in litter and in mineral soil calculated with Yasso07 also cover the influence of forest fires and other disturbances by using NFI data as an input (see chp. 2.3.3 in Didion 2020a).

- $CH_4$ and $N_2O$ emissions from wildfires (Table 6-19) were calculated using equation 2.27 in Volume 4 of IPCC (2006) with the following parameters:
- For $CH_4$ the default emission factor of 4.7 g $kg^{-1}$ dry matter burnt and for $N_2O$, the default emission factor of 0.26 g $kg^{-1}$ dry matter burnt were applied (IPCC 2006, Volume 4, Table 2.5).
- The mass of available fuel encompasses carbon stocks of living biomass, dead wood, and litter. On average, the amount of living biomass amounts to 95.42 t C $ha^{-1}$ or 190.83 t biomass $ha^{-1}$. This value was derived from the mean growing stock in NFI1, NFI2, NFI3 and NFI4 2015–2019 (see Table 6-15) as a weighted value over the reporting period of the regions affected by forest fires (82% of the fires occur in the Southern Alps, 15% in the Central Alps). In the same way, average carbon stocks in dead wood and in litter were calculated per NFI intersurvey period based on data in Table 6-16. They amounted to 19.67 t C $ha^{-1}$ or 39.34 t biomass $ha^{-1}$ on average for the reporting period.
- The fraction of the biomass combusted was 0.45 (IPCC 2006, Volume 4, Table 2.6).

$CH_4$ and and $N_2O$ emissions caused by wildfires are reported in CRF Table4(V). $CH_4$ and $N_2O$ emissions from wildfires of all types of forests were reported under 4(V)A1, because it is not known which fires occur on Forest land remaining forest land and which on Land converted to forest land. Consequently, category 4(V)A2 has the notation key "IE".

Table 6-19 Forest land affected by wildfires (WSL, Swissfire database) and resulting $CH_4$ and $N_2O$ emissions.

| Forest land | Unit | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Area burnt | ha | 1'067 | 70 | 28 | 18 | 233 | 363 | 233 | 1'390 | 198 | 11 |
| $CH_4$ | t | 519 | 34 | 14 | 9 | 114 | 177 | 113 | 676 | 96 | 5 |
| $N_2O$ | t | 28.7 | 1.9 | 0.8 | 0.5 | 6.3 | 9.8 | 6.3 | 37.4 | 5.3 | 0.3 |

| Forest land | Unit | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Area burnt | ha | 47 | 13 | 418 | 527 | 25 | 41 | 112 | 238 | 39 | 50 |
| $CH_4$ | t | 23 | 6 | 204 | 257 | 12 | 20 | 55 | 116 | 19 | 24 |
| $N_2O$ | t | 1.3 | 0.3 | 11.3 | 14.2 | 0.7 | 1.1 | 3.0 | 6.4 | 1.0 | 1.4 |

| Forest land | Unit | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area burnt | ha | 26 | 171 | 26 | 24 | 43 | 43 | 256 | 106 | 55 | 16 | 11 |
| $CH_4$ | t | 13 | 83 | 13 | 12 | 21 | 21 | 125 | 51 | 27 | 8 | 5 |
| $N_2O$ | t | 0.7 | 4.6 | 0.7 | 0.7 | 1.2 | 1.1 | 6.9 | 2.8 | 1.5 | 0.4 | 0.3 |

### 6.4.2.12. Emissions from controlled burning

Emissions from controlled burning on Forest land covers the burning of harvest residues only since controlled burning of whole forest stands is not allowed in Switzerland.

The amount of natural residues burnt openly was estimated by INFRAS (2014). Open burning of such residues is regulated in the Ordinance on Air Pollution Control OAPC (Swiss Confederation 1985: Art. 26b). In Switzerland cantonal authorities are responsible for the enforcement of the OAPC regulations. For INFRAS (2014) an inquiry of some cantonal authorities was performed in order to assess the activity data for these processes.

$CH_4$ and $N_2O$ emissions were calculated by a Tier 2b approach based on chp. 5.2. in Volume 5 of IPCC (2006). The emissions of burning of residues in forestry were calculated by multiplying the annual estimate of residues burnt (in kt, see FOEN 2022b: chp. 7.3) by emission factors as documented in EMIS 2022/5C2: 6.8 kg $t^{-1}$ for $CH_4$ and 0.180 kg $t^{-1}$ for $N_2O$.

$CO_2$ emissions from controlled burning were noted “IE” in the CRF Table4(V) and are encompassed in the data in CRF Table4.A since carbon losses in living biomass are reflected in the NFI data set.

The emission factors of $CH_4$, $N_2O$ and NMVOC of burning of residues in forestry were calculated based on the EMEP/EEA Guidebook (EMEP/EEA 2019), see also documentation in EMIS 2022/5C2 and 4VA1 Abfallverbrennung in der Land- und Forstwirtschaft.

#### 6.4.2.13. NMVOC emissions

Estimates for annual biogenic emissions of NMVOC in Switzerland for forests include emissions from the forest stands, wildfires and emissions from burning of residues in forestry as shown in FOEN (2022b: chp. 7.3 and 7.4).

The biogenic NMVOC emissions from forest stands were calculated for the years 1900–2020 and 2050 on the basis of monthly maps for the parameters temperature, vegetation period and for 12 different tree species (Meteotest 2019a and EMIS 2022/11C Wald). This corresponds to the simplified method according to chapter 11C in the EMEP/EEA guidebook (EMEP/EEA 2019).

In 1990, NMVOC emission from forest stands was 60.83 kt; from 1990 to 2020 they increased on average by 0.34% per year. The emissions from wildfires and from burning of residues in forestry fluctuated between 0.02 and 0.74 kt over the same period.

## 6.4.3. Uncertainties and time-series consistency

### 6.4.3.1. Uncertainties

<u>Activity data</u>

Uncertainties of activity data of category 4A Forest land are described in chp. 6.3.3. Table 6-5 lists the relative uncertainties in the LULUCF sector. The relative uncertainty of the total carbon stock change for Forest land was calculated as follows.

<u>Carbon stock change factors</u>

Uncertainties were estimated for the pools living biomass, dead wood, litter and soil. One source of uncertainty common to all pools is the error resulting from the estimates of changes in the pools between two NFIs based on shifting samples of sample plots common to NFI3 and five-year NFI4 subsets (see chp. 6.4.2.1 ”Updating NFI data”), i.e. 2009–2011 (GHG inventory submission 2013), 2009–2012 (GHG inventory submission 2014), 2009–2013 (GHG inventory submissions 2015 and 2016), 2011–2015 (GHG inventory submissions 2017 and 2018), and 2013–2017 (GHG inventory submissions 2019 and 2020). This was taken into account to obtain an multi-annual uncertainty estimate valid for the time of the second commitment period of the Kyoto Protocol.

Living biomass – sources of uncertainty (relative uncertainty, 2 SE) considered:

- NFI sampling between NFIs 3 and 5-year NFI4 subsets: 30.2%
- Carbon content in solid wood: 2% based on 2% relative standard deviation (RSD) in Monni et al. (2007), and 4-8% RSD in Lamlom and Savidge (2003)
- Biomass expansion function (for Forest land in the Swiss GHG inventory, allometric functions for individual trees were applied) and conversion into mass with wood density: 21.2% sampling uncertainty and 22.2% model uncertainty; based on Lehtonen and Heikkinen (2016).

Thus, the total uncertainty of net carbon stock change in living biomass ($U_{liv.biom}$) in terms of carbon per unit area can be calculated following equation 3.1 in chp. “'Quantifying Uncertainties” (Volume 1 of IPCC 2006):

$$U_{liv.biom} = \sqrt{30.2^2+2^2+21.2^2+22.2^2} = 43.1\%$$

Dead wood, litter, soil – sources of uncertainty considered in the Monte Carlo simulation approach as described in Didion 2020a (chp. 2.3):

- NFI sampling between NFIs 3 and 5-year NFI4 subsets
- carbon input estimates obtained from the NFI (measurement errors, allometries, etc.) (Didion 2020a: chp. 2.3.2)
- decomposition parameters used in the Yasso07 model (Didion 2020a: chp. 2.3.1).

The resulting relative uncertainties are:

- $U_{Soil}$ = 37.0%
- $U_{Litter}$ = 96.7%
- $U_{Dead\ wood}$ = 16.6%.

Overall uncertainty 4A

The total uncertainty associated with carbon stock change in all four pools was estimated using equation 3.2 in chp. “Quantifying Uncertainties” (IPCC 2006, Volume 1):

$$U_{tot} = \frac{\sqrt{(U_{\text{liv.biom}} * X_{\text{liv.biom}})^2 + (U_{soil} * X_{soil})^2 + (U_{Litter} * X_{Litter})^2 + (U_{Deadwood} * X_{Deadwd})^2}}{|X_{\text{liv.biom}} + X_{soil} + X_{Litter} + X_{Deadwood}|}$$

with mean carbon stock changes in

- living biomass ($X_{liv.biom}$): 1.060 t C $ha^{-1}$ $yr^{-1}$
- soil ($X_{Soil}$): -0.002 t C $ha^{-1}$ $yr^{-1}$
- litter ($X_{Litter}$): -0.009 t C $ha^{-1}$ $yr^{-1}$
- dead wood ($X_{Dead\ wood}$): -0.071 t C $ha^{-1}$ $yr^{-1}$

where positive values refer to gains in carbon stock; negative values refer to losses in carbon stock. Thus, the resulting relative uncertainty of the total carbon stock change for Forest land is 46.7%. This value is used for the whole inventory period (see also Table 6-5).

Drainage of organic soils ($CO_2$; pool organic soil in CRF Table4.A)

The $CO_2$ emissions from drained organic forest soils are very small (<0.1% of category 4A total) and were neglected in the uncertainty calculation.

Drainage of organic soils ($N_2O$; category 4(II))

The contribution of Forest land to $N_2O$ emissions from drained organic soils (category 4(II)A) is small (around 5%). Its uncertainty was included in the uncertainty calculation for Wetlands (see chp. 6.7.3).

Biomass burning ($CH_4$, $N_2O$; category 4(V))

The emission factor uncertainty for category 4(V) (biomass burning, wildfires) is 70%. It is derived from the uncertainty of the combustion factor from IPCC (2006, Volume 4, Table 2.6, mean = 0.45, 2SE = 0.32). The activity data uncertainty for wildfires is 30% (see chp. 6.3.3).

#### 6.4.3.2. Time-series consistency

Consistent time series of annual carbon stocks in living biomass were calculated backward or forward starting from the growing stock 2005, as derived from NFI3 (see chp. 6.4.2.4).

Consistent time series of annual carbon stocks in dead wood, in litter and in mineral soil were calculated with the model Yasso07 (see Didion 2020a and chp. 6.4.2.6).

### 6.4.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

#### 6.4.4.1. Suitability of the soil carbon model Yasso07 for application for forests in Switzerland

The validity of the Yasso07 model in Swiss forests was examined by Didion et al. (2014a). The study analysed, among other, the accuracy of Yasso07 for reproducing observed carbon decomposition in litter and dead wood in Swiss forests. The authors found that no significant differences existed between simulated and observed remaining carbon in foliage and fine root litter after 10 years and in lying dead trees after 14 to 21 years.

#### 6.4.4.2. Afforestation – Carbon stock and changes in growing stock

A comparison of Swiss carbon data for living biomass in afforestations with IPCC (2006) default values and NFI data from neighbouring countries is included in Thürig and Traub (2015). The study supports the plausibility of the Swiss estimates: they are well within the range of the IPCC default values as well as the Austrian and German estimates.

Swiss estimates were also compared with literature values. Based on data of the German forest inventory (Bundeswaldinventur II), Paul et al. (2009) reported a carbon sequestration rate of 2.8 t C $ha^{-1}$ $yr^{-1}$ in the first 20 years following an afforestation.

#### 6.4.4.3. Afforestation – Litter

In an experiment by Zimmermann and Hiltbrunner (2012; COST E639-project “Turnover and stabilization of soil organic matter: effect of land-use change in alpine regions”), litter accumulation in a 40 year old afforestation with Norway Spruce was determined. The authors found accumulation rates of 0.17-0.20 t C $ha^{-1}$ $yr^{-1}$. Further relevant studies are discussed in chp. 11.3.1.2.

#### 6.4.4.4. Carbon balance of two mountain forest ecosystems in Switzerland – Net ecosystem exchange and soil respiration

Measurements of the net ecosystem exchange (NEE) and of soil respiration were conducted at a montane mixed forest over 5 years (Lägeren; 2005–2009; NFI production region 2), and at a subalpine coniferous forest over 12 years (Davos; 1997–2009; Swiss Plateau, NFI production region 4).

(1) Etzold et al. (2011) determined the net ecosystem exchange (NEE) by eddy covariance (EC) measurements. EC measurements as well as biometric estimates indicate that both sites with two different mountain forest types were significant carbon sinks in the respective periods. NEE of the Lägeren forest ranged from -366 to -662 g C $m^{-2}$ $yr^{-1}$ (mean: -415 g C $m^{-2}$ $yr^{-1}$), and of the Davos forest from -47 to -274 g C $m^{-2}$ $yr^{-1}$ (mean: -154 g C $m^{-2}$ $yr^{-1}$). For comparison, net carbon stock change for 4A1 amounted to -55.44 g C $m^{-2}$ $yr^{-1}$ in 2020 (CRF Table4.A).

(2) Rühr and Eugster (2009) measured soil respiration rates at these two Swiss forest sites. Modelled changes in soil carbon storage with the dynamic soil carbon model Yasso07 gave comparable results with measured soil respiration. Rühr and Eugster (2009) found that soils at the alpine site Davos acted as a significant carbon sink. Soils at the Lägeren site were

neither a significant carbon sink nor a significant carbon source. This domestic study confirms the broadly spread knowledge that it is very difficult to detect short term changes in soil carbon stocks, since the uncertainty of the measurement is often higher than the actual change of the annual estimates (e.g. Falloon and Smith 2003).

#### 6.4.4.5. Changes in soil carbon stocks – Soil organic carbon (SOC) data set of the Swiss Soil Monitoring Network

The objective of the Swiss Soil Monitoring Network (http://www.nabo.ch; NABO) is to assess soil quality in the long term and to validate appropriate soil protection measures. NABO operates about 110 long-term monitoring sites throughout Switzerland covering all relevant land uses, such as cropland, grassland, and forest. Most of them were sampled for the first time between 1985 and 1989 and resampled every five years ever since (SAEFL 1993).

At each site, four replicate bulked soil samples from the upper soil layer 0–20 cm are taken within an area of 10m*10m. Each bulked sample consists of 25 single cores taken according to a stratified random sampling scheme. Further details are provided by SAEFL (2000a) and FOEN (2015p). Currently, results of sampling campaigns 1 to 6 are available for Forest Land, Grassland, and Cropland.

The spatial variation of bulk density was included in calculating the carbon stocks. Bulk density and soil skeleton (>2 mm) were measured repeatedly for all monitoring sites at the occasion of sampling campaigns 4 to 6 (2000–2014), but not in the previous campaigns. The mass of fine earth (<2 mm; $M_{FE}$) per total soil volume ($V_{tot}$, including skeleton and pores) was determined for four volumetric samples 0–20 cm per site and campaign to derive the so-called apparent density of fine earth ($D = M_{FE} / V_{tot}$). Subsequently, SOC stocks 0–20 cm [t/ha] were calculated by D [g/cm$^3$] * SOC [% w./w.] * 20 [cm]. For each site, the site-specific apparent density was used; repeated apparent density measurements per site were used to account for the variability of the bulk density.

The data presented here are based on samples collected from 1985 to 2014 at 27 forest sites (NABO 2021). SOC stocks for the top 20 cm of forest soils ranged from 38 to 165 t C ha$^{-1}$ with a mean of 72 t C ha$^{-1}$, although only few sites have stocks higher than 90 t C ha$^{-1}$ (Figure 6-7). There were no significant changes in SOC stocks over time except for the periods between the second and third, and the third and fourth sampling campaigns due to the exceptionally high SOC stocks in the third campaign. Previous NABO studies showed that the elevated SOC stocks for the third sampling campaign must be considered as artefact induced by sub-optimal conditions during field work. These samples were collected earlier in the year and, thus, soils were moister. It is known that soil carbon has a high natural variation which may be pronounced if soil moisture differences are high. For instance, six resamplings within three years at two forest sites revealed short-term variation of SOC contents between ±1.8% and ±0.6% (single standard errors; Keller et al. 2006).

The monitoring scheme applied by NABO is able to detect relative changes in SOC contents of roughly 2.5% per 10 years for forest soils (minimum detectable change for about 30 monitoring sites including three or more sampling campaigns). Regarding the measured SOC stocks (mean ≈ 72 t ha$^{-1}$), this corresponds to a minimum detectable change of roughly 0.18 t C ha$^{-1}$ yr$^{-1}$ for SOC stocks. In comparison, the mean change in SOC obtained with Yasso07 for the period 1991–2010 was -0.00075±0.00053 t C ha$^{-1}$ yr$^{-1}$ (2SE; based on data in Didion and Thürig 2017). This value is several orders of magnitude smaller than the minimum detectable change that can be identified in the NABO monitoring scheme.

In conclusion, NABO data indicate that Forest land mineral soils did not act as a significant net source or net sink of carbon over the last 30 years.

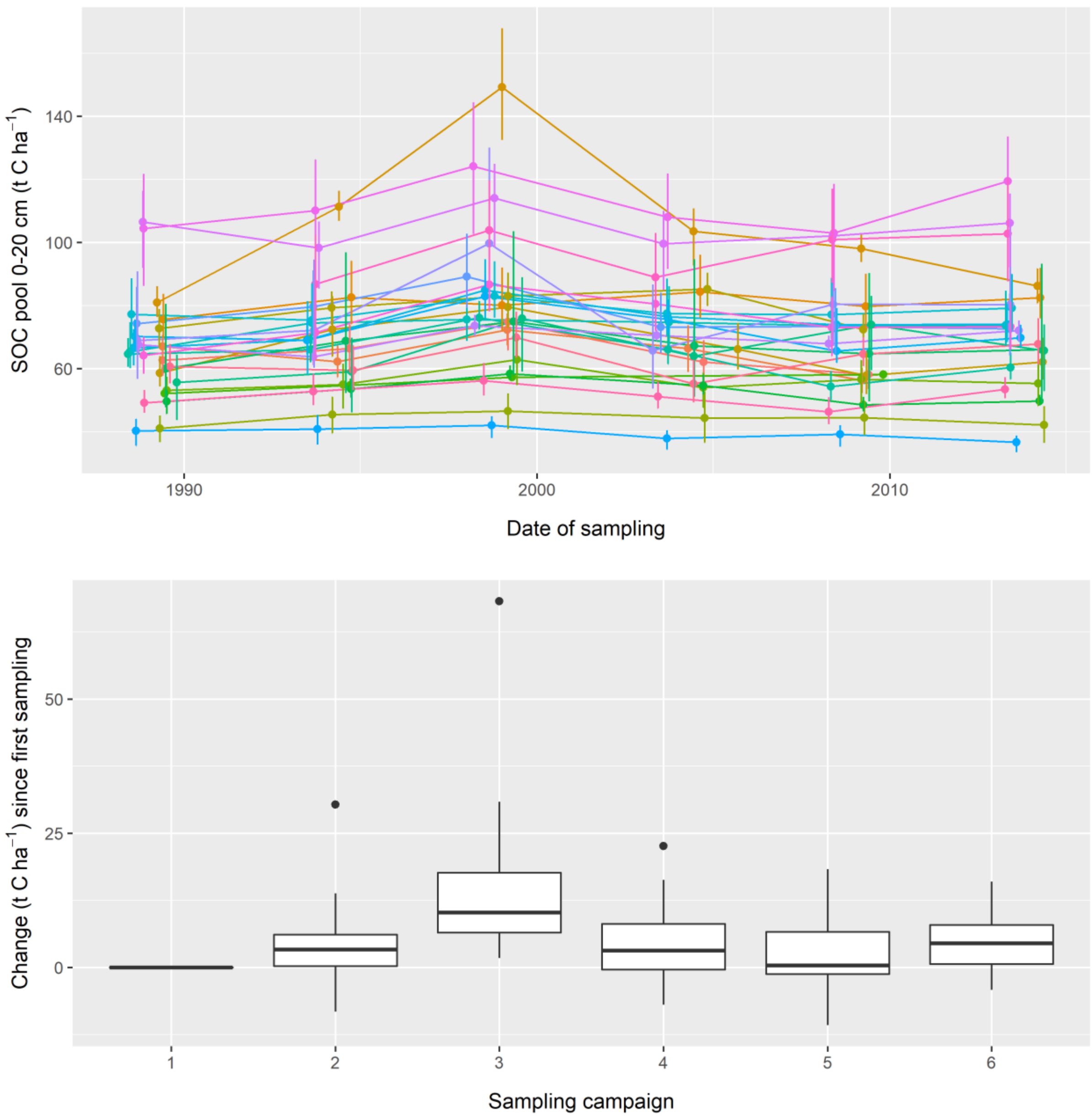



Figure 6-7 Measured SOC stocks for topsoils (0–20 cm) and their changes for 27 NABO long-term monitoring sites in forest during the time period 1985–2014. The elevation of the sites ranges from 383 to 1690 m a.s.l. Top panel: SOC stocks 0–20 cm per site and sampling; the dots indicate the mean and the bars the range of 5% and 95% percentiles of bootstrap samples taking into account the variability in SOC contents of the individual replicates per site and sampling as well as the variations of the bulk density. Bottom panel: boxplot of changes in SOC stocks in each case related to the first sampling (boxes indicate the lower und the upper quartiles with the median indicated; lines include all observations inside the range of 1.5 times the interquartile distance, observations beyond that range are indicated as dots).

#### 6.4.4.6. Uncertainty Estimates

The uncertainty for carbon stock changes in dead wood, in litter and soil organic matter reported by Finland, where the Yasso07 model is also applied, was 31.5% for the year 2015 (Statistics Finland 2017: chp. 6.4.3.2). For the total uncertainty of change in living biomass, Finland reported 20% (Statistics Finland 2017: chp. 6.4.3.1).

### 6.4.5. Category-specific recalculations

The following recalculations were implemented. Major recalculations which contribute significantly to the differences in net emissions and net removals of sector 4A between the latest and the previous submissions are additionally presented in chp. 10.1.2.4.

- 4A: Activity data 1990–2019 were updated (see chp. 6.3.5). With the inclusion of the last outstanding tranche of AREA4 data (see chp. 6.3.4.3), the following changes as a result of the recalculation were noted: Afforestation (CC11) decreased by up to 0.20 kha (in the years 2018 and 2019, corresponding to 33.3% relative decrease) and unproductive forest (CC13) decreased by up to 0.84 kha (corresponding to 0.8% relative decrease). The reallocations took place almost exclusively in the years since 2013. For productive forest (CC12), a mixed signal resulted. The area decreased with up to 0.90 kha (corresponding to 0.1% relative decrease) in 2014–2019, whereas it increased by up to 0.58 kha (corresponding to 0.1% relative increase) in 2010–2013. In the years before the above-mentioned periods, the changes in the respective CC areas as a result of recalculation were significantly smaller (in most years close to zero) or not pronounced at all.
- 4A: Updated estimates for carbon stocks in mineral soils were available from Nussbaum and Burgos (2021; see chp. 6.4.2.5). With access to a sample twice as large, the spatial statistical analysis of soil profile data using the machine learning approach “random forest” replaced the geostatistical analysis of Nussbaum et al. (2012, 2014). The new data set affected carbon stock changes in subcategory 4A2 Mineral soils on Land converted to forest land as well as associated $N_20$ emissions in category 4(III)A2.
- 4(V)A1: The time series of $CH_4$ and $N_2O$ emissions from wildfires 1990–2019 were recalculated for specific years due to updated activity data in the Swissfire database. Minor changes resulted for the years 1993, 2011, 2013, 2015, and 2018, while the 2019 change was larger (see chp. 6.4.2.11).

### 6.4.6. Category-specific planned improvements

#### 6.4.6.1. Living biomass

As a result of the continuous monitoring of the Swiss Forests, new NFI data will be available regularly (see section “Updating NFI data” in chp. 6.4.2.1). The adoption of new NFI data can affect the estimates of all reported pools as well as the calculation of the available fuel for wildfires in forests.

The average carbon stock and carbon gains and losses in living biomass of afforestations and young stands in Switzerland estimated by Thürig and Traub (2015) will be updated (planned for the submission in 2024).

#### 6.4.6.2. Dead wood, litter, and mineral soil

The implementation of the soil model Yasso07 to improve the accuracy in the estimates of temporal changes in soil carbon, litter and dead wood is continuously developed. Depending on the availability of relevant data and studies, planned improvements include:

- Review of the litter production estimates, including turnover rates (planned for the submission in 2023);
- Improving the uncertainty estimates for litter production by revising allometries and by estimating tree compartments using a Monte Carlo approach. This is expected to improve the accuracy of the estimates of carbon stocks and carbon stock changes (planned for the submission in 2023).

The Nussbaum and Burgos (2021) mineral soil carbon stock data will be further processed and used for unproductive forest (CC13) in the next submission.

## 6.5. Category 4B – Cropland

### 6.5.1. Description

Table 6-20 Key categories in category 4B. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 4B1 | Cropland Remaining Cropland | CO2 | T1, L2, T2 |

Swiss croplands belong to the cold temperate wet climatic zone. Croplands (CC21) include annual crops and leys in arable rotations (see Table 6-2 and Table 6-6).

Carbon stocks and carbon stock changes in living biomass and in mineral and organic soils were considered.

In the period 1990–2020, the total net emissions and removals of category 4B1 Cropland remaining cropland varied between 705 kt $CO_2$ in 2014 and -123 kt $CO_2$ in 2019 (average 270 kt $CO_2$). Fluctuations are mainly due to climatic influences on carbon stocks in living biomass and in mineral soils. In contrast, high stable carbon losses in organic soils characterise the net figures in category 4B1 (although organic soils accounted only for 2.7% of cropland area in Switzerland; Table 6-7). 2020 is only the third year that 4B1 has been a sink (albeit close to zero). Carbon stocks both in living biomass and in mineral soils in category 4B1 increased slightly over the inventory period.

Category 4B2 Land converted to cropland was a small net source in all years 1990–2020 (average 25 kt $CO_2$) mainly due to carbon losses in mineral soils under 4B2.2 Grassland converted to cropland.

## 6.5.2. Methodological issues

Carbon stocks in living biomass, as well as carbon stocks and carbon stock changes in mineral soils were estimated with a Tier 3 approach using the model RothC (Wüst-Galley et al. 2020). The results were integrated in category 4B by calculating area-weighted (using the relative surface of crops) average values per elevation zone. The difference in carbon stock (calculated as five-year moving average except for the previous and latest inventory years) between a specific year and the preceding year was reported as net change for living biomass and for mineral soil.

### 6.5.2.1. Carbon stocks

#### *6.5.2.1.1. Carbon stocks in living biomass*

Annual carbon stocks in living biomass per elevation zone (cf. chp. 6.2.2.2) are shown in Table 6-21. They were calculated as area-weighted means of harvested biomass for the 19 most important annual crops (barley, broad beans ["Ackerbohnen"], fallow, fodder beet, maize [grain], oat, peas ["Eiweisserbsen"], potatoes, rape [cooking oil], rye, sugar beet, silage and green corn, sun flowers [cooking oil], soybean, spelt, triticale, vegetables, wheat) and as cumulated annual harvested biomass for clover-grass (leys).

Annual values 1990–2020 for harvested yields (dt $ha^{-1}$) were published by the Swiss Farmers Union (SBV 2021 and previous editions). The same allometric equation as used for soil organic carbon modelling was applied to estimate total biomass including roots (Wüst-Galley et al. 2020). A carbon fraction of 0.45 was assumed based on Bolinder et al. (2007).

Carbon stocks and carbon stock changes in living biomass were reported as moving averages over five years (from year-2 to year+2, e.g. 1988–1992 for the year 1990; the previous and latest inventory years were reported as four-year (year-2 to year+1) and three-year (year-2 to latest inventory year) moving averages, respectively). The rationale for this smoothing is that due to stockpiling, the consumption (and thus oxidation) of the biomass is levelled out between individual years (see Figure 6-8). The resulting area-weighted (across the three elevation zones) mean carbon stock in living biomass for Cropland over the inventory time period was 6.83 t C $ha^{-1}$ with a variation of ±0.23 (1 SD) t C $ha^{-1}$.

Table 6-21 Area-weighted (using the relative surface of crops per elevation zone) carbon stocks (t C ha$^{-1}$) and net carbon stock changes (t C ha$^{-1}$ yr$^{-1}$) in living biomass of arable crops (CC21), stratified for elevation zone (Elev.: Elevation zone 1 = <601 m, 2 = 601-1200 m, 3 = >1200 m; see chp. 6.2.2.2). Highlighted data for 1990 are displayed in Table 6-4.

| Living biomass | Elev. | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC21: carbon stock [t C ha$^{-1}$] and gain/loss in living biomass [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| Stock | 1 | 6.44 | 6.53 | 6.50 | 6.49 | 6.53 | 6.56 | 6.60 | 6.64 | 6.74 | 6.68 |
| Stock | 2 | 6.46 | 6.54 | 6.52 | 6.51 | 6.55 | 6.57 | 6.62 | 6.66 | 6.76 | 6.73 |
| Stock | 3 | 6.07 | 6.16 | 6.16 | 6.14 | 6.15 | 6.15 | 6.22 | 6.30 | 6.43 | 6.48 |
| Net change | 1 | 0.07 | 0.09 | -0.03 | -0.01 | 0.04 | 0.03 | 0.04 | 0.03 | 0.10 | -0.06 |
| Net change | 2 | 0.06 | 0.08 | -0.02 | -0.01 | 0.03 | 0.03 | 0.05 | 0.04 | 0.10 | -0.03 |
| Net change | 3 | 0.09 | 0.10 | 0.00 | -0.02 | 0.02 | -0.01 | 0.08 | 0.08 | 0.13 | 0.05 |

| Living biomass | Elev. | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC21: carbon stock [t C ha$^{-1}$] and gain/loss in living biomass [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| Stock | 1 | 6.68 | 6.57 | 6.72 | 6.72 | 6.75 | 6.80 | 6.93 | 6.93 | 6.93 | 7.08 |
| Stock | 2 | 6.74 | 6.65 | 6.78 | 6.79 | 6.81 | 6.86 | 6.95 | 6.94 | 6.94 | 7.04 |
| Stock | 3 | 6.53 | 6.49 | 6.63 | 6.68 | 6.73 | 6.81 | 6.88 | 6.87 | 6.85 | 6.88 |
| Net change | 1 | 0.01 | -0.11 | 0.15 | 0.00 | 0.03 | 0.05 | 0.13 | 0.01 | -0.01 | 0.16 |
| Net change | 2 | 0.01 | -0.09 | 0.13 | 0.01 | 0.03 | 0.04 | 0.10 | -0.01 | -0.01 | 0.10 |
| Net change | 3 | 0.05 | -0.04 | 0.13 | 0.05 | 0.06 | 0.08 | 0.07 | -0.01 | -0.02 | 0.03 |

| Living biomass | Elev. | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC21: carbon stock [t C ha$^{-1}$] and gain/loss in living biomass [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| Stock | 1 | 7.11 | 7.04 | 7.13 | 7.16 | 6.98 | 7.03 | 7.06 | 6.99 | 7.07 | 7.21 |
| Stock | 2 | 7.05 | 6.99 | 7.07 | 7.10 | 6.97 | 7.03 | 7.05 | 7.00 | 7.08 | 7.19 |
| Stock | 3 | 6.86 | 6.82 | 6.87 | 6.88 | 6.84 | 6.88 | 6.87 | 6.87 | 6.96 | 7.02 |
| Net change | 1 | 0.02 | -0.07 | 0.09 | 0.03 | -0.18 | 0.05 | 0.03 | -0.08 | 0.09 | 0.23 |
| Net change | 2 | 0.01 | -0.06 | 0.08 | 0.03 | -0.12 | 0.05 | 0.02 | -0.05 | 0.08 | 0.20 |
| Net change | 3 | -0.01 | -0.04 | 0.05 | 0.01 | -0.05 | 0.04 | 0.00 | 0.00 | 0.08 | 0.14 |

| Living biomass | Elev. | 2020 |
|---|---|---|
| | | CC21: carbon stock [t C ha$^{-1}$] and gain/loss in living biomass [t C ha$^{-1}$ yr$^{-1}$] |
| Stock | 1 | 7.16 |
| Stock | 2 | 7.16 |
| Stock | 3 | 7.02 |
| Net change | 1 | 0.03 |
| Net change | 2 | 0.05 |
| Net change | 3 | 0.07 |

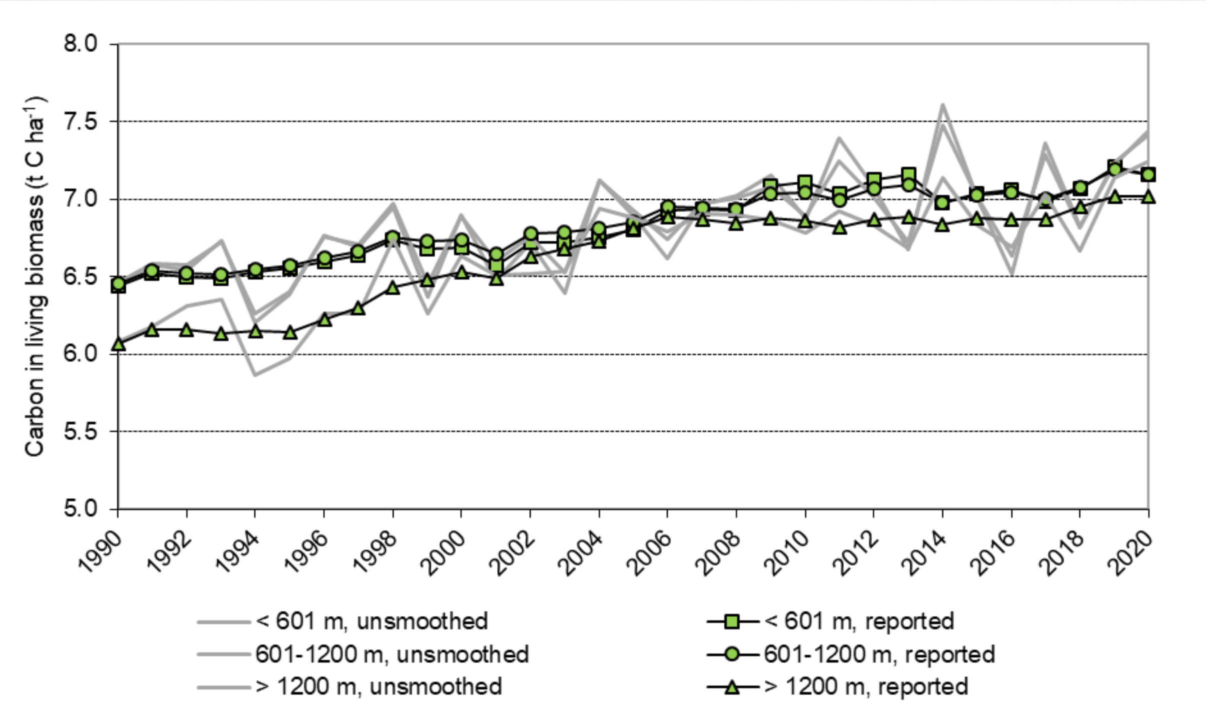



Figure 6-8 Reported carbon stocks (t C ha$^{-1}$) in living biomass of Cropland and underlying unsmoothed carbon stocks (t C ha$^{-1}$) (shown for transparency reasons), stratified for elevation zone. Elevation zone >1200 m is less important as it covers only 0.1% of the total cropland area (cf. Table 6-7).

#### *6.5.2.1.2. Carbon stocks in dead organic matter*

Applying a Tier 1 approach carbon stocks in dead organic matter were assumed to be zero.

#### *6.5.2.1.3. Carbon stocks in soils*

**Mineral soils**

Initial carbon stocks

Carbon stocks in mineral soils under Cropland were calculated based on Leifeld et al. (2003, 2005), as described in Wüst-Galley et al. (2020). The approach correlated measured soil organic carbon stocks (t ha$^{-1}$) with measured clay content. The relationship was applied to the national level using soil texture information from the Swiss digital soil map (SFSO 2000a), correcting for soil depth and stone content. The median soil organic carbon stock (0–30 cm, in 1975) for Cropland is 49.1 t C ha$^{-1}$. The variability of carbon stocks across the country is 8.6 t C ha$^{-1}$ (1 SD). These carbon stocks were applied to 1975 and were used for the initialisation of RothC modelling (see below).

Simulation of carbon stocks through time

Switzerland used the soil carbon model RothC (Coleman et al. 1997; Coleman and Jenkinson 1999) to estimate carbon stocks in mineral soil (0–30 cm) under Cropland for the inventory period. The implementation of RothC in the Swiss GHG inventory is described in detail in Wüst-Galley et al. (2020) and Wüst-Galley et al. (2019: pp. 71 and 77, the up-scaling to elevation zone).

RothC is a model for the turnover of organic carbon in mineral soil, implementing four active carbon pools each associated with their own decomposition rates. In addition, there is a small carbon pool that is considered to be stable (inert). The model runs and calculates soil carbon stocks on a monthly basis. The decomposition rates are altered by temperature, moisture, soil cover and the soil's clay content. RothC requires information on climate (monthly precipitation, temperature and evapotranspiration), monthly carbon inputs (from organic manures and from plants, including above- and below ground harvest residues and root exudates) and soil (clay content, monthly soil cover). Testing and validation of RothC are described in Wüst-Galley et al. (2020).

Input data

Gridded climate data were obtained from the Federal Office of Meteorology and Climatology (MeteoSwiss), including monthly average temperature and monthly (total) precipitation. Monthly evapotranspiration was calculated with the Priestley-Taylor method using these two data sets as well as monthly surface incoming short wave radiation (SIS), also obtained from MeteoSwiss. The most important 19 crops (as introduced in chp. 6.5.2.1.1, covering over 99% of Swiss cropland area) were considered. Annual crop yields (dt $ha^{-1}$) were obtained from the Swiss Farmers Union (SBV 2021 and previous editions). Based on yield data from crops, plant carbon inputs to the soil from crop residues, roots and rhizodeposition were estimated using an allometric function adapted from Bolinder et al. (2007), as described in Wüst-Galley et al. (2020). Annual carbon inputs from organic manures to different types of crops or grasslands were calculated based on: (1) organic manure production, calculated as a function of excretion rate of volatile solids, using the method described in chp. 5.3.2.2.1; (2) animal herd size, described in chp. 5.3.2.5.1; (3) manure management systems, described in chp. 5.3.2.2.4 (using the data for volatile solids); (4) the tendency of farmers to apply different types of manure onto different (broad) crop / grass types, using information obtained from the Swiss ammonium model AGRAMMON (Kupper et al. 2018); (5) the different fertilisation needs of individual crops or grasslands of differing management intensities (obtained from the "Principles of Fertilisation in Arable and Forage Crop Production" (GRUD; Richner et al. 2017); (6) straw production, using annual values published by the Swiss Farmers Union (SBV 2021 and previous editions); (7) the amount of manure digested anaerobically in biogas plants, as described in chp. 5.3.2.2.3; (8) the amount of liquid and solid digestates, as described in chp. 5.5.2.2.2; and (9) the number of livestock units moving annually to the summer pasture regions, using annual data (1999 to present, prior years using extrapolation) that are collected for the calculation of subsides for this summer grazing ("Sömmerungsbeiträge"), from the Federal Office for Agriculture. Clay content was derived from the Swiss Soil Suitability Map (Bodeneignungskarte; SFSO 2000a) as described in Wüst-Galley et al. (2020). Soil cover and the distribution of plant inputs throughout the year were determined using sowing and harvest dates from various agricultural guidelines, as described in Wüst-Galley et al. (2020).

Up-scaling

The RothC modelling was carried out for 4'560 different combinations (19 crops x 240 regions) representing similar climate, crop type, management systems and clay content, as described in Wüst-Galley et al. (2020). An average initial soil organic carbon stock was calculated for the cropland area (CC21) in each of these regions. The simulated carbon stocks were then upscaled using the proportion of different crop types within each region to calculate weighted means.

Reporting

Carbon stocks in mineral soils were integrated in category 4B by calculating area-weighted (using the relative surface of crops) average values per elevation zone. The results were reported as moving averages over five years (from year-2 to year+2, e.g. 1988–1992 for the year 1990; the previous and latest inventory years were reported as four-year (year-2 to year+1) and three-year (year-2 to latest inventory year) moving averages, respectively) (see Table 6-22). Unsmoothed data mainly reflect effects of climatic conditions, whereas long-term trends related to e.g. changes in agricultural management are better visible when the data are smoothed. The resulting area-weighted (across the three elevation zones) mean carbon stock in mineral cropland soils over the inventory period was 50.65 t C ha$^{-1}$ with a variation of ±0.49 (1 SD) t C ha$^{-1}$.

Table 6-22 Area-weighted (using the relative surface of crops per elevation zone) carbon stocks (t C ha$^{-1}$) and net carbon stock changes (t C ha$^{-1}$ yr$^{-1}$) in mineral soils (0-30cm) for Cropland (CC21), stratified for elevation zone (Elev: Elevation zone 1 = <601 m, 2 = 601-1200 m, 3 = >1200 m; see chp. 6.2.2.2). Highlighted data for 1990 are displayed in Table 6-4.

| **Mineral soil** | **Elev.** | **1990** | **1991** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC21: carbon stock [t C ha$^{-1}$] and net change in mineral soil [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| Stock | 1 | 50.21 | 50.23 | 50.21 | 50.15 | 50.06 | 49.97 | 49.97 | 50.03 | 50.03 | 50.01 |
| Stock | 2 | 50.22 | 50.26 | 50.29 | 50.30 | 50.29 | 50.28 | 50.31 | 50.39 | 50.43 | 50.45 |
| Stock | 3 | 42.43 | 42.59 | 42.75 | 42.87 | 42.98 | 43.15 | 43.33 | 43.59 | 43.94 | 44.31 |
| Net change | 1 | 0.01 | 0.02 | -0.02 | -0.07 | -0.09 | -0.08 | -0.01 | 0.06 | 0.01 | -0.02 |
| Net change | 2 | 0.02 | 0.05 | 0.03 | 0.01 | -0.01 | -0.01 | 0.03 | 0.08 | 0.05 | 0.01 |
| Net change | 3 | 0.13 | 0.16 | 0.16 | 0.13 | 0.11 | 0.16 | 0.19 | 0.26 | 0.34 | 0.37 |

| **Mineral soil** | **Elev.** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC21: carbon stock [t C ha$^{-1}$] and net change in mineral soil [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| Stock | 1 | 49.95 | 49.96 | 50.01 | 50.11 | 50.26 | 50.47 | 50.59 | 50.67 | 50.79 | 50.94 |
| Stock | 2 | 50.43 | 50.48 | 50.56 | 50.65 | 50.80 | 50.99 | 51.12 | 51.21 | 51.36 | 51.51 |
| Stock | 3 | 44.61 | 45.05 | 45.59 | 46.09 | 46.60 | 47.09 | 47.41 | 47.58 | 47.75 | 47.85 |
| Net change | 1 | -0.06 | 0.01 | 0.05 | 0.10 | 0.16 | 0.21 | 0.12 | 0.08 | 0.12 | 0.15 |
| Net change | 2 | -0.02 | 0.05 | 0.08 | 0.09 | 0.15 | 0.19 | 0.13 | 0.10 | 0.15 | 0.15 |
| Net change | 3 | 0.31 | 0.44 | 0.54 | 0.50 | 0.51 | 0.49 | 0.32 | 0.17 | 0.17 | 0.10 |

| **Mineral soil** | **Elev.** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC21: carbon stock [t C ha$^{-1}$] and net change in mineral soil [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| Stock | 1 | 51.03 | 51.09 | 51.11 | 51.12 | 51.01 | 50.88 | 50.89 | 50.96 | 51.03 | 51.11 |
| Stock | 2 | 51.59 | 51.64 | 51.67 | 51.68 | 51.58 | 51.48 | 51.46 | 51.46 | 51.47 | 51.50 |
| Stock | 3 | 47.90 | 47.93 | 47.93 | 47.85 | 47.74 | 47.61 | 47.62 | 47.70 | 47.86 | 47.93 |
| Net change | 1 | 0.09 | 0.06 | 0.02 | 0.01 | -0.12 | -0.12 | 0.01 | 0.07 | 0.07 | 0.18 |
| Net change | 2 | 0.08 | 0.05 | 0.03 | 0.00 | -0.10 | -0.09 | -0.03 | 0.00 | 0.01 | 0.07 |
| Net change | 3 | 0.05 | 0.03 | 0.00 | -0.08 | -0.11 | -0.12 | 0.00 | 0.09 | 0.15 | 0.20 |

| **Mineral soil** | **Elev.** | **2020** | |
|---|---|---|---|
| | | CC21: carbon stock [t C ha$^{-1}$] and net change in mineral soil [t C ha$^{-1}$ yr$^{-1}$] | |
| Stock | 1 | 51.31 | |
| Stock | 2 | 51.60 | |
| Stock | 3 | 48.14 | |
| Net change | 1 | 0.29 | |
| Net change | 2 | 0.15 | |
| Net change | 3 | 0.36 | |

**Organic soils**

Soil carbon stocks in organic soils under Cropland were calculated based on Leifeld et al. (2003, 2005). The approach used measured carbon stocks in Swiss organic soils. The mean soil organic carbon stock (0–30 cm) of cultivated organic soils was 240±48 t C $ha^{-1}$ (uncertainty 20%).

### 6.5.2.2. Changes in carbon stocks

#### *6.5.2.2.1. Carbon stock changes in living biomass*

The difference in biomass carbon stock (five-year moving average, see chp. 6.5.2.1.1) between a specific year and the preceding year was reported as net carbon stock change (gain or loss) (see Table 6-21). The resulting values were in the range between -0.18 and 0.23 t C $ha^{-1}$ $yr^{-1}$ with a mean area-weighted carbon stock change across all elevation zones of 0.03 t C $ha^{-1}$ $yr^{-1}$ for the inventory time period.

#### *6.5.2.2.2. Carbon stock changes in dead organic matter*

Applying a Tier 1 approach, carbon stock changes in dead organic matter were assumed to be in equilibrium for Cropland remaining cropland.

#### *6.5.2.2.3. Carbon stock changes in soils*

**Mineral soils**

The difference in carbon stock (five-year moving average, see chp. 6.5.2.1.3 Mineral soils) between a specific year and the preceding year was reported as net carbon stock change (gain or loss) in Cropland mineral soils (see Figure 6-9 and Table 6-22). For transparency reasons, unsmoothed changes in carbon stocks were also displayed in Figure 6-9.

The mean carbon stock change in the inventory period for elevation zone 1 was 0.042 t C $ha^{-1}$ and for elevation zone 2 0.048 t C $ha^{-1}$ (elevation zone 3 is less important as it covers 0.1% of Cropland; cf. Table 6-7). The mean area-weighted carbon stock change across all elevation zones was 0.044 t C $ha^{-1}$.

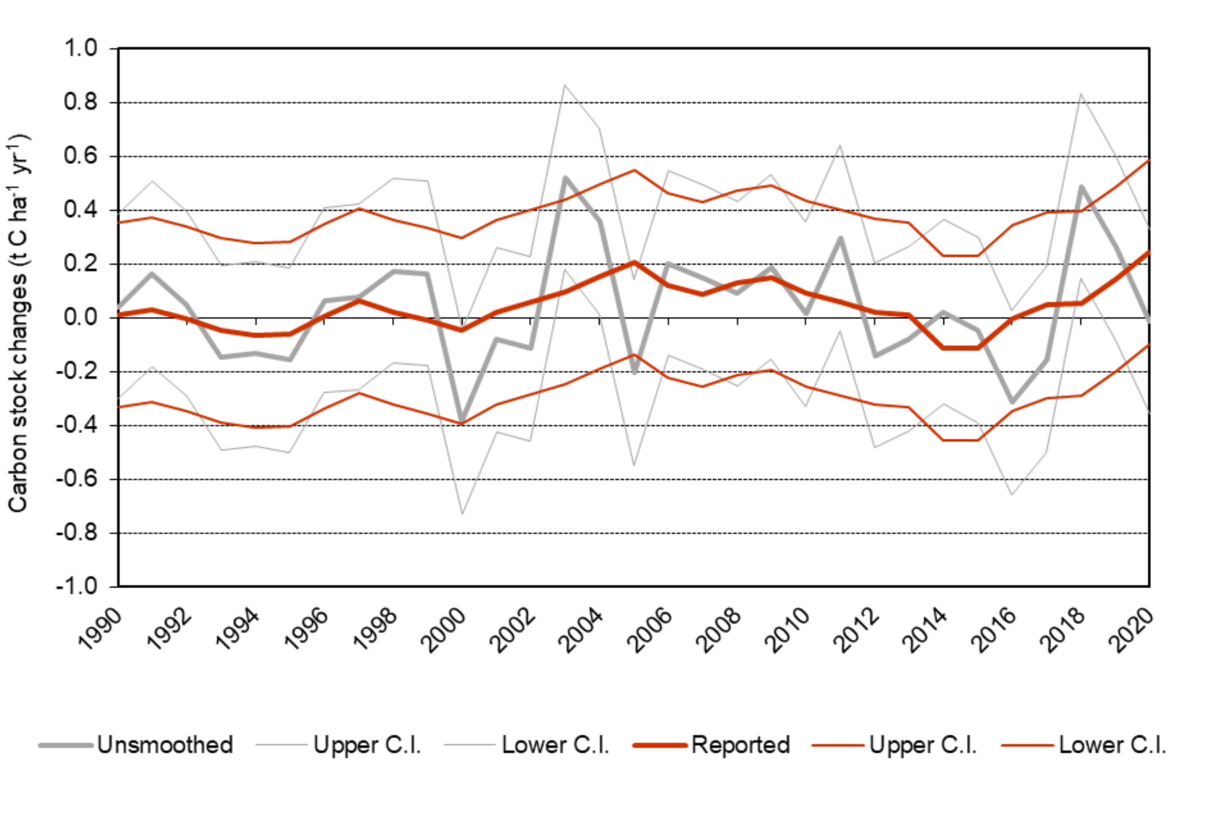



Figure 6-9 Area-weighted (across three elevation zones) mean of reported carbon stocks changes (t C $ha^{-1}$ $yr^{-1}$) in Cropland mineral soil (0–30 cm) and of underlying unsmoothed carbon stock changes (t C $ha^{-1}$ $yr^{-1}$) (shown for transparency reasons), plus upper and lower confidence intervals (C.I.; see chp. 6.5.3).

**Organic soils**

The annual net carbon stock change in organic soils was estimated to -9.52 t C $ha^{-1}$ according to measurements in Europe including Switzerland as compiled by Leifeld et al. (2003, 2005) and verified by ART (2009b) and Paul and Alewell (2018).

#### *6.5.2.2.4. Land-use change*

In the case of land-use change, the net carbon stock changes in biomass and soils were calculated as described in chp. 6.1.3.

### 6.5.2.3. $N_2O$ emissions from Cropland

$N_2O$ emissions from drainage of organic soils (category 4(II)) on Cropland were reported in the Agriculture sector (CRF Table3.D.a.6).

The calculation of emissions for categories 4(III) and 4(IV) (direct $N_2O$ emissions from nitrogen mineralisation in mineral soils and indirect $N_2O$ emissions from managed soils) is described in chp. 6.10.

## 6.5.3. Uncertainties and time-series consistency

### 6.5.3.1. Uncertainties

Activity data

Uncertainties of activity data of category 4B Cropland are described in chp. 6.3.3. For calculating the overall uncertainty of category 4B, the relevant emissions from living biomass, mineral soils and organic soils were considered (Meteotest 2022).

Living biomass

The relative uncertainty in yield determination was estimated as 13% for biomass carbon from agricultural land (Leifeld and Fuhrer 2005). The absolute uncertainties per hectare, calculated with the implied emission factors of 2020, are 0.004 t C $ha^{-1}$ $yr^{-1}$ for 4B1 and 0.012 t C $ha^{-1}$ $yr^{-1}$ for 4B2.

Mineral soils

The absolute uncertainty of 0.344 t C $ha^{-1}$ $yr^{-1}$ was used for annual carbon stock changes in categories 4B1 and 4B2, as calculated by a Monte Carlo analysis (Wüst-Galley et al. 2020). The uncertainty analysis considered variation in the following input parameters: carbon inputs from farmyard manure and plants, the extent of summer pastures, and monthly temperature, precipitation and evapotranspiration. For the Monte Carlo analysis it was assumed that the extent of variation in input parameters is unchanged from one year to the next. By comparison, the range of annual SOC changes identified for 71 different treatments of Swiss agricultural long-term experiments is 1.87 t C $ha^{-1}$ (Keel et al. 2019), suggesting that the calculated uncertainty might have been underestimated (Wüst-Galley et al. 2020).

Organic soils

The uncertainty of the carbon stock change (emission factor) in organic soils is 23% as reported by Leifeld et al. (2003: 56) and the uncertainty of the activity data (area of organic soil) is 37.3% (see chp. 6.3.3), resulting in a combined uncertainty of 43.9%. Thus, the absolute uncertainties of the total organic soil emissions in 2020 are 40.32 kt C for 4B1 and 1.71 kt C for 4B2. By dividing those uncertainties with the total area of 4B1 and 4B2, respectively, the absolute uncertainties per hectare result in 0.116 t C $ha^{-1}$ $yr^{-1}$ for 4B1 and 0.050 t C $ha^{-1}$ $yr^{-1}$ for 4B2.

Overall uncertainties 4B1 and 4B2

The root sum squares of the above-mentioned three absolute uncertainties are 0.363 t C $ha^{-1}$ $yr^{-1}$ for 4B1 and 0.348 t C $ha^{-1}$ $yr^{-1}$ for 4B2. These absolute uncertainties were used to calculate relative emission factor uncertainties for 4B1 and 4B2 by dividing with the net carbon stock change per hectare of 4B1 and 4B2, respectively. In 2020, the net carbon stock changes were 0.006 t C $ha^{-1}$ for 4B1 and -0.233 t C $ha^{-1}$ for 4B2 (calculated from CRF Table4.B). The resulting relative uncertainties are 5615.2% for 4B1 and 148.9% for 4B2, respectively (see Table 6-5). In the same way the uncertainties for the year 1990 were calculated. They are 188.8% (4B1) and 89.6% (4B2).

#### 6.5.3.2. Time-series consistency

Time series for category 4B Cropland are all considered consistent; they were calculated based on consistent methods and homogenous databases (Wüst-Galley et al. 2020). Small inconsistencies in the input data for the RothC model (related to livestock husbandry, compare chp. 5.2.3 and chp. 5.3.3) are barely relevant for the overall results.

### 6.5.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

#### 6.5.4.1. Carbon stocks in living biomass

The crop yield data for the inventory year are available always in the most recent Swiss Farmers' Union's annual report. Since this report is usually not available in time, the inventory is prepared with a provisional value for the inventory year. The correction of this provisional value in the following submission leads by default to a recalculation for the year in question.

#### 6.5.4.2. Carbon stocks in mineral soils

The initial SOC stocks for the latest submission are modelled, using the calculation of Leifeld et al. (2003, 2005), as described in Wüst-Galley et al. (2020). The calculation of the initial stocks is however, in general, limited by insufficient soil information at an appropriate spatial resolution across the country. This situation should be improved by the digital soil modelling project described in chp. 6.5.6.

#### 6.5.4.3. Carbon stock changes in living biomass

The biomass carbon pools were recalculated for the GHG inventory submission 2020 (FOEN 2020) in the course of the Tier 3 approach for quantification of carbon stocks and carbon stock changes in agricultural soils (see chp. 6.5.2.1.3). As far as possible, the input data for the simulations were consistent with input data in the Agriculture sector.

#### 6.5.4.4. Carbon stock changes in mineral soils

##### *6.5.4.4.1. RothC*

RothC, used to model SOC stock changes, is a relatively simple model that does not represent certain soil processes such as feedback due to microbial processes or consider other nutrient cycles. It was however the best-performing model given the available data for Switzerland, considering also temporal resolution (Wüst-Galley et al. 2020). The calibration of the allometric equations (for deriving carbon inputs from crop yields), as well as a comparison of simulated SOC stock changes with measured values from field experiments is described in Wüst-Galley et al. (2020). A sensitivity analysis of the RothC simulations and of the system used to upscale these simulations to the national scale was completed (Wüst-Galley et al. 2021).

In 2003 and 2018 mean area-weighted unsmoothed increases in SOC stocks are exceptionally high (see Figure 6-9). The peak carbon stock changes might be explained by strongly reduced SOC decomposition in RothC caused by high soil moisture deficits (these summers were exceptionally warm and dry in Switzerland leading to high evapotranspiration relative to precipitation). Such model behaviour in RothC was also identified by Falloon et al. (2011). Recent model experiments for potato and maize in the most important cropping region of Switzerland support this explanation by showing reduced SOC stocks with irrigation. In 2003 and 2018, peak SOC values were obtained for cropland but not for permanent grassland (see Figure 6-12). This can be explained by the distribution of these two land use types: Cropland is concentrated in regions prone to high topsoil moisture deficit (lowlands), whereas permanent grassland is distributed more evenly across the country, including wetter and cooler (upland) regions.

#### *6.5.4.4.2. Swiss Soil Monitoring Network (NABO)*

The SOC stocks measured at 29 cropland monitoring sites of the NABO (NABO 2021a; see chp. 6.4.4.5) featuring mineral soils indicate no significant changes from 1990 to 2014 (Figure 6-10). The decline from the first to the second sampling campaign was identified as artefact introduced by the date of sampling; in the first campaign, samplings were conducted substantially later in the year compared with the remaining campaigns, which induced higher SOC contents and thus SOC stocks. The range of the calculated SOC stocks was large (20.6–88.4 t C $ha^{-1}$) with a mean of 46.7 t C $ha^{-1}$.

The monitoring scheme applied by NABO is able to detect relative changes in SOC contents of roughly 3.5% per 10 years for mineral cropland soils (minimum detectable change for about 30 monitoring sites including three or more sampling campaigns; Gubler et al. 2019). Regarding the measured SOC stocks (mean ≈ 47 t $ha^{-1}$) this corresponds to a minimum detectable change of roughly 0.15 t C $ha^{-1}$ $yr^{-1}$ for SOC stocks.

The mean change in SOC which was calculated with RothC for the years 1990–2020 was 0.044±0.344 t C $ha^{-1}$ $yr^{-1}$ (area-weighted mean across three elevation zones ± absolute uncertainty based on a Monte Carlo analysis; see Figure 6-9 and chp. 6.5.3). In comparison, the modelled net change is clearly smaller than the detectable change by NABO and suggests that modelled SOC stock changes agree with the repeated soil inventories in the NABO network.

In conclusion, the NABO data indicate that Cropland mineral soils did not act as a significant net source or net sink of carbon over the last 30 years.

The SOC stocks for three additional cropland sites featuring organic soils ranged from 205 to 269 t C $ha^{-1}$ in the first and from 141 to 236 t C $ha^{-1}$ for the sixth sampling campaign (not included in Figure 6-10). Thus, SOC stocks 0–20 cm of these sites declined by 14–63 t C $ha^{-1}$ over a period of 30 years (however, the effective losses over the whole soil profiles are even higher due to decreasing depths of soil layers).

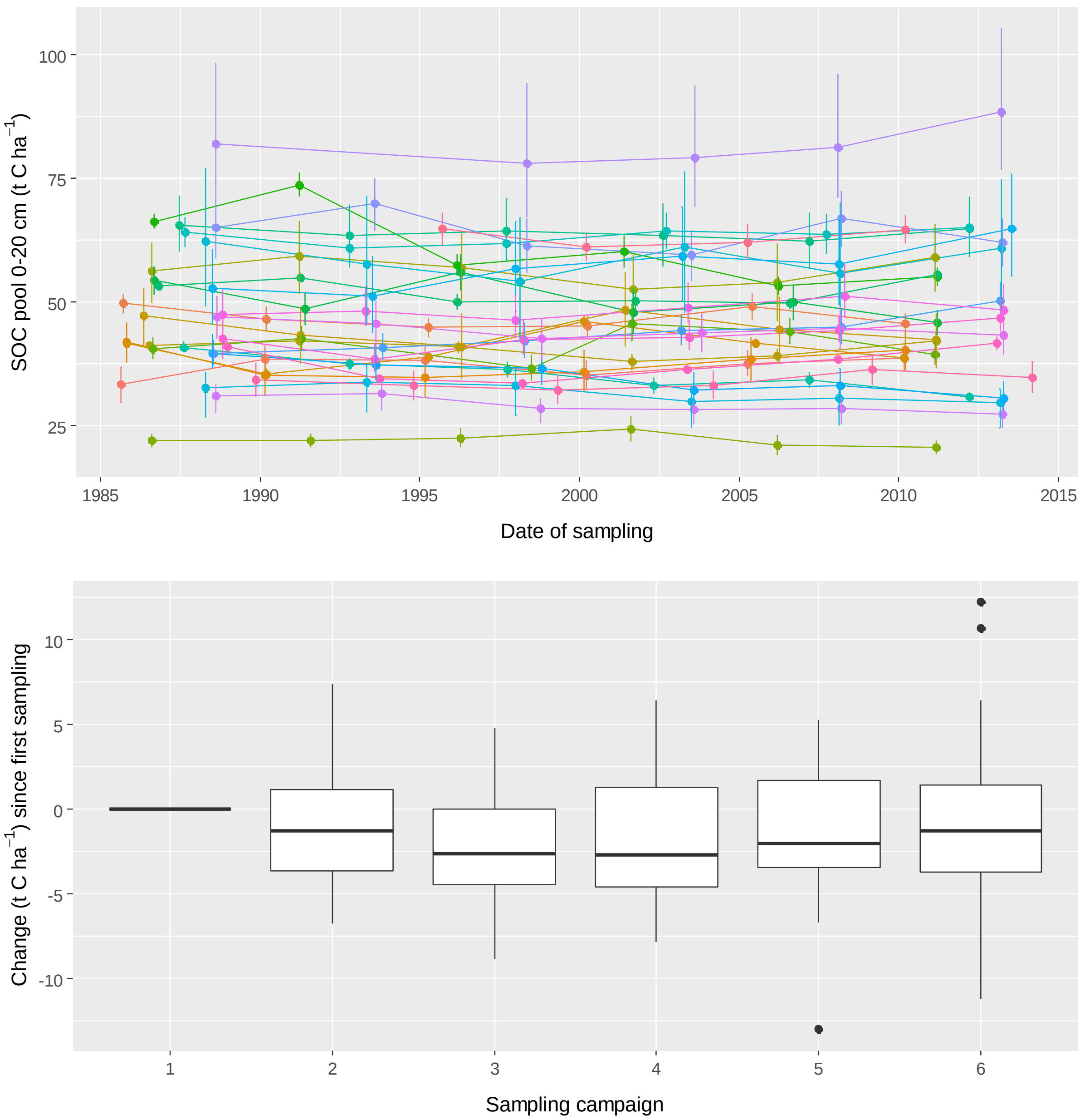



Figure 6-10 Measured SOC stocks for topsoils (0–20 cm) and their changes for 29 NABO long-term monitoring sites featuring mineral soils and used as cropland during the time period 1985–2014. The elevation of the sites ranges from 324 to 945 m a.s.l. Top panel: SOC stocks 0–20 cm per site and sampling; the dots indicate the mean and the bars the range of 5% and 95% percentiles of bootstrap samples taking into account the variability in SOC contents of the individual replicates per site and sampling as well as the variations of the bulk density. Bottom panel: boxplot of changes in SOC stocks in each case related to the first sampling (boxes indicate the lower und the upper quartiles with the median indicated; lines include all observations inside the range of 1.5 times the interquartile distance, observations beyond that range are indicated as dots).

### 6.5.4.5. Short-term land-use changes in arable rotations

Short-term land-use changes between "Grassland" and Cropland are to be expected for leys in arable rotations. However, leys were allocated to Cropland by the Swiss Land Use Statistics (AREA) and were thus not considered grasslands in the common sense (i.e. permanent grassland). Since only long-term land-use changes are registered by the Swiss Land Use Statistics (AREA), carbon stock changes in soils associated with land-use changes between Cropland and Grassland and vice versa were adequately reported in the Swiss GHG inventory.

## 6.5.5. Category-specific recalculations

The following recalculations were implemented. Major recalculations which contribute significantly to the differences in net emissions and net removals of sector 4B between the latest and the previous submissions are additionally presented in chp. 10.1.2.4.

- 4B: Activity data (areas) 1990–2019 were updated (see chp. 6.3.5). With the inclusion of the last outstanding tranche of AREA4 data (see chp. 6.3.4.3), Cropland (CC21) decreased by up to 7.83 kha (corresponding to 2.0% relative decrease). The reallocation took place almost exclusively in the years since 2013. In the period before, the changes in the area of CC21 as a result of recalculation were significantly smaller (in most years close to zero).
- 4B: Carbon stocks and carbon stock changes in living biomass were recalculated for the whole inventory period, based on updated crop yield data for several years, most importantly 2000, 2004, 2005, 2014, 2015 and 2019 (years in which data had been revised for more than four of the 19 crops or in which large changes had been made for few crops) (SBV 2021 and previous years). The effect on the biomass carbon pool was very small in most inventory years, somewhat larger for the years since 2013.
- 4B: Carbon stocks and carbon stock changes in mineral soils were recalculated for the whole inventory period, applying
  - updated crop yield data (see above). The effect on the mineral soil carbon pool was very small;
  - updated information used for the calculation of organic amendments (excretion rates of volatile solids, as described in chp. 5.2.5), as well as updated data regarding herd sizes and the movement of farmyard manure to anaerobic digesters, both in line with values used in the Agriculture sector. The effect of both adjustments on the mineral soil carbon pool was very small;
  - updated gridded climate data (MeteoSwiss). The latest data caused most of the differences in soil carbon stocks and soil carbon stock changes between the latest and previous submissions, most pronounced around the year 2011 and thereafter (see chp. 10.1.2.4.).

## 6.5.6. Category-specific planned improvements

### 6.5.6.1. Living biomass

Price et al. (2017) created a nationwide model for above ground tree biomass in Switzerland (both inside and outside of forest), using structural information available from airborne laser scanning. The model offers significant opportunity for improved estimates of carbon stocks in living biomass on land use combination categories where tree biomass has either not been included or only roughly estimated until now. The tree biomass model of Price et al. (2017) was calibrated and evaluated based on reference plots from the NFI. The model showed promising results at the Tier 3 level. However, further improvement could be achieved if additionally specific reference data from non-Forest land would be available. In a pioneering study, 62 felled urban reference trees with actual above ground tree biomass as well as many detailed predictor variables were surveyed (Mathys et al. 2019; Kükenbrink et al. 2021). To account for the detected differences in tree geometry and associated biomass pattern a nationwide non-Forest land field survey of above ground tree biomass at the plot level was initiated by FOEN (aiming for 1'500 reference plots within the project duration 2018–2024). The overall objective is to calculate a sound wall-to-wall above ground tree biomass database and map for Switzerland. The suitability of the obtained data for reporting in category 4B is subject to ongoing evaluation (Price 2020).

#### 6.5.6.2. Mineral soil

A digital soil modelling project at the newly founded Competence Center for Soils (CCSoils) (funded by FOEN 2017–2020) built on the outcomes of the national research programme "Sustainable Use of Soil as a Resource" (www.nfp68.ch/en). It addressed the shortcomings of missing spatially inclusive and comprehensive soil information in Switzerland. Initial versions of wall-to-wall data sets for soil carbon content, pH, silt content, and clay content (0–30 cm), including the respective prediction uncertainty, are available (Stumpf et al. 2021). For the submission in 2023, initial SOC stocks will be recalculated based on these newly available soil carbon and clay contents. Additional information necessary to calculate SOC stocks such as stone content and soil depth will still be used from a soil suitability map as in the current submission and described in Wüst et al. (2020). Mean SOC stocks for each stratum will still be calculated using the current approach. The use of the digital soil modelling data from Stumpf et al (2021) is the first step towards a switch to grid-based SOC modelling with RothC for the GHG inventory. Further steps are planned for the following years.

An ongoing LULUCF module at CCSoils aims at improving the estimates of soil carbon stocks in Swiss non-forest soils. Results should be available for the GHG inventory submission in 2024.

## 6.6. Category 4C – Grassland

### 6.6.1. Description

Table 6-23 Key categories in category 4C. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 4C1 | Grassland Remaining Grassland | CO2 | L1, T1, L2, T2 |
| 4C2 | Land Converted to Grassland | CO2 | L1, T1, L2 |

Swiss grasslands belong to the cold temperate wet climatic zone.

Carbon stocks and carbon stock changes in living biomass and in mineral and organic soils were considered.

Grasslands were subdivided into permanent grassland (CC31), shrub vegetation (CC32), vineyards, low-stem orchards (‘Niederstammobst’) and tree nurseries (CC33), copse (CC34), orchards (‘Hochstammobst’; CC35), stony grassland (CC36), and unproductive grassland (CC37) (see Table 6-2 and Table 6-6). In category 2 in CRF Table4.C, the land-use types CC32, CC33, CC34 and CC35 were merged under the notation ‘woody’ and CC36 and CC37 were merged under ‘unproductive’ (see Table 6-2 ).

In the period 1990–2020, the total net emissions and removals of category 4C1 Grassland remaining grassland varied between 419 kt $CO_2$ in 2019 and -103 kt $CO_2$ in 1990 (average 192 kt $CO_2$). Whereas annual carbon stocks and carbon stock changes in living biomass and in mineral soils were calculated for permanent grassland (CC31) (however, five-year averages were reported, see below), for the remaining sub-divisions CC32–CC37 carbon stocks in living biomass and in mineral soils were assumed to be in balance (i.e. no carbon stock changes occur if the land use does not change; changes of grassland sub-divisions among themselves, however, do contribute to net emissions and removals in category 4C1). High stable carbon losses in organic soils (especially under permanent grassland) characterise the net figures in category 4C1, although only 0.6% of permanent grassland soils are organic soils (Table 6-7). Contributions of other Grassland remaining grassland sub-divisions (CC32–CC37) were of minor importance except for a noticeable gain in living biomass for shrub vegetation (CC32) which can be explained mainly by the conversion of abandoned pastures (CC31) (more than 1 kha in most years, see also Table 6-9).

Category 4C2 Land converted to grassland was a net source in all years 1990–2020 (average 209 kt $CO_2$). The highest individual contribution came consistently from subcategory 4C2.1 Forest land converted to grassland. Most of this source was due to net changes in living biomass from deforestation. In contrast, the remaining subcategories 4C2.2 to 4C2.5 were net sinks due to sequestration of $CO_2$ in biomass and in mineral soils in the course of the conversion to grassland.

## 6.6.2. Methodological issues

For permanent grassland (CC31), carbon stocks in living biomass, as well as carbon stocks and carbon stock changes in mineral soils were estimated with a Tier 3 approach using the model RothC (Wüst-Galley et al. 2020). The results were integrated in category 4C by calculating area-weighted (using the relative surface of the six grassland types) average values per elevation zone (see chp. 6.5.2.1.3 for details regarding mineral soil). The difference in carbon stock (calculated as five-year moving average except for the previous and latest inventory years) between a specific year and the preceding year was reported as net change for living biomass and for mineral soil. For the remaining Grassland sub-divisions CC32–CC37, constant carbon stocks in living biomass and in mineral soils were assumed (cf. Table 6-4).

### 6.6.2.1. Carbon stocks

#### *6.6.2.1.1. Carbon stocks in living biomass*

**Permanent grassland (CC31)**

Permanent grasslands range in elevation from <300 m to 3000 m above sea level. Because both biomass productivity and soil carbon dynamics rely on the prevailing climatic and pedogenic conditions, grassland stocks were calculated separately for three elevation zones (cf. chp. 6.2.2.2).

Standing biomass for permanent grasslands (t C $ha^{-1}$) was calculated as the annual cumulative yield of six differentially managed grasslands for three elevation zones. Total harvested biomass was adopted from annual statistics of the Swiss Farmers Union (SBV 2021 and previous editions) and allocated to the below listed different grassland types and elevation zones based on standard yields from Richner et al. (2017) and area data from the Farm Structure Survey (SFSO 2016g):

- extensive meadow
- less intensive meadow
- intensive meadow
- extensive pasture
- intensive pasture
- summer pasture

Table 6-24 shows the average cumulative yield 1990–2020 assuming a carbon fraction of 0.45 (Bolinder et al. 2007). For grassland, yield was assumed to be equal to above ground biomass. Root biomass was estimated based an allometric function as described in Wüst-Galley et al. (2020).

Carbon stocks and carbon stock changes in living biomass were reported as moving averages over five years (from year-2 to year+2, e.g. 1988–1992 for the year 1990; the previous and latest inventory years were reported as four-year (year-2 to year+1) and three-year (year-2 to latest inventory year) moving averages, respectively). The rationale for this smoothing is that due to stockpiling the consumption (and thus oxidation) of the biomass is levelled out between individual years (due to the unsmoothed curve progressions, however, to a much lesser extent than with Cropland; compare Figure 6-11 with Figure 6-8). The resulting area-weighted (across the three elevation zones) mean carbon stock in living biomass for permanent grassland over the inventory time period was 4.43 t C $ha^{-1}$ with a variation of ±0.05 (1 SD) t C $ha^{-1}$.

Table 6-24 Area-weighted (using the relative surface of the six grassland types) carbon stocks (t C $ha^{-1}$) and net carbon stock changes (t C $ha^{-1}$ $yr^{-1}$) in living biomass (including roots) of permanent grassland (CC31), stratified for elevation zone (Elev: Elevation zone 1 = <601 m, 2 = 601-1200 m, 3 = >1200 m; see chp. 6.2.2.2). Highlighted data for 1990 are displayed in Table 6-4. Please note: Associated data in CRF Table 4.C.1 also include land-use changes within the Grassland sub-divisions CC31–CC37 and therefore differ from the data shown here (see also chp. 6.1.3.4).

| **Living** | | **1990** | **1991** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **biomass** | **Elev.** | CC31: carbon stock [t C $ha^{-1}$] and gain/loss in living biomass [t C $ha^{-1}$ $yr^{-1}$] | | | | | | | | | |
| Stock | 1 | 5.88 | 5.86 | 5.84 | 5.81 | 5.79 | 5.77 | 5.75 | 5.75 | 5.75 | 5.73 |
| Stock | 2 | 5.38 | 5.37 | 5.35 | 5.33 | 5.31 | 5.30 | 5.30 | 5.30 | 5.30 | 5.31 |
| Stock | 3 | 3.31 | 3.30 | 3.30 | 3.29 | 3.29 | 3.29 | 3.29 | 3.29 | 3.30 | 3.30 |
| Net change | 1 | -0.02 | -0.02 | -0.02 | -0.03 | -0.02 | -0.02 | -0.02 | -0.01 | 0.00 | -0.01 |
| Net change | 2 | -0.01 | -0.02 | -0.02 | -0.02 | -0.02 | -0.01 | 0.00 | 0.00 | 0.01 | 0.01 |
| Net change | 3 | 0.00 | 0.00 | 0.00 | -0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 |

| **Living** | | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **biomass** | **Elev.** | CC31: carbon stock [t C $ha^{-1}$] and gain/loss in living biomass [t C $ha^{-1}$ $yr^{-1}$] | | | | | | | | | |
| Stock | 1 | 5.72 | 5.71 | 5.69 | 5.66 | 5.64 | 5.61 | 5.59 | 5.56 | 5.53 | 5.50 |
| Stock | 2 | 5.31 | 5.31 | 5.31 | 5.30 | 5.29 | 5.27 | 5.25 | 5.23 | 5.22 | 5.19 |
| Stock | 3 | 3.31 | 3.31 | 3.32 | 3.32 | 3.32 | 3.32 | 3.31 | 3.31 | 3.31 | 3.30 |
| Net change | 1 | -0.01 | -0.01 | -0.02 | -0.02 | -0.02 | -0.03 | -0.03 | -0.03 | -0.02 | -0.04 |
| Net change | 2 | 0.00 | 0.00 | 0.00 | -0.01 | -0.01 | -0.02 | -0.02 | -0.02 | -0.01 | -0.02 |
| Net change | 3 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 |

| **Living** | | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **biomass** | **Elev.** | CC31: carbon stock [t C $ha^{-1}$] and gain/loss in living biomass [t C $ha^{-1}$ $yr^{-1}$] | | | | | | | | | |
| Stock | 1 | 5.48 | 5.46 | 5.47 | 5.46 | 5.46 | 5.46 | 5.44 | 5.41 | 5.40 | 5.39 |
| Stock | 2 | 5.19 | 5.18 | 5.20 | 5.19 | 5.21 | 5.21 | 5.20 | 5.19 | 5.18 | 5.16 |
| Stock | 3 | 3.30 | 3.30 | 3.30 | 3.30 | 3.31 | 3.31 | 3.31 | 3.30 | 3.30 | 3.30 |
| Net change | 1 | -0.02 | -0.02 | 0.01 | -0.02 | 0.01 | -0.01 | -0.02 | -0.02 | -0.02 | -0.02 |
| Net change | 2 | -0.01 | -0.01 | 0.02 | -0.01 | 0.02 | 0.00 | -0.01 | -0.02 | -0.01 | -0.02 |
| Net change | 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | -0.01 | 0.00 | -0.01 |

| **Living** | | **2020** |
|---|---|---|
| **biomass** | **Elev.** | CC31: carbon stock [t C $ha^{-1}$] and gain/loss in living biomass [t C $ha^{-1}$ $yr^{-1}$] |
| Stock | 1 | 5.38 |
| Stock | 2 | 5.16 |
| Stock | 3 | 3.29 |
| Net change | 1 | -0.02 |
| Net change | 2 | -0.02 |
| Net change | 3 | -0.01 |

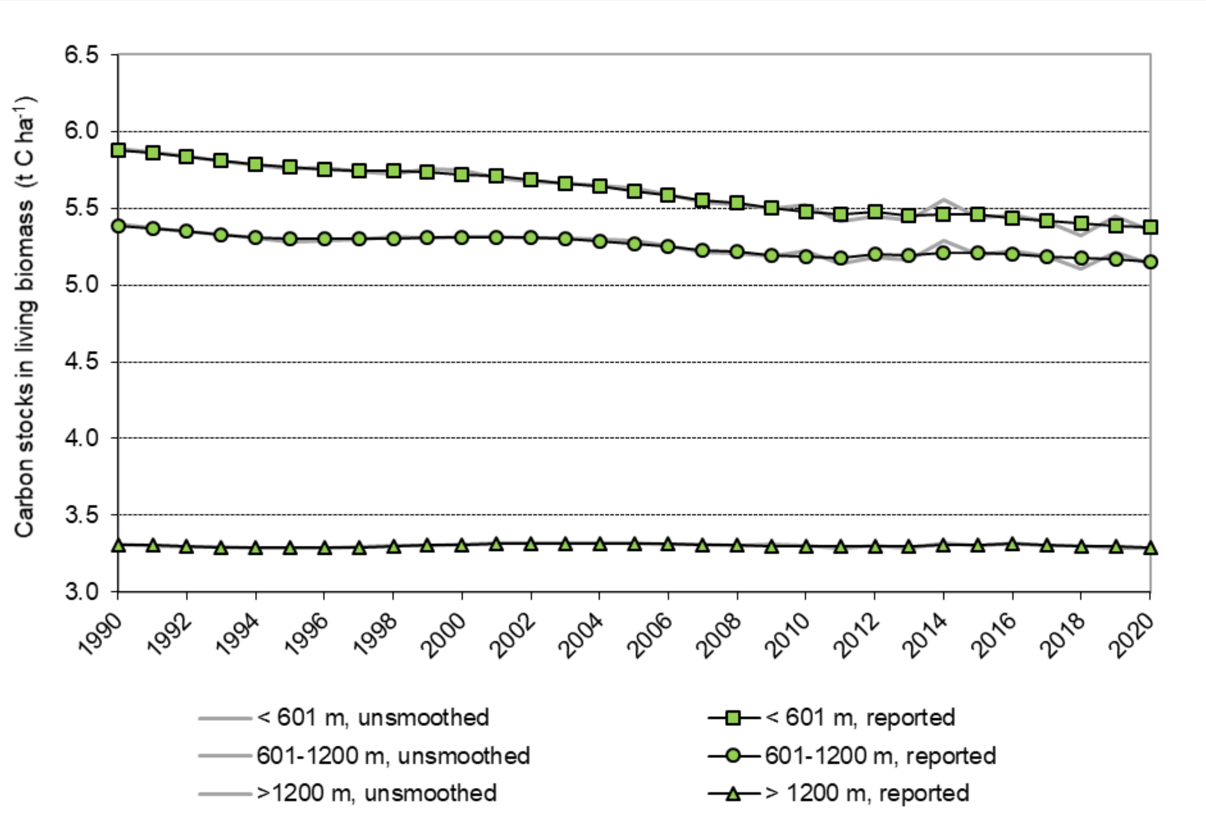



Figure 6-11 Reported carbon stocks (t C $ha^{-1}$) in living biomass of permanent grassland (CC31) and underlying unsmoothed carbon stocks (t C $ha^{-1}$) (shown for transparency reasons), stratified for elevation zone.

### Shrub vegetation (CC32) and Copse (CC34)

Due to the lack of accurate data, the living biomass of shrub vegetation and copse was assumed to be equal to the living biomass of brush forest as described in chp. 6.4.2.7, where brush forest is assumed to contain 20.45 t C $ha^{-1}$ (Düggelin and Abegg 2011).

### Vineyards, low-stem orchards and tree nurseries (CC33)

Low-stem orchards are small fruit trees distinguished from CC35 ('orchards') by a maximum stem height of 1 m and a much higher stand density. Only low-stem orchards and vineyards are considered in the following because no stand densities for tree nurseries are available. This is justified because tree nurseries comprise only ca. 8% (1'378 ha tree nurseries, SFSO 2002) of the total area of CC33, i.e., 17'054 ha, 15'436 ha are vineyards (SFSO 2005) and 240 ha are low-stem orchards (Widmer 2006).

The standing carbon stock of living biomass per ha (Cl) for CC33 was therefore calculated as:

$$Cl = \left[\left(Cl_{vineyards} * area_{vineyards}\right) + \left(Cl_{low-stem\ orchards} * area_{low-stem\ orchards}\right)\right] / \left(area_{vineyards} + area_{low-stem\ orchards}\right)$$

CI of vineyards (5.43 t C $ha^{-1}$) was calculated as the sum of the woody biomass (3.61 t C $ha^{-1}$) and the biomass in the grass layer (1.82 t C $ha^{-1}$).

Woody biomass for vineyards was calculated based on the mean stand density (5’556 vines $ha^{-1}$) and the mean carbon content in the woody biomass of one plant including roots (0.65 kg C; Ruffner 2005).

The mean carbon stock of the grass layer in vineyards was calculated using the following information and assumptions: (1) Most vineyards in Canton Valais (around 5'000 ha) have no grass layer, in the other cantons the share of vineyards with grass understorey is very high (95%). Thus, it can be assumed that on the average 65% of the Swiss vineyards exhibit a grass layer. (2) The grass layer between the vine rows has a lower carbon stock than permanent grassland. It is assumed that it is 50% less than the carbon stock of CC31 (elevation <600 m, average of the period 1990–2020).

CI of low-stem orchards (15.06 t C $ha^{-1}$) was calculated as the sum of the woody biomass (12.25 t C $ha^{-1}$) and the biomass in the grass layer (2.81 t C $ha^{-1}$).

For small fruit trees on low-stem orchards, no literature value was found for biomass expansion factors. Therefore, the following assumptions were made: Diameter at breast height (DBH) of such trees was assumed to be 10 cm and the stem height was assumed to be 1 m. The bole shape of low-stem apple trees can be approximated by a cylinder shape.

Stem wood volume = $r^2 * \pi *$ height = $(5\ \text{cm})^2 * 3.1 * 100\ \text{cm} = 7.75\ \text{dm}^3$

Based on expert knowledge (Kaufmann 2005), the percentage of branches was estimated as 100%, and the percentage of roots was estimated as 30% of the stem wood volume. This results in a BEF of 2.3. A wood density of 0.55 kg $dm^{-3}$ (Vorreiter 1949) and the default IPCC carbon content of 50% (IPCC 2006, Volume 4, chp. 5.2.2.2) were assumed. With these assumptions the carbon stock of a tree of the type low-stem (‘Niederstamm’) was calculated as follows:

C low-stem = stem wood volume * BEF * wood density * carbon content

= $7.75\ \text{dm}^3 * 2.3 * 0.55\ \text{kg/dm}^3 * 0.5 = 4.9$ kg C

The mean stand density of low-stem orchards was estimated as 2500 $ha^{-1}$ (Widmer 2006), resulting in a CI of 12.25 t C $ha^{-1}$ in woody biomass.

The mean carbon stock of the grass layer in low-stem orchards was calculated using the following information and assumptions: (1) All low-stem orchards have a grass layer. (2) The grass layer between the tree rows has a lower carbon stock than permanent grassland. It is assumed that it is 50% less than the carbon stock of CC31 (elevation <600 m, average of the period 1990–2020).

The resulting carbon stock in living biomass (CI) for CC33 is 5.58 t C $ha^{-1}$.

**Orchards (CC35)**

Orchards consists of larger fruit trees (‘Hochstammobst’) planted at a low density with grass understory. CI of orchards trees was calculated as:

CI biomass = (carbon per fruit tree [t C] * number of fruit trees / area orchards [ha]) + carbon in grass [t C $ha^{-1}$]

The carbon stock of a large fruit tree with a DBH of 25–35 cm was calculated as follows:

C (Hochstamm) = Stem wood volume * KE-Factor = 225 kg C

where:

- Stem wood volume of an apple tree assuming a cylindrical stem with mean DBH of 30 cm and a stem height of 7 m amounts to 0.5 $m^3$, and
- KE-Factor [t C $m^{-3}$] = BEF * Density * carbon content = 0.45 (Wirth et al. 2004: 68, Table 16).

From the total fruit-growing area of 41’480 ha (SFSO 2005), the area of low-stem trees (240 ha, see CC33) was subtracted, and the remaining area of 41’240 ha was divided by the number of large fruit trees calculated as the mean of the counts in 1991 (3’616’301 trees) and 2001 (2’900’000 trees; SFSO 2002). This resulted in a mean stand density of 79 trees $ha^{-1}$. The resulting carbon stock in woody biomass of CC35 is thus 17.78 t C $ha^{-1}$. Because orchards typically have a grass understory, the biomass of CC31 was added to the woody biomass. The average biomass 1990–2020 of CC31 (cf. Table 6-24) was weighted with the area of CC35 in the three elevation zones (cf. Table 6-7) – resulting in 5.54 t C $ha^{-1}$ – and added to the woody biomass to obtain a total carbon stock of 23.32 t C $ha^{-1}$ for CC35.

**Stony grassland (CC36)**

Approximately 35% of the surface of CC36 (herbs and shrubs on stony surfaces) is covered by vegetation. No accurate data were available for this category. Therefore, the carbon stock of brush forest (20.45 t C $ha^{-1}$; cf. chp. 6.4.2.7; Düggelin and Abegg 2011) was multiplied by 0.35 to account for the 35% vegetation coverage. This results in a carbon stock for stony grassland of 7.16 t C $ha^{-1}$.

**Unproductive grassland (CC37)**

The category CC37 includes grass and herbaceous plants at watersides of lakes and rivers including dams and other flood protection structures, constructions to protect against avalanches and rock slides, and alpine infrastructure (e.g. for skiing). For none of these land-use types, biomass data are currently available. Therefore, the area-weighted mean (cf. Table 6-7) of carbon stocks of permanent grasslands (average 1990–2020) in the three elevation zones (cf. Table 6-24) was assumed to be representative for the carbon stock on unproductive grassland CC37. Carbon stock in living biomass in unproductive grassland appeared to be 3.45 t C $ha^{-1}$.

##### *6.6.2.1.2. Carbon stocks in dead organic matter*

Applying a Tier 1 approach carbon stocks in dead organic matter were assumed to be zero.

#### *6.6.2.1.3. Carbon stocks in soils*

**Permanent grassland (CC31)**

Mineral soils

Carbon stocks in mineral soils under grassland were calculated based on Leifeld et al. (2003, 2005) as described in Wüst-Galley et al. (2020) and in chp. 6.5.2.1.3. The median soil organic carbon stock (0–30 cm, in 1975) for permanent grassland is 64.3 t C $ha^{-1}$. The variability of carbon stocks across the country is 19.3 t C $ha^{-1}$ (1 SD). These carbon stocks were used to initialise the RothC model (see below and chp. 6.5.2.1.3) which was used to estimate carbon stocks from 1990 to 2020.

Switzerland used the soil carbon model RothC to estimate carbon stocks in mineral soil (0–30 cm) under permanent grassland for the period 1990 to 2020, as described in chp. 6.5.2.1.3, in Wüst-Galley et al. (2020) and in Wüst-Galley et al. (2019: pp. 71–78, the upscaling to elevation zone). Six differently managed permanent grassland types (as listed in chp. 6.6.2.1.1, covering over 99% of Swiss permanent grassland) were considered. Plant carbon inputs into the soil from grasslands were assumed to be constant, in accordance to the approach in Franko et al. (2011) and as detailed in Wüst-Galley et al. (2020). Mean carbon stocks in mineral soils calculated for permanent grasslands (CC31) are given in Table 6-25 (area-weighted average values using the relative surface of the six grassland types in each elevation zone). They were reported as moving averages over five years (from year-2 to year+2, e.g. 1988–1992 for the year 1990; the previous and latest inventory years were reported as four-year (year-2 to year+1) and three-year (year-2 to latest inventory year) moving averages, respectively). Unsmoothed data mainly reflect effects of climatic conditions, whereas long-term trends related to e.g. changes in agricultural management are better visible when the data are smoothed. The resulting area-weighted (across the three elevation zones) mean carbon stock in mineral soils for permanent grassland over the inventory period was 63.03 t C $ha^{-1}$ with a variation of ±0.43 (1 SD) t C $ha^{-1}$.

Table 6-25 Area-weighted (using the relative surface of the six grassland types) carbon stocks (t C ha$^{-1}$) and net carbon stock changes (t C ha$^{-1}$ yr$^{-1}$) in mineral soils (0-30cm) for permanent grassland (CC31), stratified for elevation zone (Elev: Elevation zone 1 = <601 m, 2 = 601-1200 m, 3 = >1200 m; see chp. 6.2.2.2). Highlighted data for 1990 are displayed in Table 6-4. Please note: Associated data in CRF Table4.C.1 also include land-use changes within the grassland sub-divisions CC31–CC37 and therefore differ from the data shown here (see also chp. 6.1.3.4).

| Mineral soil | Elev. | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC31: carbon stock [t C ha$^{-1}$] and net change in mineral soil [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| Stock | 1 | 60.51 | 60.49 | 60.43 | 60.33 | 60.20 | 60.02 | 59.85 | 59.74 | 59.60 | 59.38 |
| Stock | 2 | 65.39 | 65.34 | 65.27 | 65.19 | 65.10 | 64.99 | 64.88 | 64.80 | 64.73 | 64.59 |
| Stock | 3 | 62.65 | 62.82 | 62.98 | 63.12 | 63.25 | 63.37 | 63.48 | 63.61 | 63.73 | 63.81 |
| Net change | 1 | -0.02 | -0.02 | -0.06 | -0.10 | -0.13 | -0.18 | -0.17 | -0.11 | -0.13 | -0.22 |
| Net change | 2 | -0.05 | -0.05 | -0.06 | -0.08 | -0.09 | -0.11 | -0.11 | -0.08 | -0.08 | -0.13 |
| Net change | 3 | 0.18 | 0.17 | 0.16 | 0.14 | 0.13 | 0.12 | 0.11 | 0.12 | 0.12 | 0.08 |

| Mineral soil | Elev. | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC31: carbon stock [t C ha$^{-1}$] and net change in mineral soil [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| Stock | 1 | 59.16 | 59.01 | 58.89 | 58.78 | 58.77 | 58.77 | 58.71 | 58.60 | 58.50 | 58.37 |
| Stock | 2 | 64.45 | 64.32 | 64.19 | 64.08 | 64.02 | 63.94 | 63.87 | 63.80 | 63.74 | 63.66 |
| Stock | 3 | 63.87 | 63.92 | 63.96 | 64.01 | 64.05 | 64.07 | 64.13 | 64.19 | 64.25 | 64.32 |
| Net change | 1 | -0.22 | -0.15 | -0.12 | -0.11 | -0.01 | 0.00 | -0.06 | -0.12 | -0.10 | -0.13 |
| Net change | 2 | -0.15 | -0.13 | -0.13 | -0.11 | -0.07 | -0.08 | -0.06 | -0.07 | -0.06 | -0.08 |
| Net change | 3 | 0.06 | 0.06 | 0.04 | 0.05 | 0.05 | 0.02 | 0.06 | 0.06 | 0.06 | 0.07 |

| Mineral soil | Elev. | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CC31: carbon stock [t C ha$^{-1}$] and net change in mineral soil [t C ha$^{-1}$ yr$^{-1}$] | | | | | | | | | |
| Stock | 1 | 58.22 | 58.03 | 57.80 | 57.57 | 57.34 | 57.12 | 56.96 | 56.88 | 56.76 | 56.71 |
| Stock | 2 | 63.57 | 63.45 | 63.29 | 63.11 | 62.92 | 62.74 | 62.55 | 62.38 | 62.21 | 62.12 |
| Stock | 3 | 64.37 | 64.38 | 64.39 | 64.36 | 64.31 | 64.29 | 64.25 | 64.17 | 64.09 | 64.06 |
| Net change | 1 | -0.15 | -0.18 | -0.23 | -0.23 | -0.23 | -0.22 | -0.16 | -0.09 | -0.11 | -0.12 |
| Net change | 2 | -0.09 | -0.12 | -0.16 | -0.18 | -0.19 | -0.18 | -0.19 | -0.18 | -0.17 | -0.18 |
| Net change | 3 | 0.05 | 0.01 | 0.00 | -0.03 | -0.05 | -0.03 | -0.04 | -0.08 | -0.08 | -0.09 |

| Mineral soil | Elev. | 2020 |
|---|---|---|
| | | CC31: carbon stock [t C ha$^{-1}$] and net change in mineral soil [t C ha$^{-1}$ yr$^{-1}$] |
| Stock | 1 | 56.69 |
| Stock | 2 | 62.03 |
| Stock | 3 | 64.02 |
| Net change | 1 | -0.09 |
| Net change | 2 | -0.18 |
| Net change | 3 | -0.10 |

<u>Organic soils</u>

Soil carbon stocks in organic soils under permanent grassland were calculated based on Leifeld et al. (2003, 2005). The approach used measured carbon stocks in Swiss organic soils without differentiation between Cropland and Grassland. The mean soil organic carbon stock (0–30 cm) of organic soils is 240±48 t C ha$^{-1}$ (uncertainty 20%).

**Shrub vegetation (CC32) and Copse (CC34)**

Due to the lack of more specific data, the average carbon stocks of CC31 for each elevation zone (see Table 6-25) in the period 1990–2020 were used:

- Elevation zone 1 (<601 m a.s.l.): 58.65 t C ha$^{-1}$
- Elevation zone 2 (601-1200 m a.s.l.): 63.89 t C ha$^{-1}$

- Elevation zone 3 (>1200 m a.s.l.): 63.88 t C $ha^{-1}$.

The mean soil organic carbon stock (0–30 cm) of organic soils is 240 t C $ha^{-1}$.

**Vineyards, low-stem orchards and tree nurseries (CC33)**

No specific value for mineral soils under CC33 was available. As CC33 is only partially covered by grass understorey the average soil carbon stock of Cropland (CC21) for the period 1990–2020 was taken, weighted with the area of CC33 per elevation zone: 50.58 t C $ha^{-1}$ (0–30 cm).

The mean soil organic carbon stock (0–30 cm) of organic soils is 240 t C $ha^{-1}$.

**Orchards (CC35)**

No specific value for mineral soils under orchards was available. As most orchard areas have grass understorey the average soil carbon stock of permanent grassland (CC31) for the period 1990–2020 was taken, weighted with the area of CC35 per elevation zone: 59.70 t C $ha^{-1}$ (0–30 cm).

The mean soil organic carbon stock (0–30 cm) of organic soils is 240 t C $ha^{-1}$.

**Stony grassland (CC36)**

Soil organic carbon stocks under herbs and shrubs on stony surfaces were calculated according to the procedure described in chp. 6.6.2.1.1, i.e. it was assumed that not more than 35% of the area of CC36 is covered with vegetation and thus only 35% of the area bears a mineral soil while the remainder is bare rock. Land use of this category is mainly located at elevations >1200m a.s.l. The soil carbon stock of CC36 was calculated as average soil carbon stock of permanent grassland (CC31) for the period 1990–2020, weighted with the area of CC36 per elevation zone, considering a 35% coverage:

Cs of CC36 = 0.35 * 63.86 t C $ha^{-1}$ = 22.35 t C $ha^{-1}$ (0–30 cm)

The mean soil organic carbon stock (0–30 cm) of organic soils is 240 t C $ha^{-1}$. It was assumed that the small area covered by organic soils in CC36 (cf. Table 6-7), albeit entitled ‘stony grassland’, does not contain significant contributions from stones because bogs are free of stones as a matter of nature and fens usually contain, if any, only fine mineral sediments.

**Unproductive grassland (CC37)**

Unproductive grassland includes grass and herbaceous plants at watersides of lakes and rivers including dams and other flood protection structures, constructions to protect against avalanches and rock slides, and alpine infrastructure (e.g. for skiing). For none of these land-use types, soil carbon stock data are currently available. Therefore, the carbon stock of mineral soils was calculated as average soil carbon stock of permanent grassland (CC31) for the period 1990–2020, weighted with the area of CC37 per elevation zone: 63.65 t C ha$^{-1}$ (0–30 cm).

The mean soil organic carbon stock (0–30 cm) of organic soils is 240 t C ha$^{-1}$.

### 6.6.2.2. Changes in carbon stocks

#### *6.6.2.2.1. Carbon stock changes in living biomass*

For permanent grassland (CC31), the difference in carbon stock in living biomass (five-year moving average, see chp. 6.6.2.1.1 Permanent grassland) between a specific year and the preceding year was reported as net carbon stock change (gain or loss) as shown in Table 6-24. The resulting values were in the range between -0.04 and 0.02 t C ha$^{-1}$ yr$^{-1}$ with a mean area-weighted carbon stock change across all elevation zones of -0.006 t C ha$^{-1}$ yr$^{-1}$ for the inventory time period. Applying a Tier 1 approach, changes in carbon stocks in living biomass were assumed to be in equilibrium for Grassland remaining grassland in the other sub-divisions CC32–CC37.

#### *6.6.2.2.2. Carbon stock changes in dead organic matter*

Applying a Tier 1 approach, carbon stock changes in dead organic matter were assumed to be in equilibrium for Grassland remaining grassland.

#### *6.6.2.2.3. Carbon stock changes in soils*

**Mineral soils: Permanent grassland (CC31)**

The difference in carbon stock (five-year moving average, see chp. 6.6.2.1.3 Permanent grassland – Mineral soils) between a specific year and the preceding year was reported as net carbon stock change (gain or loss) in permanent grassland mineral soils (see Figure 6-12 and Table 6-25). For transparency reasons, unsmoothed changes in carbon stocks were also displayed in Figure 6-12.

The mean carbon stock change in the inventory period for elevation zone 1 was -0.129 t C ha$^{-1}$, for elevation zone 2 -0.116 t C ha$^{-1}$ and for elevation zone 3 0.047 t C ha$^{-1}$. The mean area-weighted carbon stock change across all elevation zones was -0.044 t C ha$^{-1}$.

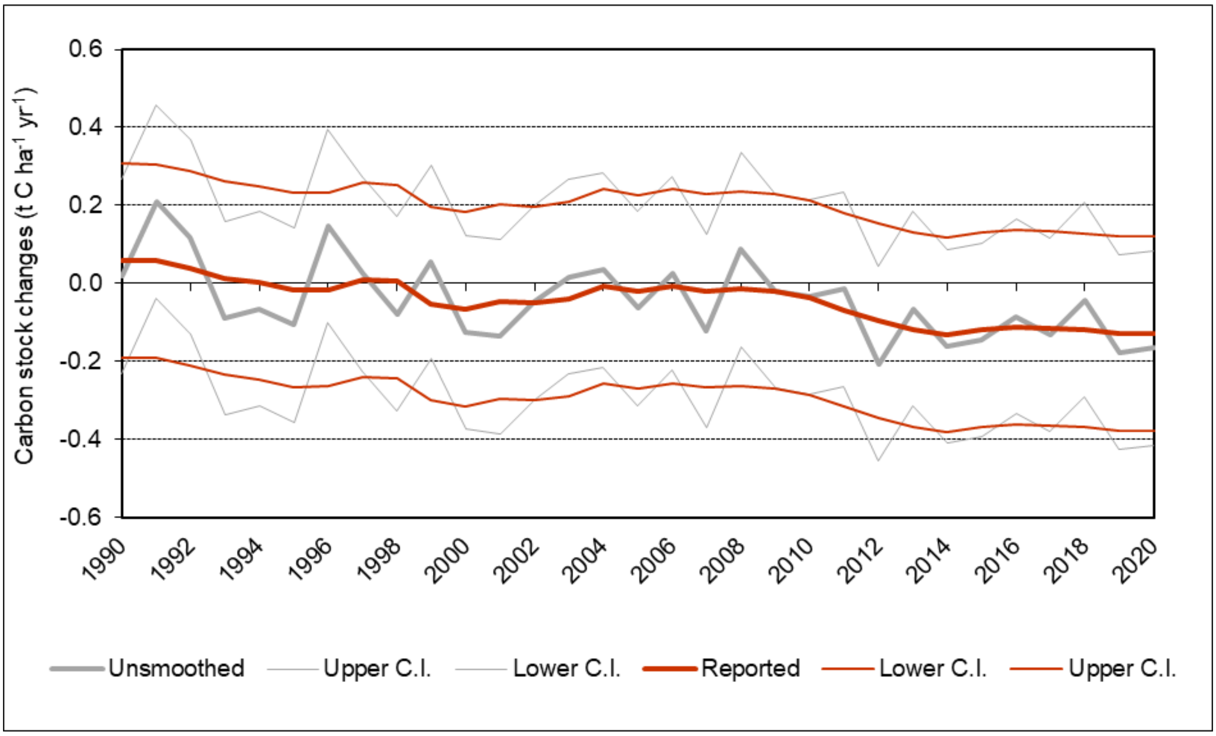



Figure 6-12 Area-weighted (across three elevation zones) mean of reported carbon stocks changes (t C $ha^{-1}$ $yr^{-1}$) in permanent grassland mineral soil (0–30 cm) and of underlying unsmoothed carbon stock changes (t C $ha^{-1}$ $yr^{-1}$) (shown for transparency reasons), plus upper and lower confidence intervals (C.I.; see chp. 6.6.3).

**Mineral soils: Remaining grassland sub-divisions (CC32–37)**

A Tier 1 approach (changes in soil carbon stocks are in equilibrium) was assumed for carbon stock changes in mineral soils in the sub-divisions CC32–37.

**Organic soils**

The annual net carbon stock change in organic soils on managed grassland (CC31, CC33 and CC35) was estimated as -9.52 t C $ha^{-1}$ according to measurements in Europe including Switzerland as compiled by Leifeld et al. (2003, 2005) and verified by ART (2009b) and Paul and Alewell (2018). For extensively managed grasslands (CC32, CC34, CC36 and CC37) the emission from organic soils was estimated as 5.30 t C $ha^{-1}$ $yr^{-1}$ according to available domestic data (ART 2011b; Paul and Alewell 2018; Paul et al. 2021).

#### *6.6.2.2.4. Land-use change*

In the case of land-use change, the net carbon stock changes in biomass and soils of CC31, CC32, CC33, CC34, CC35, CC36, and CC37 were calculated as described in chp. 6.1.3.

### 6.6.2.3. $N_2O$ emissions from Grassland

$N_2O$ emissions from drainage of organic soils (category 4(II)) on Grassland were reported in the Agriculture sector (CRF Table3.D.a.6).

The calculation of emissions for categories 4(III) and 4(IV) (direct $N_2O$ emissions from nitrogen mineralisation in mineral soils and indirect $N_2O$ emissions from managed soils) is described in chp. 6.10.

#### 6.6.2.4. Emissions from wildfires

Data on wildfires affecting Grassland are obtained from cantonal authorities and were compiled by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL, Swissfire database, http://www.wsl.ch/swissfire; Pezzatti et al. 2019). Table 6-26 shows the time series 1990 to 2020 of affected areas and associated emissions. The Swissfire database differentiates between 'grassland' and 'unproductive land'. As 'unproductive land' can partially cover the Grassland sub-divisions CC32, CC34, CC36 and CC37 the sum of both categories was reported. Controlled burning is not a common practice in Switzerland. Therefore, all fires were assigned to wildfires.

The $CH_4$ and $N_2O$ emissions were calculated using equation 2.27 in Volume 4 of IPCC (2006) with the following parameters:

- The mass of available fuel encompasses the carbon stock of living biomass (litter and dead wood carbon stocks were assumed to be zero for grassland). On average, the amount of living biomass amounted to 16.58 t biomass $ha^{-1}$ (7.46 t C $ha^{-1}$). This value was derived from the carbon stocks of all grassland sub-divisions (CC31–CC37) as an area-weighted mean using the geographical extensions in 1990 and a carbon fraction of 0.45.
- The fraction of the biomass combusted was assumed to be 0.74 (IPCC 2006 Volume 4, Table 2.6, Savanna and Grassland).
- For $CH_4$ the default emission factor of 2.3 g (kg combusted biomass)$^{-1}$ and for $N_2O$, the default emission factor of 0.21 g (kg combusted biomass)$^{-1}$ was applied (IPCC 2006, Volume 4, Table 2.5, Savanna and Grassland).

The resulting annual $CH_4$ and $N_2O$ emissions 1990–2020 on burnt areas in category 4C Grassland are shown in Table 6-26 and are reported in CRF Table4(V).

Table 6-26 Grassland areas affected by wildfires (WSL, Swissfire database) and resulting $CH_4$ and $N_2O$ emissions.

| Grassland | Unit | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Area burnt | ha | 637 | 22 | 6 | 19 | 175 | 82 | 43 | 372 | 72 | 19 |
| $CH_4$ | t | 17.98 | 0.63 | 0.17 | 0.53 | 4.92 | 2.31 | 1.21 | 10.49 | 2.03 | 0.54 |
| $N_2O$ | t | 1.64 | 0.06 | 0.02 | 0.05 | 0.45 | 0.21 | 0.11 | 0.96 | 0.19 | 0.05 |

| Grassland | Unit | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Area burnt | ha | 22 | 8 | 257 | 138 | 4 | 20 | 14 | 98 | 29 | 4 |
| $CH_4$ | t | 0.62 | 0.21 | 7.26 | 3.89 | 0.12 | 0.55 | 0.40 | 2.76 | 0.82 | 0.11 |
| $N_2O$ | t | 0.06 | 0.02 | 0.66 | 0.36 | 0.01 | 0.05 | 0.04 | 0.25 | 0.08 | 0.01 |

| Grassland | Unit | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area burnt | ha | 1 | 66 | 14 | 4 | 3 | 8 | 212 | 38 | 29 | 16 | 30 |
| $CH_4$ | t | 0.04 | 1.85 | 0.38 | 0.10 | 0.07 | 0.22 | 5.99 | 1.08 | 0.82 | 0.46 | 0.86 |
| $N_2O$ | t | 0.00 | 0.17 | 0.04 | 0.01 | 0.01 | 0.02 | 0.55 | 0.10 | 0.07 | 0.04 | 0.08 |

#### 6.6.2.5. NMVOC emissions

Estimates for annual biogenic emissions of NMVOC (CRF Table4) for unproductive grassland in Switzerland are available in SAEFL (1996a). The value for those areas (unproductive vegetation) is 0.51 kt $yr^{-1}$. This value was used over the entire time series.

## 6.6.3. Uncertainties and time-series consistency

### 6.6.3.1. Uncertainties

Activity data

Uncertainties of activity data of category 4C Grassland are described in chp. 6.3.3. For calculating the overall uncertainty of category 4C, the relevant emissions from living biomass, mineral soils and organic soils were considered (Meteotest 2022).

Living biomass

The relative uncertainty in yield determination was estimated as 13% for biomass carbon from both Cropland and Grassland (Leifeld and Fuhrer 2005). Data on biomass yields for different elevations and management intensities were derived from many agricultural field experiments and have a high reliability (SBV 2021; Richner et al. 2017). The absolute uncertainties per hectare, calculated with the implied emission factors of 2020, are 0.002 t C $ha^{-1}$ $yr^{-1}$ for 4C1 and 0.091 t C $ha^{-1}$ $yr^{-1}$ for 4C2.

Mineral soils

0.249 t C $ha^{-1}$ $yr^{-1}$ was used as absolute uncertainty for annual carbon stock changes in categories 4C1 and 4C2. This value was calculated by a Monte Carlo analysis (Wüst-Galley et al. 2020), see chp. 6.5.3. By comparison, the range of annual SOC changes identified for 9 different treatments of Swiss agricultural long-term experiments is 0.51 t C $ha^{-1}$ $yr^{-1}$ (Keel et al. 2019), indicating that the calculated uncertainty is plausible.

Organic soils

The uncertainty of the carbon stock change (emission factor) in organic soils is 23% as reported by Leifeld et al. (2003: 56) and the uncertainty of the activity data (area of organic soil) is 68.6% (see chp. 6.3.3), resulting in a combined uncertainty of 72.3%. Thus, the absolute uncertainties of the total organic soil emissions in 2020 are 38.3 kt C for 4C1 and 8.5 kt C for 4C2. By dividing those uncertainties with the total area of 4C1 and 4C2, respectively, the absolute uncertainties per hectare result in 0.030 t C $ha^{-1}$ $yr^{-1}$ for 4C1 and 0.078 t C $ha^{-1}$ $yr^{-1}$ for 4C2.

Overall uncertainties 4C1 and 4C2

The root sum squares of the above-mentioned three absolute uncertainties are 0.251 t C $ha^{-1}$ $yr^{-1}$ for 4C1 and 0.276 t C $ha^{-1}$ $yr^{-1}$ for 4C2. These absolute uncertainties were used to calculate relative emission factor uncertainties for 4C1 and 4C2 by dividing with the net carbon stock change per hectare of 4C1 and 4C2, respectively. In 2020, the net carbon stock changes were -0.086 t C $ha^{-1}$ for 4C1 and -0.640 t C $ha^{-1}$ for 4C2 (calculated from CRF Table4.C). The resulting relative uncertainties are 292.7% for 4C1 and 43.1% for 4C2, respectively (see Table 6-5). In the same way the uncertainties for the year 1990 were calculated. They are 1227.8% (4C1) and 52.5% (4C2).

Wildfires

For wildfires, the emission factor uncertainties of $CH_4$ and $N_2O$ were set to 70% (identical to forest land, see chp. 6.4.3). The activity data uncertainty is 30% (see chp. 6.3.3).

#### 6.6.3.2. Time-series consistency

Time series for category 4C Grassland are all considered consistent; they were calculated based on consistent methods and homogenous databases (Wüst-Galley et al. 2020). Small inconsistencies in the input data for the RothC model (related to livestock husbandry, compare chp. 5.2.3 and chp. 5.3.3) are barely relevant for the overall results.

### 6.6.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

#### 6.6.4.1. Carbon stocks in living biomass

The grassland yield data for the inventory year are available always in the most recent Swiss Farmers' Union's annual report. Since this report is usually not available in time, the inventory is prepared with a provisional value for the inventory year. The correction of this provisional value in the following submission leads by default to a recalculation for the year in question (However, this was not the case in the latest submission, as the value for 2019 was definite in the previous submission (FOEN 2021)).

#### 6.6.4.2. Carbon stocks in mineral soils

The initial SOC stocks for the latest submission are modelled, using the calculation of Leifeld et al. (2003, 2005), as described in Wüst-Galley et al. (2020). The calculation of the initial stocks is however, in general, limited by insufficient soil information at an appropriate spatial resolution across the country. This situation should be improved by the digital soil modelling project described in chp. 6.6.6.

#### 6.6.4.3. Carbon stock changes in living biomass

The biomass carbon pools for permanent grassland (CC31) were recalculated in the course of the Tier 3 approach for quantification of carbon stocks and carbon stock changes in agricultural soils in the GHG inventory submission 2020 (FOEN 2020). As far as possible, the input data for the simulations were consistent with input data in the Agriculture sector.

### 6.6.4.4. Carbon stock changes in mineral soils

#### *6.6.4.4.1. RothC*

RothC, used to model SOC stock changes, is a relatively simple model that does not represent certain soil processes such as feedback due to microbial processes or consider other nutrient cycles. It was however the best-performing model given the available data for Switzerland, considering also temporal resolution (Wüst-Galley et al. 2020). The calibration of the allometric equations (for deriving carbon inputs from the cumulative yield of six differentially managed grasslands), as well as a comparison of simulated SOC stock changes with measured values from field experiments is described in Wüst-Galley et al. (2020). A sensitivity analysis of the RothC simulations and of the system used to upscale these simulations to the national scale was completed (Wüst-Galley et al. 2021). The model performance is evaluated on an ongoing basis.

#### *6.6.4.4.2. Swiss Soil Monitoring Network (NABO)*

NABO provided data from 31 monitoring sites identified as grassland (NABO 2021b; see chp. 6.4.4.5) according to the land-use definitions used for LULUCF (see chp. 6.2); thus, the selected sites included – in addition to meadows and pastures – also vineyards, orchards, and urban parks. SOC stocks for the top 20 cm of these soils ranged from 25.3 to 142.1 t C $ha^{-1}$ with a mean of 73.5 t C $ha^{-1}$ (Figure 6-13). The highest stocks were found for alpine pastures at high elevation. On average, a slight increase during the period 1985 to 2000 (sampling campaigns 1 to 3) and a slight decrease thereafter (campaigns 3 to 4) were observed. However, these minor changes were statistically non-significant. In addition, previous studies showed that the elevated SOC stocks for the third sampling campaign must be considered as artefact induced by sub-optimal conditions during field work. From sampling campaigns 4 to 6, SOC stocks remained stable.

The monitoring scheme applied by NABO is able to detect relative changes in SOC contents of roughly 2.5% per 10 years for mineral grassland soils (minimum detectable change for about 30 monitoring sites including three or more sampling campaigns). Regarding the measured SOC stocks (mean ≈ 74 t $ha^{-1}$) this corresponds to a minimum detectable change of roughly 0.19 t C $ha^{-1}$ $yr^{-1}$ for SOC stocks (or 0.21 t C $ha^{-1}$ $yr^{-1}$ if vineyards are excluded).

The mean change in SOC which was calculated with RothC for the years 1990–2020 was -0.044±0.249 t C $ha^{-1}$ $yr^{-1}$ (area-weighted mean across three elevation zones ± the absolute uncertainty based on a Monte Carlo analysis, see Figure 6-12 and chp. 6.6.3). In comparison, the modelled net change is clearly smaller than the detectable change by NABO and suggests that modelled SOC stock changes agree with the repeated soil inventories in the NABO network.

In conclusion, NABO data provide evidence that Grassland mineral soils did not act as a significant net source or net sink of carbon over the last 30 years.

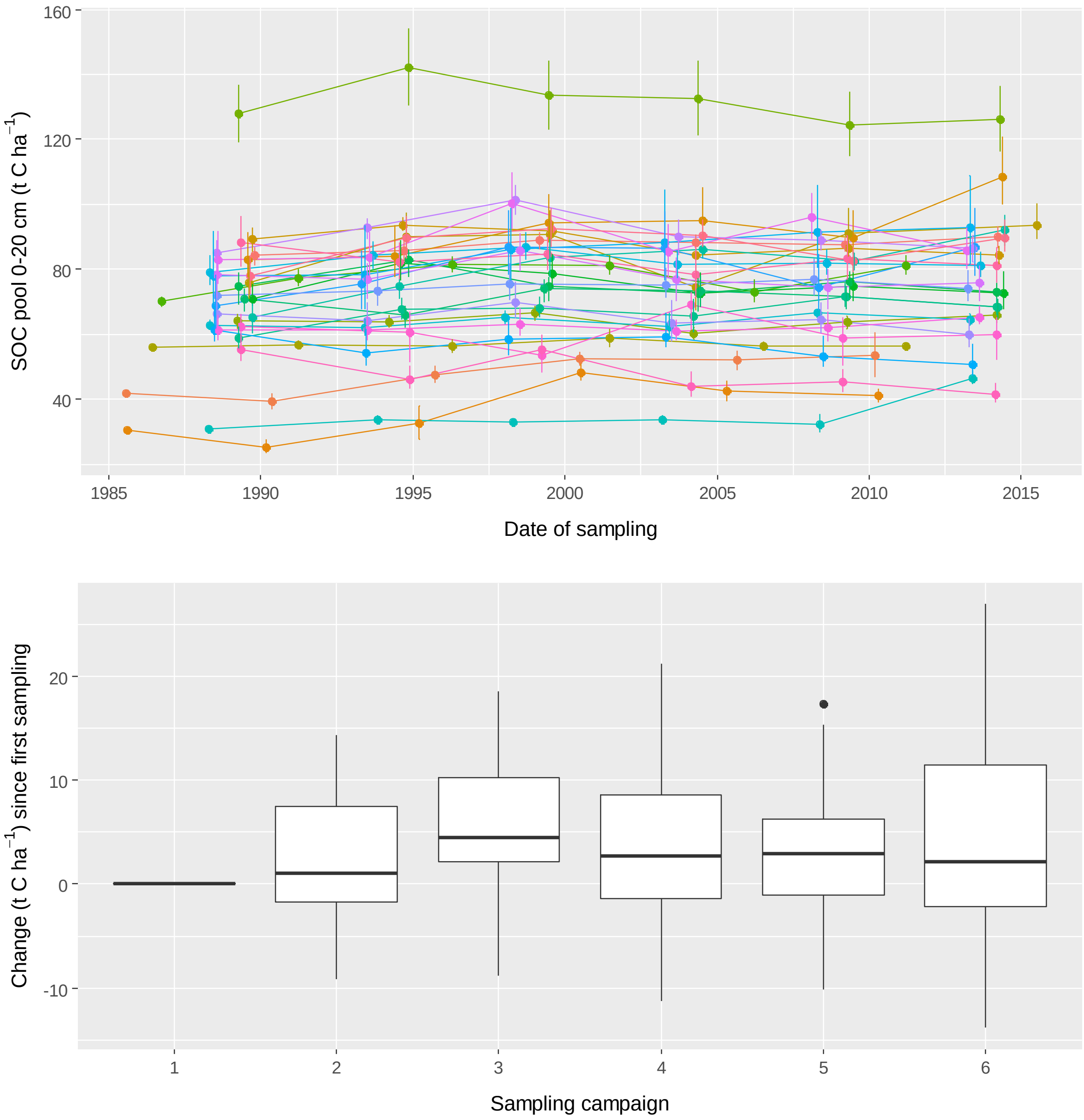



Figure 6-13 Measured SOC stocks for topsoils (0–20 cm) and their changes for 31 NABO long-term monitoring sites used as grassland during the time period 1985–2014. The elevation of the sites ranges from 265 to 2400 m a.s.l. Top panel: SOC stocks 0–20 cm per site and sampling; the dots indicate the mean and the bars the range of 5% and 95% percentiles of bootstrap samples taking into account the variability in SOC contents of the individual replicates per site and sampling as well as the variations of the bulk density. Bottom panel: boxplot of changes in SOC stocks in each case related to the first sampling (boxes indicate the lower und the upper quartiles with the median indicated; lines include all observations inside the range of 1.5 times the interquartile distance, observations beyond that range are indicated as dots).

### 6.6.4.5. Short-term land-use changes between Grassland and Cropland

See chp. 6.5.4.5.

#### 6.6.4.6. Justification for the use of a one-year conversion period for land converted to woody grassland types

In response to UNFCCC (2022, ID#L.5) the following information is provided to increase the transparency of $CO_2$ emissions and removals in category 4C2. Category 4C2 is a permanent net source of $CO_2$ due to biomass losses in 4.C2.1 Forest land converted to grassland. In this category, it is evident to assume a one-year conversion time (for all sub-divisions, i.e. permanent, unproductive, and woody).

Land-use change towards vineyards, low-stem orchards and tree nurseries (CC33) and orchards (CC35) has taken place almost exclusively on Cropland or Grassland since 1990 (Table 6-9). New planting of these crops is usually not done with seedlings, but with already established plants (except for tree nurseries, which are negligible in terms of area).

In subcategory 4C2.5 Other Land converted to grassland, $CO_2$ removals of the subgroup “woody” are mainly due to the shift of vegetation zones in the mountain region as a result of climate change. The land-use change Other land (CC61) to woody grassland (CC32, CC33, CC34, CC35) was largely stable until 2006 (ca. 130 ha $yr^{-1}$). After a steady increase within a few years, it has since fluctuated in a range between 210 and 220 ha $yr^{-1}$. Biological processes at altitude are slow. However, if sufficient woody biomass is detected in the aerial photographs on which the Swiss land use statistics are based to be designated as woody grassland in the CC classification, then the inventory is doing nothing more than accounting for the processes that have already occurred in nature. The fact that the environmental conditions there do not allow the further build-up of a biomass stock as at low altitudes and/or on fertile sites strengthens the assumption that a one-year conversion time is justified in these cases of land-use change.

In summary, for the quantitatively most important land conversions to woody grassland (and generally for all land-use changes to CC33 and CC35), good reasons can be given for the use of a one-year conversion period.

### 6.6.5. Category-specific recalculations

The following recalculations were implemented. Major recalculations which contribute significantly to the differences in net emissions and net removals of sector 4C between the latest and the previous submissions are additionally presented in chp. 10.1.2.4.

- 4C: Activity data (areas) 1990–2019 were updated (see chp. 6.3.5). With the inclusion of the last outstanding tranche of AREA4 data (see chp. 6.3.4.3), the following changes as a result of the recalculation were noted: Permanent grassland (CC31) showed a relative increase of up to 0.6% (maximum 5.52 kha, mainly since 2014), vineyard, low-stem orchard, tree nursery (CC33) up to 1.3% (maximum 0.33 kha, mainly since 2014), copse (CC34) up to 4.8% (maximum 3.34 kha, mainly since 2010), orchard (CC35) up to 7.6% (maximum 0.11 kha, mainly since 2015), and stony grassland (CC36) up to 1.2% (maximum 1.87 kha, mainly since 2010), whereas shrub vegetation (CC32) recorded a relative decrease of up to 1.1% (maximum 1.65 kha, mainly since 2010). For unproductive grassland (CC37), a mixed signal resulted with a relative increase of up to 0.4% (maximum 0.24 kha) in 2015–2019 and a relative decrease of up to 0.3% (maximum 0.20 kha) in 1998–2014. In the years before the above-mentioned periods, the changes in the respective CC areas as a result of recalculation were significantly smaller (in many years close to zero) or not pronounced at all.

- 4C, permanent grassland (CC31): The same yield data 1990–2019 were used as in the previous submission. Due to multi-year averaging (cf. the approach in chp. 6.6.2.1.1), carbon stocks and carbon stock changes in living biomass in the latest time series 1990–2020 were recalculated for the years 2018 and 2019. The effect on the biomass carbon pool was very small.
- 4C, vineyard, low-stem orchard, tree nursery (CC33), orchard (CC35), and unproductive grassland (CC37): Carbon stocks in living biomass were adjusted to the recalculated carbon stock in living biomass of CC31 (see above) averaged over the inventory period. The effect on the biomass carbon pool was very small.
- 4C, permanent grassland (CC31): Carbon stocks and carbon stock changes in mineral soils were recalculated for the whole inventory period, applying
  - updated information used for the calculation of organic amendments (excretion rates of volatile solids, as described in chp. 5.2.5), as well as updated data regarding herd sizes and the movement of farmyard manure to anaerobic digesters, both in line with values used in the Agriculture sector). The effect of both adjustments on the mineral soil carbon pool was very small;
  - updated gridded climate data (MeteoSwiss). The latest data caused most of the differences in soil carbon stocks and soil carbon stock changes between the latest and previous submissions around the year 2011 and partly in the years thereafter (see below and chp. 10.1.2.4).
- 4C, permanent grassland (CC31): An error in a script used to generate an import file for RothC was corrected. This error affected the climate data for 2019 (only) in the previous submission. The recalculation also had a strong impact on the carbon stocks and carbon stock changes of the years 2017 and 2018 (due to multi-year averaging).
- 4C, shrub vegetation (CC32), copse (CC34), orchard (CC35), stony grassland (CC36), and unproductive grassland (CC37): Carbon stocks in mineral soils were adjusted to the recalculated carbon stock in mineral soil of CC31 (see above) averaged over the inventory period. The effect on the mineral soil carbon pool was very small.
- 4C, vineyard, low-stem orchard, tree nursery (CC33): Carbon stock in mineral soil was adjusted to the recalculated carbon stock in mineral soil of CC21 (see chp. 6.5.5) averaged over the inventory period. The effect on the mineral soil carbon pool was very small.
- 4(V)C1: $CH_4$ and $N_2O$ emissions from wildfires were recalculated for the years 2018 and 2019 based on an updated area affected by wildfires in the Swissfire database. Very small changes resulted from this recalculation.
- 4(V)C1: For calculating the amount of available fuel consumed by wildfires, the recalculated carbon stocks in living biomass for CC31, CC33, CC35, and CC37 (see above) were used. Very small changes in $CH_4$ and $N_2O$ emissions resulted from this recalculation (see chp. 6.6.2.4).

### 6.6.6. Category-specific planned improvements

#### 6.6.6.1. Living biomass

The project process to achieve a sound wall-to-wall above ground tree biomass database and map for Switzerland is described in chp. 6.5.6. The suitability of the obtained data for reporting in category 4C is subject to ongoing evaluation (Price 2020).

#### 6.6.6.2. Mineral soil

The information in chp. 6.5.6.2 on the switch to grid-based SOC modelling with RothC for the GHG inventory also applies to permanent grassland (CC31) mineral soil.

#### 6.6.6.3. Organic soil

A study on GHG ($CO_2$, $CH_4$, $N_2O$) emissions from an intensively used fen under grassland management in the Rhine valley (canton Sankt Gallen; Agroscope 2017–2022, financed by FOEN) will improve the robustness of country-specific carbon stock change and emission factor estimates for Grassland soils rich in organic matter in the medium term. A further objective of the study is to test if mineral cover fills reduce peat oxidation and how they change GHG emissions from managed organic soils (Paul et al. 2020; Wang et al. 2021, 2022).

## 6.7. Category 4D – Wetlands

### 6.7.1. Description

Table 6-27 Key categories of 4D Wetlands. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 4D1 | Wetland Remaining Wetland | CO2 | L2 |

Carbon stocks and carbon stock changes in living biomass and in mineral and organic soils were considered. $CH_4$ emissions from flooded land were reported under category 4(II)D2.

Wetlands were subdivided into surface waters (CC41) and unproductive wetlands such as shore vegetation, fens or (raised) bogs (CC42) (see Table 6-2 and Table 6-6).

## 6.7.2. Methodological issues

### 6.7.2.1. Carbon stocks

#### *6.7.2.1.1. Carbon stocks in living biomass*

**Surface waters (CC41)**

Surface waters have no carbon stocks by definition.

**Unproductive wetland (CC42)**

CC42 consists of (very) extensively managed grassland, bushes or tree groups. The carbon stock of living biomass was estimated as 6.50 t C $ha^{-1}$ (Mathys and Thürig 2010).

#### *6.7.2.1.2. Carbon stocks in dead organic matter*

Applying a Tier 1 approach carbon stocks in dead organic matter were assumed to be zero.

#### *6.7.2.1.3. Carbon stocks in soils*

**Surface waters (CC41)**

The mineral soil carbon stock for surface waters (CC41) is zero. For CC41 situated in areas with organic soil (see chp. 6.2.2.1 and Table 6-7), a soil carbon stock of 240 t C $ha^{-1}$ (0–30 cm) was assumed. These surface waters were assumed to be shallow ponds as integrated parts of fens or bogs.

**Unproductive wetland (CC42)**

Land cover in CC42 includes (raised) bogs and fens protected by Federal Legislation (Swiss Confederation 1991a, 1994) as well as reed. More than 10% of the unproductive wetland are located on organic soils (cf. Table 6-7). In this case the carbon stock in soils is 240 t C $ha^{-1}$ (0–30 cm). No specific soil data are available for CC42 on mineral soils. As a first approximation, it was assumed that the soil carbon stock of unproductive wetland is similar like in mineral soils of permanent grassland (CC31). Therefore, the averages 1990–2020 of CC31 (see chp. 6.6.2.1.3) were calculated and weighted with the area per elevation zone of CC42: 62.80 t C $ha^{-1}$ (0–30 cm).

### 6.7.2.2. Changes in carbon stocks

#### *6.7.2.2.1. Carbon stock changes in living biomass, in dead organic matter, and in mineral soils*

Applying a Tier 1 approach, carbon stock changes in living biomass, in dead organic matter, and in mineral soils were assumed to be in equilibrium for Wetlands remaining wetlands.

##### *6.7.2.2.2. Carbon stock changes in organic soils*

Carbon loss from organic soils under CC41 was assumed to be zero because the respective areas are not drained.

Carbon loss from organic soils under CC42 was estimated to be 5.30 t C $ha^{-1}$ $yr^{-1}$ according to domestic data (ART 2011b; Paul and Alewell 2018). This value was used for weakly managed ecosystems such as fens and (very) extensively managed ecosystems such as raised bogs. Bogs and fens are protected to a large part by Federal Ordinances (Swiss Confederation 1991a, 1994) and drainage is not allowed any more. However, the impact of old drainages constructed before 1990 probably still triggers certain emissions.

##### *6.7.2.2.3. Land-use change*

In the case of land-use change, the net carbon stock changes in biomass and soils of both CC41 and CC42 were calculated as described in chp. 6.1.3.

For land converted to unproductive wetland (CC42) a conversion time of one year was chosen for the carbon stock change in living biomass and in dead organic matter (see Table 6-3). For carbon stock changes in mineral soils the conversion time is 20 years.

#### 6.7.2.3. Non-$CO_2$ emissions from Wetlands

No emissions were reported in category D in CRF Table4(I) (notation key “NO”). Input of nitrogen fertilisers to unproductive wetlands (CC42) is very unlikely as these areas represent mostly nature conservation areas (raised bogs, fens) protected by legislation (Swiss Confederation 1991a, 1994), where fertilising is prohibited.

An estimate of 0.4 kt $CH_4$ $yr^{-1}$ emitted by reservoirs (flooded lands) was given by Hiller et al. (2014). The estimate encompasses 97 artificial lakes covering a total area of 10.6 kha. This emission is reported in category D.2 in CRF Table4(II).

$N_2O$ emissions from drainage of organic soils was calculated for unproductive wetlands (CC42) and reported in category D.3 in CRF Table4(II) (labelled as “WL drained”). Activity data correspond to the total area of organic soils for sub-division "unprod wetland" (CC42) in CRF Table4.D.The emission factor of 1.6 kg $N_2O$-N $ha^{-1}$ used is the default value given in the IPCC Wetlands Supplement (IPCC 2014a: Table 2.5) for shallow drained, nutrient-rich grassland.

The calculation of emissions for categories 4(III) and 4(IV) (direct $N_2O$ emissions from nitrogen mineralisation in mineral soils and indirect $N_2O$ emissions from managed soils) is described in chp. 6.10.

### 6.7.3. Uncertainties and time-series consistency

#### 6.7.3.1. Uncertainties in category 4D1

<u>Activity data</u>

Uncertainties of activity data of category 4D Wetlands are described in chp. 6.3.3.

For calculating the overall uncertainty of 4D1, only the relevant emissions from organic soils were considered (Meteotest 2022).

Organic soils

The uncertainty of the carbon stock change factor in organic soils is 72.2% both for 1990 and 2020. It was calculated on the basis of measurement data compiled by ART (2011b). The uncertainty of the activity data (area of organic soil) is 90.8% (see chp. 6.3.3 and Table 6-5).

#### 6.7.3.2. Uncertainties in category 4D2

Activity data

Uncertainties of activity data of category 4D Wetlands are described in chp. 6.3.3.

For calculating the overall uncertainty of 4D2, the relevant emissions from living biomass, mineral soils and organic soils were considered (Meteotest 2022).

Living biomass

The relative uncertainty in yield determination was estimated as 13% for biomass carbon from both Cropland and Grassland (Leifeld and Fuhrer 2005). The absolute uncertainty per hectare, calculated with the implied emission factors of 2020, is 0.147 t C $ha^{-1}$ $yr^{-1}$ for 4D2.

Mineral soils

Based on expert judgement, an uncertainty of 50% was chosen for the carbon stock changes calculated with the stock-difference approach in category 4D2. The absolute uncertainty per hectare, calculated with the implied emission factor of 2020, is 0.365 t C $ha^{-1}$ $yr^{-1}$ for 4D2.

Organic soils

The uncertainty of the carbon stock change factor in organic soils is 72.2% calculated on the basis of measurement data compiled in ART (2011b) and the uncertainty of the activity data (area of organic soil) is 90.8% (see chp. 6.3.3), resulting in a combined uncertainty of 116.0%. Thus, the absolute uncertainties of the total organic soil emissions in 2020 are 1.23 kt C for 4D2. By dividing this uncertainty with the total area of 4D2, the absolute uncertainty per hectare results in 0.211 t C $ha^{-1}$ $yr^{-1}$ for 4D2.

Overall uncertainty 4D2

The root sum squares of the above-mentioned three absolute uncertainties is 0.446 t C $ha^{-1}$ $yr^{-1}$ for 4D2. This absolute uncertainty was used to calculate the relative emission factor uncertainty for 4D2 by dividing with the net carbon stock change per hectare of 4D2. In 2020, the net carbon stock change was -2.188 t C $ha^{-1}$ for 4D2 (calculated from CRF Table4.D). The resulting relative uncertainty is 20.4% for 4D2 (see Table 6-5). In the same way the uncertainty for the year 1990 was calculated: 23.9%.

Flooded lands ($CH_4$)

The emission factor uncertainty for $CH_4$ emitted by flooded lands can be very high (IPCC 2006, Volume 4, Appendix 3). As a best guess, a value of 70% was chosen for the $CH_4$

emission factor of category 4(II)D2 (Table 6-5). The activity data uncertainty of flooded lands was set to 10% based on an expert judgment considering the methods used by Hiller et al. (2014) for estimating the area of reservoirs/flooded land.

Drainage of organic soils ($N_2O$; category 4(II))

For $N_2O$ emissions from drainage of organic soils (category 4(II)), the emission factor uncertainty for shallow-drained, nutrient-rich grassland given in the Wetlands Supplement Guidelines (IPCC 2014a: Table 2.5) was used. It was calculated as arithmetic mean of the lower and upper bound uncertainty (66.9%; cf. Table 6-5). The respective activity data uncertainty is 48.9% (Meteotest 2022); it was calculated by combining the uncertainties of the area of organic soils (see chp. 6.3.3) for Forest land (35.3%) and for Wetlands (90.8%).

#### 6.7.3.3. Time-series consistency

Time series for category 4D Wetlands are all considered consistent; they were calculated based on consistent methods and homogenous databases.

### 6.7.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

No category-specific QA/QC activities were carried out.

### 6.7.5. Category-specific recalculations

- 4D: Activity data (areas) 1990–2019 were updated (see chp. 6.3.5). With the inclusion of the last outstanding tranche of AREA4 data (see chp. 6.3.4.3), surface water (CC41) decreased by up to 0.18 kha (corresponding to 0.1% relative decrease), whereas unproductive wetland (CC42) increased by up to 0.24 kha (corresponding to 0.9% relative increase). The reallocations took place mainly in the years since 2014. In the period before, the changes in the areas of CC41 and CC 42 as a result of recalculation were significantly smaller (in many years close to zero).
- 4D, unproductive wetlands (CC42): The carbon stock in mineral soils was adjusted to the recalculated average (1990–2020) of permanent grassland (CC31) (cf. chp.6.6.5). The effect on the mineral soil carbon pool was very small.

The resulting differences of both recalculations in net emissions and removals between the latest and the previous submissions for categories 4D are shown in Figure 10-9. They are insignificantly small over most of the inventory period and reach a peak with 8.9 kt $CO_2$ eq in the year 2016.

## 6.7.6. Category-specific planned improvements

### 6.7.6.1. Living biomass

The project process to achieve a sound wall-to-wall above ground tree biomass database and map for Switzerland is described in chp. 6.5.6. The suitability of the obtained data for reporting in category 4D is subject to ongoing evaluation (Price 2020).

### 6.7.6.2. Mineral soil

The information in chp. 6.5.6.2 on the switch to grid-based SOC modelling with RothC for the GHG inventory also applies to unproductive wetland (CC42) mineral soil.

# 6.8. Category 4E – Settlements

## 6.8.1. Description

Table 6-28 Key categories in category 4E Settlements. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 4E2 | Land Converted to Settlements | CO2 | L1, L2 |

Carbon stocks and carbon stock changes in living biomass and in mineral and organic soils were considered.

Settlements were subdivided into buildings/constructions (CC51), herbaceous biomass in settlements (CC52), shrubs in settlements (CC53), and trees in settlements (CC54) (see Table 6-2 and Table 6-6).

GHG emissions by biomass burning in Settlements (category 4(V)E) do not occur.

## 6.8.2. Methodological issues

### 6.8.2.1. Carbon stocks

#### *6.8.2.1.1. Carbon stocks in living biomass*

**Buildings and constructions (CC51)**
By default, buildings/constructions have no carbon stocks.

**Herbaceous biomass, shrubs and trees in settlements (CC52, CC53, CC54)**
Carbon stocks in living biomass are: 9.54 t C $ha^{-1}$ for CC52, 15.43 t C $ha^{-1}$ for CC53, and 20.72 t C $ha^{-1}$ for CC54 (Mathys and Thürig 2010: Table 7).

#### 6.8.2.1.2. *Carbon stocks in dead organic matter*

Applying a Tier 1 approach carbon stocks in dead organic matter were assumed to be zero.

#### 6.8.2.1.3. *Carbon stocks in soils*

**Buildings and constructions (CC51)**

The carbon stocks in mineral and in organic soils for CC51 were assumed to be zero.

**Herbaceous biomass, shrubs and trees in settlements (CC52, CC53, CC54)**

The carbon stocks in mineral soils for CC52, CC53, and CC54 are 50.38 t C $ha^{-1}$, 50.38 t C $ha^{-1}$, and 50.43 t C $ha^{-1}$, respectively (0–30 cm). These values correspond to soil carbon stocks in mineral soils on Cropland (see chp. 6.5.2.1.3); they were calculated as average soil carbon stock of CC21 for the period 1990–2020, weighted with the area of CC52, CC53, and CC54 per elevation zone.

For organic soils the carbon stock for CC52, CC53, and CC54 was assumed as 240 t C $ha^{-1}$ (0–30 cm), see chp. 6.5.2.1.3.

### 6.8.2.2. Changes in carbon stocks

#### 6.8.2.2.1. *Carbon stock changes in living biomass, in dead organic matter, and in mineral soils*

Applying a Tier 1 approach, carbon stock changes in living biomass, in dead organic matter, and in mineral soils were assumed to be in equilibrium for Settlements remaining settlements.

#### 6.8.2.2.2. *Carbon stock changes in organic soils*

On organic soils, the following emission factors were applied:

- 9.52 t C $ha^{-1}$ $yr^{-1}$ for CC52. This corresponds to the value used for Cropland because CC52 areas are managed (gardens, parks) (Leifeld et al. 2003, 2005 and verified by ART 2009b and Paul and Alewell 2018).
- 5.30 t C $ha^{-1}$ $yr^{-1}$ for CC53 and CC54. This corresponds to the value used for extensively managed grasslands (ART 2011b; Paul and Alewell 2018).

#### 6.8.2.2.3. *Land-use change*

In case of land-use changes from non-CC51 to CC51 on mineral or on organic soils a loss of 20% of the initial carbon stock was reported following IPCC 2006 (Volume 4, chp. 8.3.3.2). The reason for this is that 20% of the soil organic matter is assumed to be lost as a result of disturbance, removal or relocation on these areas being sealed. This assumption is supported by paragraph 7 of the federal "Ordinance against deterioration of soils" (Swiss Confederation 1998) stating that the soil material excavated on a construction site must be treated in such a way that it can be used as a soil again. When the material is re-used (e.g.

for re-cultivations) the fertility of the soil must not be affected. This regulation ensures that a large part of the soil organic matter is preserved on land converted to CC51.

Thus, equation 6.8 presented in chp. 6.1.3.2 was adjusted as follows if a=CC51:

$$deltaC_{s,i,b51} = [\ 0.2 * (0 - stockC_{s,i,b}) / CT\ ] * A_{i,b51}$$

where:

| | |
|---|---|
| $stockC_{s,i,b}$ | carbon stock in soil (t C $ha^{-1}$) |
| b | land-use category before conversion (CC = b ≠ 51) |
| b51 | land use conversion from b to CC51 |
| i | spatial stratum |
| $A_{i,b51}$ | area of land (ha) converted from b to CC51 in the spatial stratum i (the sum of the areas converted within the last 20 years) |
| CT | conversion time (20 years; see Table 6-3). |

In case of land-use changes from CC51 to non-CC51 categories, the regular stock-difference approach and gain-loss approach, respectively, according to chp. 6.1.3.2 and Table 6-3 were applied.

In the case of land-use change from or to CC52, CC53, and CC54, the net carbon stock changes in biomass and soils of CC52, CC53, and CC54 were calculated as described in chp. 6.1.3.2.

#### 6.8.2.3. $N_2O$ emissions from Settlements

$N_2O$ emissions associated with inputs from N in Settlements (category 4(I)E) were included in the Agriculture sector (category 3Da Direct $N_2O$ emissions form managed soils; see chp. 5.5).

The calculation of $N_2O$ emissions for categories 4(III) and 4(IV) (direct $N_2O$ emissions from nitrogen mineralisation in mineral soils and indirect $N_2O$ emissions from managed soils) is described in chp. 6.10.

### 6.8.3. Uncertainties and time-series consistency

#### 6.8.3.1. Uncertainties

Based on expert judgement, a value of 50% was chosen for the carbon stock change factor uncertainty in category 4E (Table 6-5).

Uncertainties of activity data of category 4E Settlements are described in chp. 6.3.3.

#### 6.8.3.2. Time-series consistency

Time series for category 4E Settlements are all considered consistent; they were calculated based on consistent methods and homogenous databases.

### 6.8.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

No category-specific QA/QC activities were carried out.

### 6.8.5. Category-specific recalculations

- 4E: Activity data (areas) 1990–2019 were updated (see chp. 6.3.5). With the inclusion of the last outstanding tranche of AREA4 data (see chp. 6.3.4.3), a slight shift within the settlement area took place: Vegetated areas increased, especially those with tree biomass (CC54) by up to 2.09 kha (corresponding to 7.4% relative increase) and shrubs (CC53) by up to 0.21 kha (corresponding to 5.4% relative increase), whereas sealed areas (CC51) decreased by up to 0.63 kha (corresponding to 0.3% relative decrease). The reallocations took place mainly in the years since 2013. The rate of land-use change from non-settled land to CC53 and CC54 contributed significantly to this shift, increasing to a maximum of 136% for CC54 (2015) and 142% for CC53 (2016). In the period before 2013, the changes in the areas of CC51, CC53 and CC54 as a result of recalculation were significantly smaller (in most years close to zero) or not pronounced at all.
- 4E: The carbon stocks in mineral soil for non-sealed settlement areas (CC52, CC53, CC54) were adjusted to the recalculated average (1990–2020) of Cropland (CC21) mineral soil (see chp. 6.5.5). The effect on the mineral soil carbon pool was small.

The resulting differences of both recalculations in net emissions and removals between the latest and the previous submissions for categories 4E are shown in Figure 10-9. They are insignificantly small over most of the inventory period and peak with -40.6 kt $CO_2$ eq and -38.8 kt $CO_2$ eq in the two years 2013 and 2014.

### 6.8.6. Category-specific planned improvements

#### 6.8.6.1. Living biomass

The project process to achieve a sound wall-to-wall above ground tree biomass database and map for Switzerland is described in chp. 6.5.6. The suitability of the obtained data for reporting in category 4E is subject to ongoing evaluation (Gardi et al. 2016; Price 2020).

#### 6.8.6.2. Mineral soil

The information in chp. 6.5.6.2 on the switch to grid-based SOC modelling with RothC for the GHG inventory also applies to Settlements mineral soil.

# 6.9. Category 4F – Other land

## 6.9.1. Description

Table 6-29 Key categories in category 4F Other land. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 4F2 | Land Converted to Other Land | CO2 | L1, L2 |

As shown in Table 6-2 and in Table 6-6 Other land (CC61) covers unmanaged, non-vegetated areas such as glaciers, rocks, screes and shores.

The area of Land converted to other land has increased since 1990 from 361 ha $yr^{-1}$ to 523 ha $yr^{-1}$ in 2020 (see Table 6-9). Primarily the conversions of Forest land and Grassland to Other land lead to $CO_2$ emissions caused by the loss of biomass and soil carbon. Mudflows, erosion, landslides, and dynamic changes in stream beds were identified as the main processes causing the land-use changes. The trigger for the altered morphodynamics is not known, but a connection with climate change can be assumed.

It should be noted that another phenomenon strongly linked to climate change, namely the shift of vegetation zones in mountainous regions (as especially expressed in subcategory 4C2.5 Other land converted to stony grassland (CC36), see Table 6-9), has a higher rate of land-use change, and therefore the total area of Other land has decreased by 4% over the inventory period (Table 6-8).

## 6.9.2. Methodological issues

By definition, Other land has no carbon stocks. Coherently, changes in carbon stock in living biomass, in dead organic matter, and in soils were assumed to be zero for Other land remaining other land.

In the case of land converted to other land, the net carbon changes in biomass and soils were calculated as described in chp. 6.1.3.

The calculation of $N_2O$ emissions on land converted to other land for categories 4(III) and 4(IV) (direct $N_2O$ emissions from nitrogen mineralisation in mineral soils and indirect $N_2O$ emissions from managed soils) is described in chp. 6.10.

## 6.9.3. Uncertainties and time-series consistency

### 6.9.3.1. Uncertainties

Based on expert judgement, a value of 50% was chosen for the carbon stock change factor uncertainty in category 4F2 (Table 6-5).

Uncertainties of activity data of category 4F Other Land are described in chp. 6.3.3.

#### 6.9.3.2. Time-series consistency

Time series for category 4F Other land are all considered consistent; they were calculated based on consistent methods and homogenous databases.

### 6.9.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

No category-specific QA/QC activities were carried out.

### 6.9.5. Category-specific recalculations

- 4F: Activity data (areas) 1990–2019 were updated (see chp. 6.3.5). With the inclusion of the last outstanding tranche of AREA4 data (see chp. 6.3.4.3), the area of Other land decreased by 0.38 to 2.01 kha (the latter corresponding to 0.3% relative decrease) over the period 2010–2019. Simultanously, land-use changes toward Other Land intensified with rates between 115% (2010) and 153% (2016) over these years. In the period before 2010, the changes in the area of CC61 as a result of recalculation were significantly smaller. The resulting differences in net emissions between the latest and the previous submissions for categories 4F are shown in Figure 10-9. They are very small over most of the inventory period and reach their maximum with 28.8 kt $CO_2$ eq in 2016.

### 6.9.6. Category-specific planned improvements

No category-specific improvements are planned.

## 6.10. Categories 4(III) and 4(IV) – $N_2O$ emissions

### 6.10.1. Description

Table 6-30 Key categories in category 4(III) Direct $N_2O$ from disturbance. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 4III | Direct N2O from Disturbance | N2O | L2 |

Category 4(III) is a key category, 4(IV) is not.

This chapter presents the methods for calculating direct (category 4(III)) and indirect (category 4(IV)) $N_2O$ emissions from nitrogen (N) mineralisation in mineral soils. The source of nitrogen is N mineralisation associated with loss of soil organic matter resulting from change of land use or management of mineral soils. As the approaches applied were not Tier 3, no $N_2O$ immobilisation is reported (cf. footnote 1 in CRF Table4(III)).

- In category 4(III), direct $N_2O$ emissions from nitrogen mineralisation associated with loss of soil organic matter are reported.
- In category 4(IV)2, indirect emissions of $N_2O$ due to nitrogen leaching and run-off after mineralisation of soil organic matter are reported.

The following $N_2O$ emissions were included in the Agriculture sector:

- Direct $N_2O$ emissions on Cropland remaining cropland (no category registered in CRF Table4(III)) and on Grassland remaining grassland (category 4(III)C1). In Switzerland, grassland is considered to be under agricultural management, see chp. 5.5.2.2 (category 3Da);
- Indirect $N_2O$ emissions due to atmospheric deposition (category 4(IV)1; all land uses) and leaching and run-off on agricultural land (category 4(IV)2; Cropland remaining cropland and Grassland remaining grassland), see chp. 5.5.2.3 (category 3Db1) and chp. 5.5.2.4 (category 3Db2).

On productive forest land (CC12), small annual changes in carbon stocks of mineral soils are reported that were calculated with the Yasso07 model (chp. 6.4.2.6). These changes were deliberately not considered for the calculation of $N_2O$ emissions in categories 4(III) and 4(IV) as they are not associated with a land-use change or any change in management. Accordingly, $N_2O$ emissions for category 4A.1 in CRF Table4(III) are reported as “NO”.

## 6.10.2. Methodological issues

### 6.10.2.1. Direct $N_2O$ emissions

Direct $N_2O$ emissions (category 4(III)) as a result of the disturbance of mineral soils associated with change of land use or management of mineral soils were calculated according to IPCC (2006, Volume 4, chp. 11):

Emission($N_2O$) = – deltaCs * 1 / (C:N) * EF1 * 44/28, if deltaCs <0 [kt $N_2O$]

where:

- deltaCs: soil carbon stock change induced by change of land-use or management [kt C]
- C:N: C to N ratio of the soil before the land-use change
- EF1: default emission factor = 0.01 kg $N_2O$-N (kg N)$^{-1}$ (IPCC 2006, Volume 4, Table 11.1).

deltaCs was calculated according to the methodology described in chp. 6.1.3.2. If deltaCs is zero or positive (carbon gain) there are no $N_2O$ emissions provoked by the specific change of land-use or management.

The value of the C:N ratio is related to the land-use category before the change. For Cropland and Grassland the ratio is 9.8 according to Leifeld et al. (2007). This value was also used for mineral soils in Wetlands (CC42) and unsealed settlement areas (CC 52, CC53, CC54). For Forest land, the default value of C:N=15 was used (IPCC 2006, Volume 4, equation 11.8).

#### 6.10.2.2. Indirect $N_2O$ emissions

Indirect $N_2O$ emissions (category 4(IV)) as a result of N leaching and run-off after mineralisation of soil organic matter were calculated as follows using default emission factors (IPCC 2006, Volume 4, Table 11.3):

$$\text{Emission}(N_2O) = -\text{deltaCs} * \text{Frac}_{LEACH} / (C:N) * EF5 * 44/28, \text{ if deltaCs} < 0 \quad [\text{kt } N_2O]$$

where:

- $\text{Frac}_{LEACH}$: fraction of mineralised N lost by leaching or run-off; see Table 6-31.
- C:N ratio as above for direct $N_2O$ emissions
- EF5: default emission factor = 0.0075 kg $N_2O$-N (kg N)$^{-1}$ (IPCC 2006, Volume 4, Table 11.3).

deltaCs was calculated according to the methodology described in chp. 6.1.3.2. If deltaCs is zero or positive (carbon gain) there are no $N_2O$ emissions provoked by the specific change of land-use or management.

For calculating deltaCs, all land-use changes and conversions between land-use combination categories were taken into account.

Table 6-31 Fractions of mineralised N lost by leaching or run-off ($\text{Frac}_{LEACH}$), see chp. 5.5.2.4.2.

| | Unit | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $\text{Frac}_{LEACH}$ | -- | 0.206 | 0.206 | 0.206 | 0.206 | 0.206 | 0.206 | 0.204 | 0.202 | 0.201 | 0.199 |

| | Unit | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $\text{Frac}_{LEACH}$ | -- | 0.197 | 0.195 | 0.193 | 0.191 | 0.189 | 0.188 | 0.186 | 0.184 | 0.182 | 0.180 |

| | Unit | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $\text{Frac}_{LEACH}$ | -- | 0.178 | 0.178 | 0.178 | 0.178 | 0.178 | 0.178 | 0.178 | 0.178 | 0.178 | 0.178 |

| | Unit | 2020 |
|---|---|---|
| $\text{Frac}_{LEACH}$ | -- | 0.178 |

## 6.10.3. Uncertainties and time-series consistency

#### 6.10.3.1. Uncertainties

Emission factors categories 4(III) and 4(IV)

Relative uncertainties for the emission factors were taken from IPCC (2006, Vol 4, Tables 11.1 and 11.3). Since the uncertainty envelopes are skewed and no negative values occur, a gamma distribution was chosen (see details in Annex A2.1):

- Uncertainty 4(III) (EF1): gamma distribution, 2 standard deviations of 156%, 95% confidence interval (from 2.5% to 97.5%) of -91.4%, +200.8%
- Uncertainty 4(IV) (EF5): gamma distribution, 2 standard deviations of 178%, 95% confidence interval (from 2.5% to 97.5%) of -95.1%, +233.7%

Activity data category 4(III)

The uncertainty of the activity data for category 4(III) corresponds to the uncertainty of the amount of mineralised N. It was calculated as the combined uncertainty of:

- Uncertainty of the carbon stock losses in mineral soils: Land converted to settlements (category 4E2) is the main source in category 4(III). Therefore, the uncertainty of the area converted to settlements (4.6%; Table 6-5) and the uncertainty of the $CO_2$ emission factor (50.0%) were combined to estimate the uncertainty of the carbon stock loss: 50.2%.
- Uncertainty of the C:N ratio: The uncertainty of the C:N ratio for Forest land is used here. With a value of 15 and a 95%-range between 10 and 30 (IPCC 2006, Volume 4, equation 11.8) the mean uncertainty results in 66.7%.

The resulting uncertainty for AD of category 4(III) is 83.5%, calculated as $(50.2^2+66.7^2)^{0.5}$.

Activity data for category 4(IV)2

The uncertainty of the activity data for category 4(IV)2 is 85.8%. It is the combined uncertainty of the amount of leached N, which is calculated from the amount of mineralised N (uncertainty 83.5%, see category 4(III)) and $Frac_{LEACH}$ (uncertainty 20%, adopted from ART 2008a) (cf. Table 6-5).

#### 6.10.3.2. Time-series consistency

Time series for categories 4(III) and 4(IV) $N_2O$ emissions from nitrogen mineralisation are all considered consistent; they were calculated based on consistent methods and homogenous databases.

### 6.10.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

No category-specific QA/QC activities were carried out.

### 6.10.5. Category-specific recalculations

- 4(III), 4(IV): Activity data (areas) 1990–2019 were updated (see chp. 6.3.5).
- 4(III), 4(IV2): Activity data (loss of soil organic matter) were recalculated due to various recalculations of carbon stocks in mineral soils. In the case of a land-use change, the recalculated carbon stocks in mineral soils of Forest land, Cropland,

Grassland, Wetlands and Settlements (see chp. 6.4.5, chp. 6.5.5, chp.6.6.5, chp.6.7.5, and chp.6.8.5) led to recalculations of soil carbon stock changes (deltaCs) following the stock-difference approach (see Table 6-3) and – in a next step – of resulting direct and indirect $N_2O$ emissions.

### 6.10.6. Category-specific planned improvements

No category-specific improvements are planned.

## 6.11. Category 4G – Harvested wood products (HWP)

### 6.11.1. Description

Table 6-32 Key categories in category 4G Harvested wood products (HWP). Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 4G | HWP Harvested Wood Products | CO2 | T1, T2 |

Estimates of net emissions and removals from HWP due to losses and gains of carbon, respectively, were reported. Gains refer to annual carbon inflow to the HWP pool, whereas losses refer to annual carbon outflow from the HWP pool.

The approach to calculate carbon stock changes in HWP corresponds to a production approach as described in Annex 12.A.1, Volume 4 of IPCC (2006). Changes in carbon stocks in Swiss forests are presented in chp. 6.4. The estimate covers all wood products originating from trees harvested in Switzerland (sawnwood, wood based panels, and paper and paperboard) that are processed in Switzerland and that are used for material (i.e. not for energetic) purposes.

The HWP pool includes products made from domestic harvest that were exported and are in use in other countries. Imported HWP are not included in the HWP pool.

To calculate carbon stock changes in HWP, product categories and half-lives were used following the methodologies described in IPCC (2006) and IPCC (2014). Further details and result evaluations are presented in FOEN (2022e).

### 6.11.2. Methodological issues

The same methodology was used for reporting under the UNFCCC and accounting under the Kyoto Protocol. It is consistent with paragraph 29 in the Annex to Decision 2/CMP.7, which states that “transparent and verifiable activity data for Harvested wood products categories are available, and accounting is based on the change in the Harvested wood products pool of the second commitment period, estimated using the first-order decay function”. Therefore, in this chapter the terminology of the Kyoto Protocol is used, i.e. it is referred to the activities Afforestation, Deforestation and Forest management (as defined in FOEN 2006h; see chp. 11.1.3).

For the estimation of carbon stocks and carbon stock changes, the equations described in IPCC (2014: chp. 2.8) were used. A Tier 2 approach, first order decay, was applied for the product categories sawnwood, wood based panels, and paper and paperboard according to equation 2.8.5 in IPCC (2014).

- Emissions occurring during the second commitment period from HWP removed from forests prior to the start of the second commitment period were also accounted for. The starting year used to estimate the delayed emissions from the existing pools is 1900.
- Emissions from the HWP pool accounted for in the first commitment period on the basis of instantaneous oxidation were excluded from the accounting for the second commitment period.
- Emissions from wood harvested for energy purposes were accounted on the basis of instantaneous oxidation (FOEN 2022e).
- HWP going to solid waste disposals were not included in the HWP pool for LULUCF, i.e. instantaneous oxidation is assumed. Information on wood in solid waste disposals is given in the waste sector, see chp. 7.2.2.
- Imported HWP were not included in the HWP pool.
- Exported HWP were included in the HWP pool. In CRF 4(KP-I)C, Forest management, exported HWP are reported as "IE" since they are not quantified separately from domestically consumed HWP.
- The share of industrial roundwood ($f_{IRW}$) used for calculating the domestic production of HWP originating from domestic forests was derived according to equation 2.8.1 in IPCC (2014).
- For estimating the domestic HWP contribution of paper and paperboard, the feedstock factors $f_{IRW}$ and $f_{PULP}$ (see equation 2.8.2 in IPCC 2014) were applied according to equation 2.8.4 in IPCC (2014).
- For estimating the HWP contribution of paper and paperboard, the recovered wood pulp from recovered paper was excluded from the feedstock. For this purpose, the net consumption of recovered pulp was calculated from FAO data on production, export and import of recovered fibre pulp (see FOEN 2022e).
- Based on the available data sets it was not possible to differentiate between HWP from Afforestation and HWP from Forest management. Since Afforestation in Switzerland typically serves purposes other than timber production such as recreation, ground water protection, noise control, improvement of microclimate and air quality, biomass is not removed to enter the HWP pool. In case there is some wood of first thinnings in Afforestations since 1990, it is a negligible amount which is mostly left on the site or sometimes collected for energy purposes. Therefore, the amount of HWP from Afforestation was reported as not occurring (“NO”) in CRF 4(KP-I)C and all carbon stock changes in HWP were reported under Forest management.
- The change in carbon stocks of HWP was estimated separately for each product category and differentiating HWP from Deforestation and from Forest management (including HWP from Afforestations) by applying equation 2.8.4 in IPCC (2014). Applying instantaneous oxidation to HWP originating from Deforestation, the same

results were obtained for changes in carbon stocks of HWP reported under the UNFCCC (CRF Table4.Gs1) and under the Kyoto Protocol (CRF 4(KP-I)C).

#### 6.11.2.1. Activity data

The time series are shown in CRF Table4.Gs2. The activity data are described in detail in FOEN (2022e):

- Production data for all product categories (sawnwood, wood panels, paper and paperboard, and recovered fibre pulp) were retrieved from FAOSTAT for the years 1961–2020 (http://www.fao.org/faostat/en/#data/FO, Forestry Production and Trade).
- In order to estimate the share of industrial roundwood and the share of fibre pulp originating from domestic forests, as feedstock for HWP production, data from national wood processing statistics and foreign trade statistics (import and export) available from FAOSTAT 1961–2020 were used.

In order to estimate carbon amounts in each HWP category and subcategory, default carbon conversion factors were taken from IPCC (2014: Table 2.8.1) for wood-based panels. For sawnwood, country-specific wood density values measured by the wood industry and checked with the values published by the NFI (Werner 2019a) and an IPCC (2006) default carbon fraction of 0.5 were used:

- Coniferous sawnwood: 0.41 $t/m^3$
- Non-coniferous sawnwood: 0.59 $t/m^3$.

#### 6.11.2.2. Carbon stock change factors

Carbon stock change factors for specific product categories were calculated following equation 2.8.5 in IPCC (2014) using default half-lives of 25 years for wood panels, 35 years for sawnwood and 2 years for paper products (IPCC 2014: Tab. 2.8.2).

#### 6.11.2.3. Results

The resulting emissions and removals per product category are listed in Table 6-33 and shown in Figure 6-14.

Table 6-33 $CO_2$ emissions and removals from Harvested wood products (HWP) derived from sawnwood ($changeC_{HWP-sawnwood}$), panels ($changeC_{HWP-panels}$), and paper and paperboard ($changeC_{HWP-paper\ and\ paperboard}$), originating from Forest management, in kt $CO_2$ (positive values refer to emissions, negative values refer to removals).

| | Unit | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| HWP | kt $CO_2$ | -1'169 | -764 | -556 | -477 | -358 | -487 | -302 | -256 | -308 | -386 |
| $changeC_{HWP-sawnwood}$ | kt $CO_2$ | -662 | -409 | -230 | -149 | -92 | -256 | -141 | -104 | -186 | -239 |
| $changeC_{HWP-panels}$ | kt $CO_2$ | -466 | -376 | -401 | -370 | -294 | -237 | -194 | -166 | -181 | -166 |
| $changeC_{HWP-paper\ and\ paperboard}$ | kt $CO_2$ | -41 | 22 | 74 | 42 | 28 | 6 | 33 | 13 | 58 | 19 |

| | Unit | 2'000 | 2'001 | 2'002 | 2'003 | 2'004 | 2'005 | 2'006 | 2'007 | 2'008 | 2'009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| HWP | kt $CO_2$ | -723 | -427 | -300 | -358 | -581 | -727 | -541 | -363 | -430 | -420 |
| $changeC_{HWP-sawnwood}$ | kt $CO_2$ | -364 | -120 | -54 | -59 | -214 | -295 | -284 | -71 | -189 | -151 |
| $changeC_{HWP-panels}$ | kt $CO_2$ | -387 | -306 | -241 | -272 | -347 | -417 | -290 | -253 | -275 | -292 |
| $changeC_{HWP-paper\ and\ paperboard}$ | kt $CO_2$ | 28 | -1 | -6 | -27 | -20 | -15 | 33 | -40 | 34 | 23 |

| | Unit | 2'010 | 2'011 | 2'012 | 2'013 | 2'014 | 2'015 | 2'016 | 2'017 | 2'018 | 2'019 | 2'020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HWP | kt $CO_2$ | -455 | -354 | -133 | 58 | -112 | -95 | -52 | -15 | -96 | 57 | -51 |
| $changeC_{HWP-sawnwood}$ | kt $CO_2$ | -141 | -51 | 50 | 137 | 38 | 31 | 37 | 85 | 17 | 42 | -8 |
| $changeC_{HWP-panels}$ | kt $CO_2$ | -331 | -296 | -187 | -123 | -145 | -142 | -109 | -113 | -128 | 1 | -75 |
| $changeC_{HWP-paper\ and\ paperboard}$ | kt $CO_2$ | 16 | -6 | 5 | 44 | -5 | 16 | 20 | 13 | 16 | 14 | 33 |

Fluctuations in the HWP pool are mainly caused by changes in the production of sawnwood and panels; the share of paper and paperboard is relatively small (see Table 6-33). Because of the strong reduction in the production of sawnwood since 2011, the relative contribution of panels and paper and paperboard to the HWP pool considerably increased (see Figure 6-14). In 2019, the production of wood panels decreased by almost 25% and, as a consequence, HWP became a net $CO_2$ source (for the second time next to 2013).

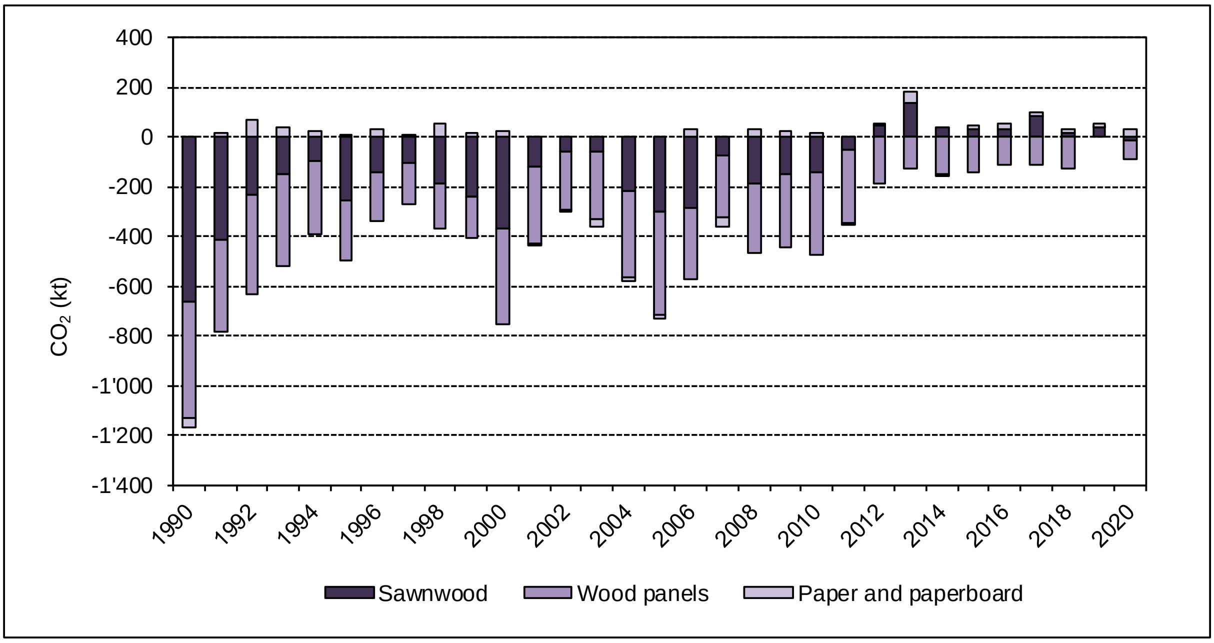



Figure 6-14 $CO_2$ emissions and removals from category 4G Harvested wood products (HWP) originating from Forest management (KP) (in kt $CO_2$; positive values refer to emissions, negative values refer to removals).

## 6.11.3. Uncertainties and time-series consistency

### 6.11.3.1. Uncertainties

For category 4G HWP, the following information on relative uncertainty was used:

Activity data

A mean uncertainty of 11.2% (Table 6-5) was estimated based on the following expert judgements considering the type and reliability of data source:

- Roundwood harvest: 5% (national activity data from the Swiss Forestry Statistics, annual complete survey)
- Sawnwood production: 5% (national activity from survey on wood processing in sawmills, combined survey)
- Wood Panels production: 5% (national activity from survey in the wood industry)
- Paper and Paperboard production: 5% (activity data from FAOSTAT)
- Share of domestic wood used in the production of sawnwood, panels and paper: 10% (based on foreign trade statistics in the FAO database)

$$U_{HWP}AD = \sqrt{5^2 + 10^2} = 11.2\%$$, for each product category.

Conversion factors (carbon stock change factors)

The uncertainties of conversion factors used to calculate emission factors were based on the following sources:

- Wood density: 20%; a preliminary uncertainty assessment based on expert judgement results in medium to high uncertainty for the country-specific measurements of the wood industry. According to Werner (2019a), the main source of uncertainty is the water content of the HWP.
- Carbon contents in wood products: 10% (Lamlom and Savidge 2003, assessment of carbon content in wood; IPCC 2006, Volume 4, Table 12.6).
- Half-lives: 50% (default from IPCC 2006, Volume 4, Table 12.6).

The resulting uncertainty of the carbon stock change factors (CSCF) for HWP amounts to 54.8% (Table 6-5):

$$U_{HWP}CSCF = \sqrt{20^2 + 10^2 + 50^2} = 54.8\%$$

Overall uncertainty 4G

The overall relative uncertainty of carbon losses and gains in HWP was thus calculated as:

$$U_{HWP}Combined = \sqrt{11.2^2 + 54.8^2} = 55.9\%$$

#### 6.11.3.2. Time-series consistency

Time series for category 4G Harvested wood products are all considered consistent; they were calculated based on consistent methods and homogenous databases.

### 6.11.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

In 2019, methods and calculations were reviewed by an external expert (Werner 2019a). Based on the review, the calculation procedure for HWP was thoroughly restructured and several improvements and recalculations were made in the course of inventory preparation for the submission 2020 (FOEN 2020).

### 6.11.5. Category-specific recalculations

The following recalculations were implemented:

- 4G: Production of paper and paperboard was recalculated based on updates in the FAO database for 2019 (+6.8%).
- 4G: Production of non-coniferous sawnwood was recalculated based on updates in the FAO database for 2018 (+66%) and 2019 (+8.5%).
- 4G: Production of coniferous sawnwood was recalculated based on updates in the FAO database for 2019 (+1.5%).
- 4G: Export of particle boards and oriented strand boards (OSB) was recalculated based on updates in the FAO database for 2019 (-0.2%).
- 4G: 1990–2019, due to recalculations of AREA data (cf. chp. 6.3.5) the split between HWP from Afforestation and from Forest management as well as the split between HWP from Deforestation and from Forest management were also recalculated. This procedure resulted in minor changes.

### 6.11.6. Category-specific planned improvements

Further improvement could be achieved if also plant-specific activity data could be used instead of exclusively FAO statistics, e.g. for the share of domestic wood used for producing wood panel and sawnwood. The FOEN will check if such data can be made available for the GHG inventory, and, if they are applicable, will include them in future submissions.

# 7. Waste

| Responsibilities for sector Waste | |
|---|---|
| Overall responsibility | Daiana Leuenberger (FOEN) |
| Method updates & authors | Daiana Leuenberger (FOEN), Rainer Kegel (FOEN) |
| EMIS database operation | Daiana Leuenberger (FOEN), Rainer Kegel (FOEN) |
| Annual updates (NIR text, tables, figures) | Beat Rihm (Meteotest), Dominik Eggli (Meteotest) |
| Quality control NIR (annual updates) | Dominik Eggli (Meteotest), Rainer Kegel (FOEN), Daiana Leuenberger (FOEN), Adrian Schilt (FOEN) |
| Internal review | Rainer Kegel (FOEN), Daiana Leuenberger (FOEN), Adrian Schilt (FOEN) |

## 7.1. Overview

### 7.1.1. Greenhouse gas emissions

Within sector 5 Waste, emissions from five source categories are considered:

- 5A Solid waste disposal
- 5B Biological treatment of solid waste
- 5C Incineration and open burning of waste
- 5D Wastewater treatment and discharge
- 5E Other (no direct GHG emissions, but indirect GHG emissions included in CRF Table6 as documented in chp. 9)

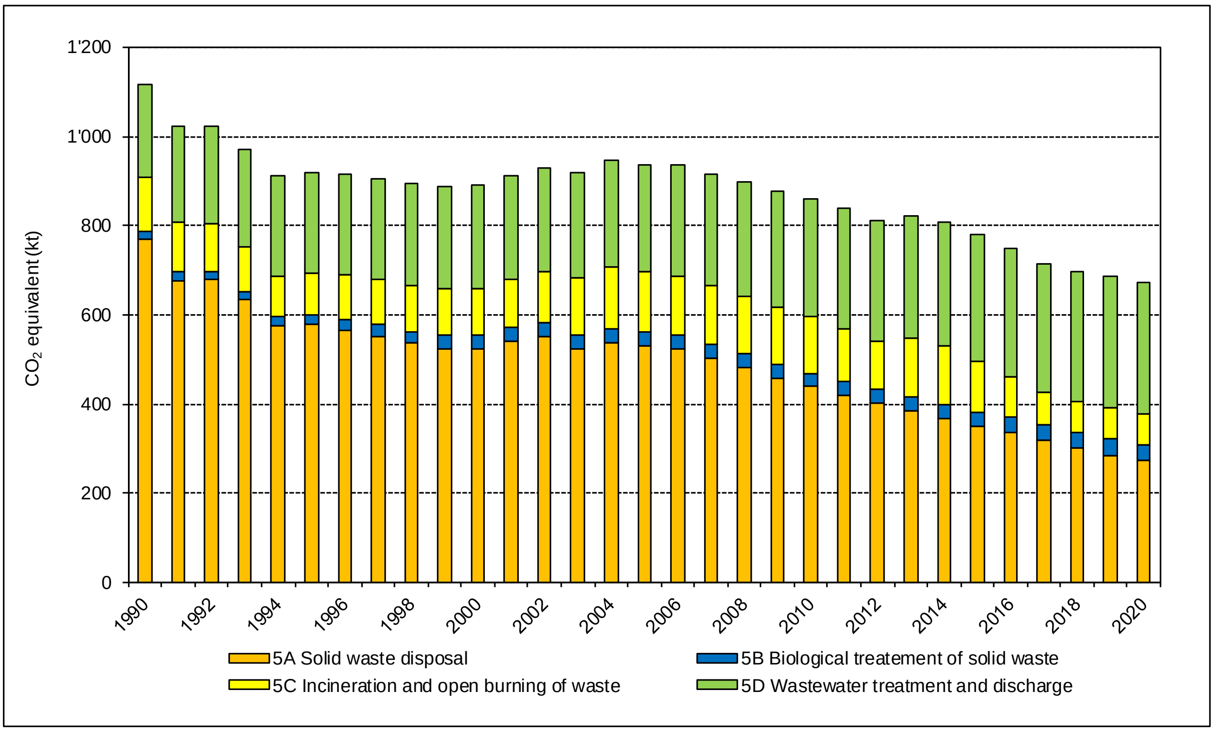



Figure 7-1 Switzerland's greenhouse gas emissions from sector 5 Waste. There are no direct greenhouse gas emissions from sector 5E Other.

The total greenhouse gas emissions from sector 5 Waste show a decrease within the reporting period. 5A Solid waste disposal and 5D Wastewater treatment and discharge are the two dominant source categories. The former shows decreasing emissions, while the latter shows an increase in greenhouse gas emissions.

Table 7-1 Trend of total GHG emissions from sector 5 Waste in Switzerland.

| Gas | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | |
| $CO_2$ | 40 | 22 | 17 | 12 | 11 |
| $CH_4$ | 920 | 741 | 699 | 710 | 631 |
| $N_2O$ | 158 | 155 | 176 | 215 | 220 |
| Sum | 1118 | 919 | 892 | 938 | 862 |

| Gas | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | | | | | | |
| $CO_2$ | 11 | 10 | 10 | 10 | 10 | 10 | 10 | 9 | 9 | 9 |
| $CH_4$ | 615 | 598 | 585 | 573 | 559 | 549 | 536 | 521 | 508 | 496 |
| $N_2O$ | 215 | 202 | 227 | 226 | 211 | 190 | 170 | 167 | 170 | 168 |
| Sum | 840 | 810 | 821 | 809 | 780 | 749 | 716 | 697 | 687 | 674 |

$CH_4$ is the most important greenhouse gas in sector 5 Waste over the entire reporting period. Nevertheless, $CH_4$ emissions have decreased. The main source for $N_2O$ emissions is 5D Wastewater treatment and discharge. The increasing population in Switzerland leads to gradually increasing emissions.

The relative trends of the gases are shown in Figure 7-2.

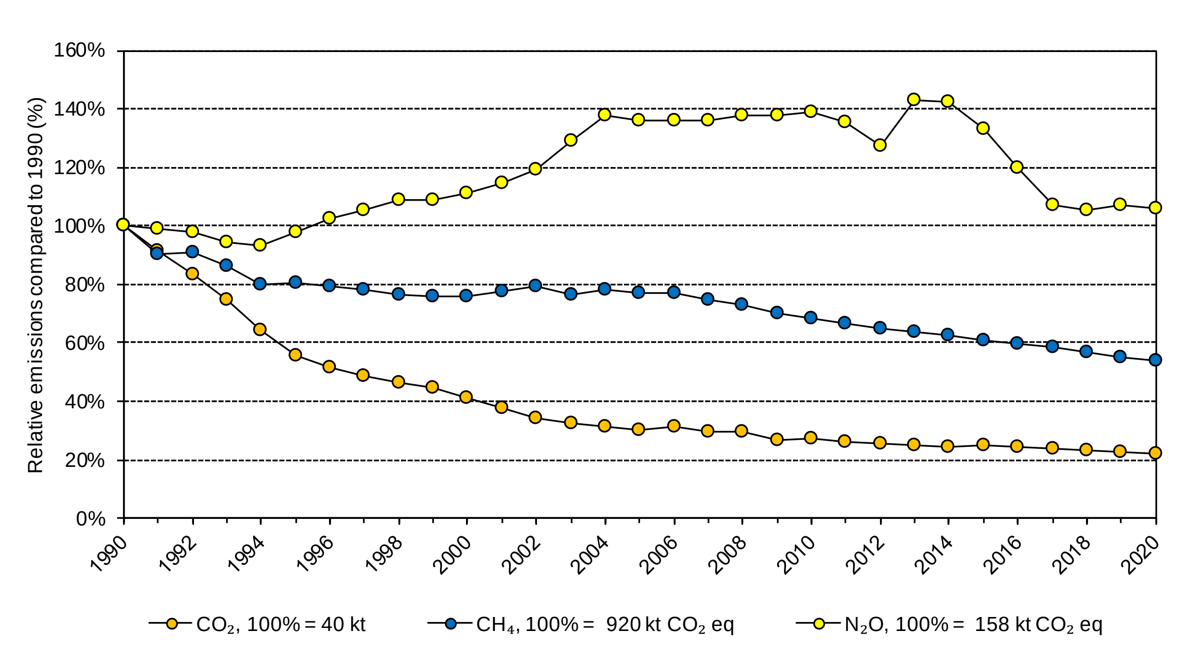



Figure 7-2 Relative trends of greenhouse gas emissions from sector 5 Waste. The base year 1990 represents 100%.

According to the 2006 IPCC Guidelines (IPCC 2006) all emissions from waste-to-energy, i.e. emissions resulting when waste material is used directly as fuel or converted into a fuel, are reported under sector 1 Energy (see also Figure 7-5). Therefore, the largest share of waste-related emissions in Switzerland is not reported under sector 5 Waste. This is illustrated in Figure 7-3 which provides an overview of all waste-related GHG emissions in Switzerland reported in chp. 7 and elsewhere in the NIR (see also Figure 7-5).

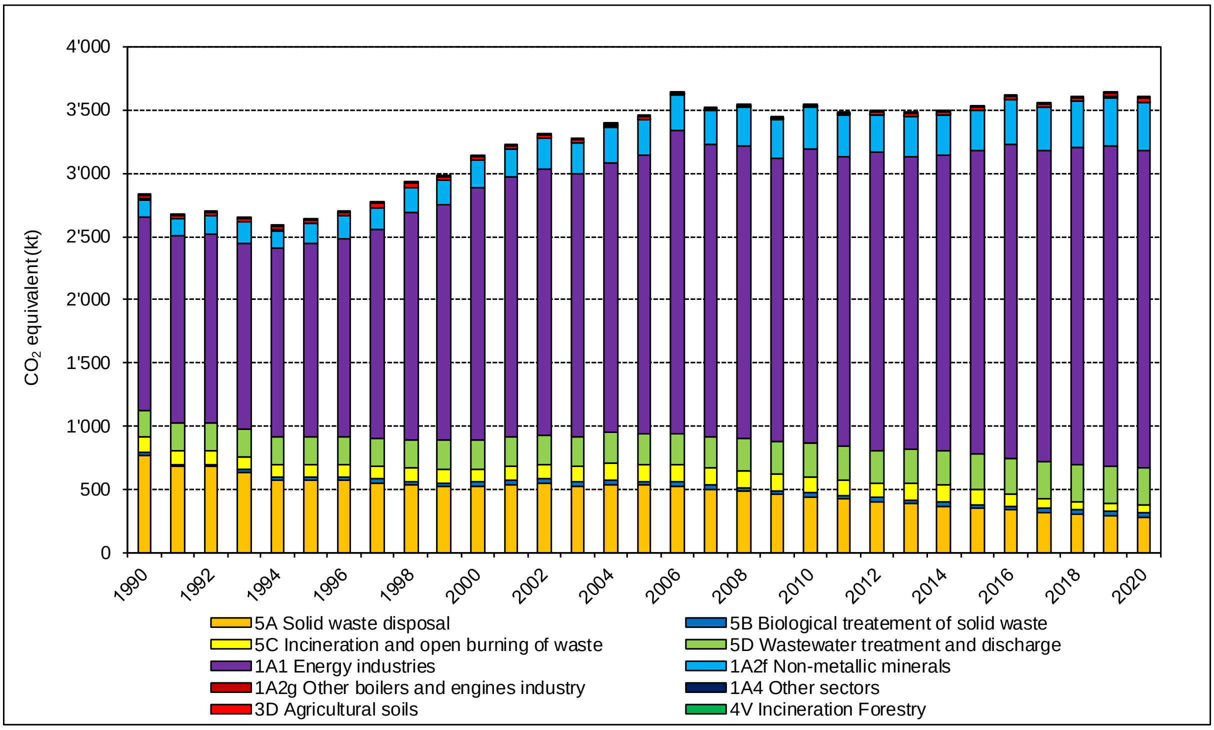



Figure 7-3 Total waste-related GHG emissions, reported in different sectors. The energetic use of waste-related biomass is not considered for this figure, as it predominantly leads to emissions of biogenic $CO_2$ (and only very minor emission of $CH_4$ and $N_2O$).

For sector 5 Waste, there are a total of four identified key categories, emitting $CH_4$ and $N_2O$, see Figure 7-4.

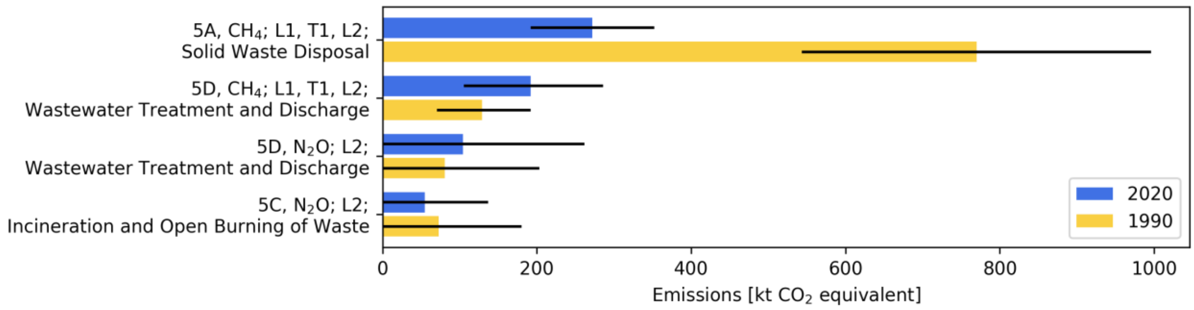



Figure 7-4 Key categories in the Swiss GHG inventory from sector 5 Waste determined by the key category analyses, approaches 1 and 2. Categories are set out in order of decreasing emissions in 2020. L1: key category according to approach 1 level in 2020; L2: same for approach 2; T1: key category according to approach 1 trend 1990–2020; T2: same for approach 2. Black uncertainty bars represent the narrowest 95% confidence interval obtained by Monte Carlo simulations (see chp. 1.6 for details).

## 7.1.2. Overview of waste management in Switzerland

Goals and principles regarding waste management in Switzerland are stated in the Guidelines on Swiss Waste Management (BUS 1986), in the Waste Concept for Switzerland (SAEFL 1992) and in the Ordinance on the Avoidance and the Disposal of Waste (Swiss Confederation 2015).

The four principles are:

- The generation of waste shall be avoided as far as possible.
- Pollutants from manufacturing processes and in products shall be reduced as far as possible.
- Waste shall be recycled wherever this is environmentally beneficial and economically feasible.
- Waste shall be treated in an environmentally sound way. In the long term only materials of final storage quality shall be disposed of in landfills.

Figure 7-5 gives a general overview of the type of treatment and amounts of waste treated in the respective sectors in Switzerland, including waste imports and waste exports. Only waste fractions that are relevant for emissions are shown. The figure further illustrates where the processes related to the waste management system are reported in the NIR. The following details can be provided regarding the different sectors:

- **1 Energy:** In accordance with the IPCC Guidelines (IPCC 2006) emissions from waste-to-energy activities, where waste is used as an alternative fuel for energy production, are reported in 1A Fuel combustion. This applies to municipal solid waste incineration plants and special waste incineration plants, where energy is recovered (1A1a). Municipal solid waste incineration plants treat burnable municipal solid waste as well as sewage sludge, burnable construction waste and some special wastes. Cement industry uses conventional fossil fuels but also alternative fuels, which are special waste, dried sewage sludge, biomass as well as plastics collected separately or segregated from solid waste streams (1A2fi). The digestion of biomass in agricultural and industrial biogas facilities and of sewage sludge in wastewater treatment plants as well as the use of landfill gas are also reported in sector 1 Energy (source categories 1A1a, 1A2gviii and 1A4ci), as such biogas and sewage gas is used for combined heat and power generation. The energy production from renewable goods, such as the use of wood waste in wood-fired power stations, is reported under 1A1a, 1A2, 1A4ai and 1A4bi and 1A4ci.
- **3 Agriculture:** Since 2003 it is forbidden in Switzerland to use sewage sludge as a fertiliser. As of 2006, this prohibition has been made effective for all agricultural areas with a transition period to 2008. Since 2009, sewage sludge has no longer been applied; however, the use of compost (other organic fertiliser) has increased (see chp. 5.5.2.2, Direct $N_2O$ emissions from managed soils, Table 5-24).
- **5 Waste:** Only emissions from waste management activities not used for energy production are reported under sector 5 Waste. Solid waste disposal does not occur anymore in Switzerland as incineration is mandatory for disposal of combustible waste since 2000. Emissions from composting are described under 5B1. Emissions related to digestion, but not directly related to energy production (such as the storage of digested biomass), are reported under 5B2. 5C Waste incineration and open burning of waste accounts for a small fraction only, consisting of illegal waste incineration, sewage sludge incineration, burning of residues in agriculture and private households as well as cremations. Special waste incineration without energy recovery, such as cable incineration or hospital waste incineration plants, no longer takes place in Switzerland and is thus crossed out in the figure. These waste fractions are nowadays incinerated in municipal solid waste incineration plants and are therefore reported under sector 1 Energy. Emissions related to wastewater treatment are reported under 5D.

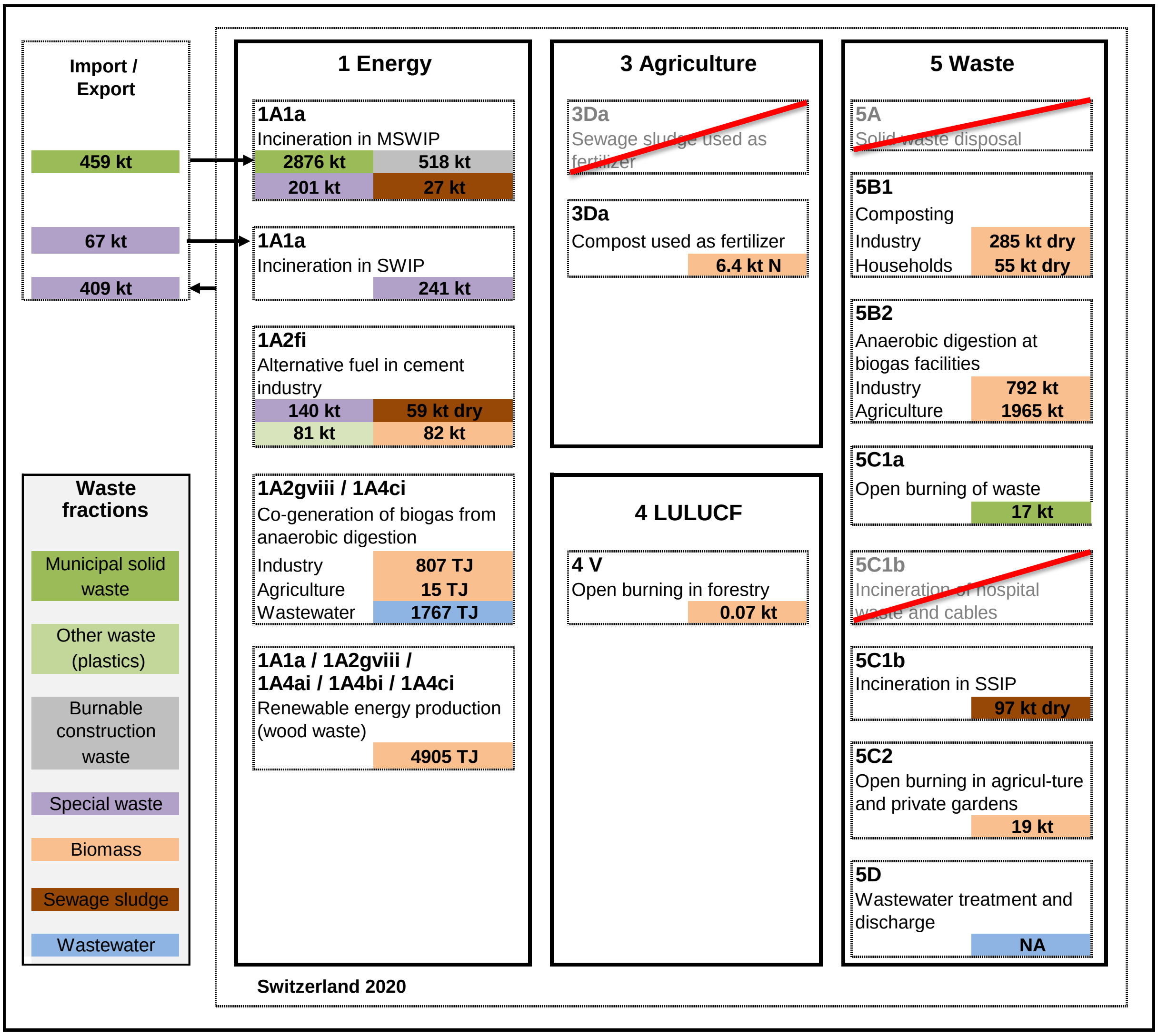



Figure 7-5 Overview on the type of treatment and amounts of waste treated in the respective sectors in Switzerland in 2020. Abbreviations: MSWIP: Municipal Solid Waste Incineration Plant, SWIP: Special Waste Incineration Plant, SSIP: Sewage Sludge Incineration Plant.

Regarding the treatment and amounts of relevant waste types the following details can be provided (state in 2020, recycled amounts are not shown in Figure 7-5 because they are not relevant for emissions):

- **Municipal solid waste:** In Switzerland more than 50% of the municipal solid waste is collected separately and recycled (FOEN 2021h). The amount of waste incinerated includes imported municipal solid waste, mainly from neighbouring countries such as Germany, France, Austria and Italy. The import of waste into Switzerland needs to be authorized by the Federal Office for the Environment. A part of the separately collected plastic fractions from households and industry which cannot be recycled is used as an alternative fuel in the cement industry.
- **Construction waste:** More than 50% of the construction waste is recycled. About half of the recycling takes place at the construction sites, e.g. by reusing material left after breaking up the road cover. The other half is separated at the construction sites and recycled individually, e.g. used glass, metals, concrete etc. A minor amount of combustible construction waste is incinerated in municipal solid waste incineration

plants. The remaining, inert construction waste is disposed of in landfills for inert waste (ERM 2016; Wüest & Partner 2015).

- **Special waste:** Special waste refers to a highly diverse waste fraction encompassing hospital wastes, batteries, electronic waste, hazardous industrial sludge, contaminated soils, solvents, chemicals etc. Special waste is either recycled, biologically treated, landfilled, burnt or exported for landfilling in foreign countries (FOEN 2021h). Only the amount of incinerated special waste is relevant for emissions (EMIS 2022/1A1a Kehrichtverbrennungsanlagen and EMIS 2022/1A1a Sondermüllverbrennungsanlagen). Some special waste is also used as an alternative fuel in the cement production (EMIS 2022/1A2f i Zementwerke Feuerung).
- **Sewage sludge:** Since 2009 sewage sludge has not been used anymore as a fertiliser in agriculture. Such use has been prohibited due to the content of organic contaminants, heavy metals and other substances (see chp. 5.5.2.2.2). Therefore, all sewage sludge is incinerated, either in municipal solid waste incineration plants or in sewage sludge incineration plants without energy recovery (internal information provided by the waste section of FOEN). Dried sewage sludge is also used as an alternative fuel in the cement industry (EMIS 2022/1A2fi Zementwerke Feuerung).
- **Biomass:** The term biomass refers to a broad range of materials such as garden waste, grass, wood waste, liquid manure and production remains e.g. from the food industry. Biomass from agriculture, forestry and private gardens are burnt without energy recovery (EMIS 2022/5C2 & 4VA1 Abfallverbrennung Land- und Forstwirtschaft). Biomass is also digested or composted (in large-scale composting facilities or backyards). Quantities of biomass refer to wet matter. Biomass such as used wood or animal fat is used as an alternative fuel in the cement industry (EMIS 2022/1A2fi Zementwerke Feuerung). Compost is used as a fertiliser and quantities refer to dry matter (see Table 5-24 “Other organic fertilisers”).

## 7.2. Source category 5A – Solid waste disposal

### 7.2.1. Source category description

Table 7-2 Key categories of 5A Solid waste disposal. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 5A | Solid Waste Disposal | CH4 | L1, T1, L2 |

Source category 5A1 Managed waste disposal sites comprises all emissions from managed solid waste landfill sites. As incineration has been mandatory for combustible waste since 2000, inputs into managed solid waste landfill sites have dropped to zero. Remaining emissions thus originate from landfilling before 2000. Emissions from source category 5A2 Unmanaged waste disposal sites are included in source category 5A1 Managed waste disposal sites. This is motivated by the fact that in Switzerland to date no official unmanaged waste disposal sites exist. Although no reliable data is available, the effective quantity of waste not properly treated in landfills is estimated to be very small.

In Switzerland, less than four managed biogenically active landfill sites were equipped to recover landfill gas in 2020 (SFOE 2021a). While some landfill gas is used to generate heat only, the landfill gas is generally used in co-generation plants in order to produce electricity and heat. A small amount of the landfill gas is flared (Consaba 2016).

Emissions from the usage of landfill gas in combined heat and power units are reported in sector 1 Energy in source category 1A1a Public electricity and heat production (see Figure 3-18).

Table 7-3 Specification of source category 5A Solid waste disposal in Switzerland.

| 5A | Source category | Specification |
|---|---|---|
| 5A1 | Managed waste disposal sites | Emissions from managed solid waste landfill sites. |
| 5A2 | Unmanaged waste disposal sites | Officially no unmanaged waste disposal sites exist (included in 5A1) |
| 5A3 | Uncategorized waste disposal sites | Not ocurring in Switzerland |

## 7.2.2. Methodological issues

### Methodology (5A)

Emissions are calculated by a Tier 2 method based on the decision tree in the IPCC Guidelines (IPCC 2006, vol. 5, chp. 3, Fig. 3.1). The spreadsheet for the First Order Decay (FOD) model provided by IPCC (2006) has been applied and parametrised for Swiss conditions (FOEN 2022m).

The values for the parameter degradable organic carbon are provided for each waste fraction (Table 7-4). For all waste types the IPCC (2006) default values are used, except for industrial waste. For industrial waste the default value for wood and straw is used, as most of the industrial waste deposited in Switzerland is assumed to be wood waste.

Table 7-4 Degradable organic carbon values for fractions of different waste compositions (weight fraction, wet basis).

| Waste composition | IPCC default value | | Country-specific parameters | |
|---|---|---|---|---|
| (weight fraction, wet basis) | Range | Default | Swiss Value | Reference and remarks |
| Food waste | 0.08-0.20 | 0.15 | 0.15 | |
| Garden | 0.18-0.22 | 0.2 | 0.2 | |
| Paper | 0.36-0.45 | 0.4 | 0.4 | |
| Wood and straw | 0.39-0.46 | 0.43 | 0.43 | |
| Textiles | 0.20-0.40 | 0.24 | 0.24 | |
| Disposable nappies | 0.18-0.32 | 0.24 | NO | not relevant/no activity data |
| Sewage sludge | 0.04-0.05 | 0.05 | 0.05 | |
| Industrial waste | 0.00-0.54 | 0.15 | 0.43 | all waste wood |

The methane generation rate [1/yr] is chosen according to wet temperate conditions (Table 7-5). For all waste types the IPCC (2006) default values are used, except for industrial waste. For industrial waste the default value for wood and straw is used, again based on the fact that most of it is assumed to be wood waste.

Table 7-5 Methane generation rate [1/yr] according to waste by composition for wet temperature conditions.

| **Waste composition** | **IPCC default value** | | **Country-specific parameters** | |
|---|---|---|---|---|
| (weight fraction, wet basis) | Range | Default | Swiss Value | Reference and remarks |
| Food waste | 0.1–0.2 | 0.185 | 0.185 | |
| Garden | 0.06–0.1 | 0.1 | 0.1 | |
| Paper | 0.05–0.07 | 0.06 | 0.06 | |
| Wood and straw | 0.02–0.04 | 0.03 | 0.03 | |
| Textiles | 0.05–0.07 | 0.06 | 0.06 | |
| Disposable nappies | 0.06–0.1 | 0.1 | NO | not relevant/no activity data |
| Sewage sludge | 0.1–0.2 | 0.185 | 0.185 | |
| Industrial waste | 0.08–0.1 | 0.09 | 0.03 | all waste wood |

The general parameters are set as follows:

- DOCf (fraction of degradable organic carbon dissimilated) = 0.5 (IPCC (2006) default value)
- Delay time (months) = 6 (IPCC (2006) default value)
- Fraction of methane (F) in developed landfill gas = 0.5 (IPCC (2006) default value)
- Conversion factor, C to $CH_4$ = 1.33 (IPCC (2006) default value)
- Oxidation factor (OX) = 0.1

The oxidation factor has been set to 0.1 according to the 2006 IPCC Guidelines (IPCC 2006, vol. 5, chp. 3), since it is standard practice in Switzerland to cover the landfills, e.g. with soil.

For the methane correction factors (MCF) for the different solid waste disposal site types IPCC default values are used. Between 1990 and 2015 (the IPCC spreadsheet has to be parametrised from 1950 to 2030/2050) waste distribution to the following three solid waste disposal site types has taken place (for both municipal solid waste and industrial waste):

- Methane correction factor for unmanaged, shallow solid waste disposal sites (SWDS) = 0.4 (IPCC (2006) default value)
- Methane correction factor for unmanaged, deep solid waste disposal sites = 0.8 (IPCC (2006) default value)
- Methane correction factor for managed solid waste disposal sites = 1 (IPCC (2006) default value)
- The other two methane correction factor (managed, semi-aerobic and uncategorised) are not relevant because such solid waste disposal sites are not occurring in Switzerland, i.e. no waste has been distributed to such sites.

The waste composition of municipal solid waste deposited has changed during the last 60 years (see Table 7-6).

Table 7-6 Composition of municipal solid waste going to solid waste disposal sites (BUS 1978, BUS 1984, FOEN 2014o).

| Waste fraction | 1950-1979 | 1980-1989 | 1990-1999 | 2000-2009 | since 2010 |
|---|---|---|---|---|---|
| Food | 20.0% | 26.5% | 21.4% | 26.6% | 31.5% |
| Garden | 8.0% | 2.9% | 1.6% | 1.4% | 1.7% |
| Paper | 36.0% | 30.6% | 28.0% | 21.0% | 17.2% |
| Wood | 4.0% | 4.3% | 5.0% | 2.0% | 1.8% |
| Textile | 4.0% | 3.1% | 3.0% | 3.0% | 3.2% |
| Nappies | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Plastics, other inert | 28.0% | 32.6% | 41.0% | 46.0% | 44.6% |

With these parametrisations and the activity data for municipal solid waste, industrial waste and sewage sludge the amount of $CH_4$ generated in landfills is calculated. The amount of $CH_4$ recovered and used as fuel for combined heat and power generation or flared is then subtracted.

For combined heat and power generation and flaring, the emissions of other gases are considered to be proportional to the amount of $CH_4$ burnt (Table 7-7).

Long-term storage of carbon in waste disposal sites, annual change in total long-term storage of carbon and annual change in total long-term storage of carbon in harvested wood products has been calculated with the parametrised spreadsheet model provided by IPCC (2006) as well and is reported in CRF Table5 as memo item. As incineration has been mandatory for combustible waste since 2000 in Switzerland and solid waste disposal activities have ceased there is no annual change since 2007.

### Emission factors (5A)

Emission factors for $CO_2$, $CH_4$, CO, NMVOC and $SO_2$ are country-specific based on measurements and expert estimates, as documented in EMIS 2022/1A1 & 5A Kehrichtdeponien. The emission factor of NMVOC from flaring has been introduced based on a study on emissions from landfill gas installations (Butz 2003) suggesting NMVOC emissions equalling to 82.15 g/t $CH_4$ flared ±10%. $CO_2$ emissions from non-biogenic waste are included, while $CO_2$ emissions from biogenic waste are excluded from total emissions. Table 7-7 presents the emission factors used in 5A1.

Table 7-7 Emission factors for 5A1 Managed waste disposal sites in 2020.

| 5A1 Managed waste disposal sites | Unit | $CO_2$ biogen | $CO_2$ fossil | $CH_4$ | $NO_x$ | CO | NMVOC | $SO_2$ |
|---|---|---|---|---|---|---|---|---|
| Direct emissions from landfill | t / t $CH_4$ produced | 3.0 | NA | 1.0 | NA | NA | 0.013 | NA |
| Flaring | kg / t $CH_4$ burned | 2750 | NA | NA | 1.0 | 17 | 0.082 | NA |
| Open burning | kg / t waste burned | 571 | 523 | 6.0 | 2.5 | 50 | 16 | 0.75 |

**Activity data (5A)**

There are three kinds of activity data for 5A1 Managed waste disposal sites: Waste quantities disposed on landfills, direct $CH_4$ emissions and $CH_4$ flared.

For the calculation of these three kinds of activity data, the amounts of municipal solid waste, construction waste and sewage sludge (deposited on managed waste disposal sites) are relevant.

Table 7-8 Activity data in 5A1: Waste disposed on managed waste disposal sites since 1950 (documented in EMIS 2022/1A1a & 5A Kehrichtdeponien).

| 5A1 Managed waste disposal sites | Unit | 1950 | 1960 | 1970 | 1980 | 1990 | 1995 | 2000 | 2005 | 2010 - 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| Municipal solid waste (MSW) | kt | 570 | 675 | 864 | 532 | 650 | 540 | 292 | 14 | NO |
| Construction waste (CW) | kt | 9.9 | 11 | 36 | 85 | 150 | 60 | 54 | 1.4 | NO |
| Sewage sludge (SS) | kt (dry) | NO | NO | 3.2 | 30 | 60 | 28 | 4.2 | 0.98 | NO |
| Open burned waste | kt | 299 | 294 | 226 | 97 | NO | NO | NO | NO | NO |
| Total waste quantity | kt | 879 | 980 | 1129 | 744 | 860 | 628 | 350 | 16 | NO |

Table 7-8 documents the amounts of municipal solid waste, construction waste and sewage sludge disposed of on managed waste disposal sites since 1950 (as documented in EMIS 2022/1A1a & 5A Kehrichtdeponien). An increase of waste landfilled until 1970 can be observed. The decline of waste amounts landfilled afterwards is due to changes in the legislative framework, making incineration mandatory for disposal of combustible waste and banning the disposal of combustible waste on landfills from 1 January 2000. The amounts of combustible waste disposed of on managed waste disposal sites reached zero in 2009. While open burning of waste on managed waste disposal sites occurred in the distant past it is assumed that, by reason of legal requirements and regulations, open burning has not taken place since 1990 anymore (Consaba 2016) and is therefore NO in Table 7-8.

With these primary activity data total $CH_4$ emissions generated are calculated using the spreadsheet first order decay model provided by IPCC (2006). For the calculation of direct $CH_4$ emissions, $CH_4$ flared and used in co-generation units is determined and subtracted from total $CH_4$ emissions (Table 7-9). The landfill gas recovered and used as fuel for co-generation units is reported under 1A1 Energy in accordance with the 2006 IPCC Guidelines (IPCC 2006). The sum of landfill gas flared and landfill gas used in co-generation units is reported as being recovered in CRF Table5.A.

The amount of $CH_4$ used in co-generation is taken from the Swiss statistics of renewable energies (SFOE 2021a). The amount of landfill gas flared has been assessed in a separate investigation (Consaba 2016). The $CH_4$ flared has been estimated as follows:

- A list of all managed waste disposal sites that are still operated or have been closed since 1990 was compiled.
- Their technical equipment was assessed and deduced (motors, torches, gas drainage, etc.).
- Four types of managed landfill sites according to their equipment and $CH_4$ management were distinguished:
    - landfills with gas recovery in combined heat and power generation, boiler and torch; category a);

    - landfills with gas recovery or thermal treatment (boiler, torch, non-catalytic oxidation, flameless oxidation; category b);
    - landfill gas recovery without methane elimination (bio filter, aerobiosation); category c);
    - landfills without gas treatment (direct release); category d).
- A survey was conducted in 14 managed waste disposal sites and data on their operation mode has been collected.
- With these data the amounts flared in managed waste disposal sites categories a) and b) were estimated.
- The amount flared on all managed waste disposal sites has been extrapolated considering the waste amounts deposited.
- A time series for the amount of methane torched relative to the total amount of $CH_4$ estimated with the Swiss first order decay IPCC 2006 model (managed and unmanaged sites) has been calculated.

The amount flared is expressed as a percentage of $CH_4$ produced in all managed waste disposal sites in Switzerland. The percentage flared varies between 5% and 15% since 1990.

Table 7-9 Activity data in 5A1: Direct $CH_4$ emissions, $CH_4$ flared and $CH_4$ used in combined heat and power units (as documented in EMIS 2022/1A1a & 5A Kehrichtdeponien).

| 5A1 Managed waste disposal sites | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| $CH_4$ direct emissions | kt | 31 | 23 | 21 | 21 | 18 |
| $CH_4$ flared | kt | 1.8 | 5.3 | 5.6 | 3.4 | 2.4 |
| $CH_4$ used in co-generation units (reported under 1A1a) | kt | 4.9 | 12 | 11 | 4.1 | 0.97 |

| 5A1 Managed waste disposal sites | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $CH_4$ direct emissions | kt | 17 | 16 | 15 | 15 | 14 | 13 | 13 | 12 | 11 | 11 |
| $CH_4$ flared | kt | 2.1 | 1.8 | 1.6 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 |
| $CH_4$ used in co-generation units (reported under 1A1a) | kt | 0.88 | 0.88 | 0.76 | 0.62 | 0.42 | 0.25 | 0.13 | 0.12 | 0.17 | 0.078 |

Waste quantities disposed in landfills started to decrease in the early 1990s and have ceased completely from 2009 onwards. The continuous decrease of $CH_4$ generated by decaying waste over time, in combination with the relative increase of $CH_4$ recovery from 1990 until 2017 yields a pronounced trend of $CH_4$ emissions from source category 5A.

## 7.2.3. Uncertainties and time-series consistency

### Uncertainty in $CH_4$ and $CO_2$ emissions from 5A Solid waste disposal

For lack of a detailed uncertainty analysis with the new first order decay model, a combined uncertainty of 30% is assumed for the $CH_4$ emissions (EMIS 2022/1A1a & 5A Kehrichtdeponien).

Consistency: Time series for 5A Solid waste disposal are all considered consistent.

### 7.2.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

### 7.2.5. Category-specific recalculations

The following recalculations were implemented in submission 2022:

- 5A1 Managed waste disposal sites: A new emission factor for direct emissions of NMVOC has been introduced based on EMEP Guidebook 2019 recommendations (5A Chapter 3.2.2). A fraction of 1.3% of all VOC emissions (1.317% of $CH_4$ emissions) occur as NMVOC. This has led to changes in annual NMVOC emissions of 405–150 t.
- 5A1 Managed waste disposal sites: A new emission factor for emissions of NMVOC from flaring has been introduced based on a study on emissions from landfill gas installations (Butz 2003) suggesting NMVOC emissions equalling to 82.15 g/t $CH_4$ flared ±10%. This has led to changes in annual NMVOC emissions of 510–110 kg.

### 7.2.6. Category-specific planned improvements

No category-specific improvements are planned.

## 7.3. Source category 5B – Biological treatment of solid waste

### 7.3.1. Source category description

Source category 5B – Biological treatment of solid waste is not a key category.

Source category 5B Biological treatment of solid waste comprises the process-related GHG emissions from composting and from digesting of organic waste.

Within 5B1 Composting two kinds of composting are distinguished, i.e. industrial composting and backyard composting. Industrial composting covers the emissions from centralized composting activities with a capacity of more than 100 tonnes of organic matter per year as well as the composting of organic material at the border of agricultural fields. Backyard composting in private households or communities is also common practice in Switzerland and therefore considered.

In 5B2 Anaerobic digestion at biogas facilities emissions occur from gas leakages as well as from digested matter (solid leftovers after completion of anaerobic microbial degradation of organic matter) which is being composted. The biogas is used for combined heat and power generation or is upgraded and used as fuel.

In 5B Biological treatment of solid waste the emissions from the composting of digested matter as well as the $CH_4$ losses from biogas facilities and emerging from biogas upgrading are included. Emissions related to the use of biogas for combined heat and power generation are reported in sector 1 Energy source categories 1A2gviii Other and 1A4ci Agriculture/forestry/fishing (see Figure 3-18). Emissions related to the use of upgraded biogas fed into the natural gas grid are reported in sector 1 Energy source categories 1A3bi-iii Road transportation and 1A4ai Commercial boilers (see Figure 3-18).

Table 7-10 Specification of source category 5B Biological treatment of solid waste.

| 5B | Source category | Specification |
|---|---|---|
| 5B1 | Composting | Process-related emissions from composting of organic waste |
| 5B2 | Anaerobic digestion at biogas facilities | Process-related emissions from digesting of organic waste |

## 7.3.2. Methodological issues

### 7.3.2.1. Composting (5B1)

**Methodology (5B1)**

Emissions are calculated by a Tier 2 method based on the IPCC Guidelines (IPCC 2006, vol. 5, chp. 4.1.1 Biological treatment of solid waste).

Activity data and emission factors for industrial and backyard composting have been thoroughly reassessed in 2017 (Schleiss 2017), new data were gained and EMIS 2022/5B1 Kompostierung, which serves as basis for greenhouse gas emission estimates, has been revised accordingly.

**Emission factors (5B1)**

Emission factors used for source category 5B1 Composting are summarized in Table 7-11 and documented in detail in EMIS 2022/5B1 Kompostierung. Emission factors are country-specific and encompass $CH_4$, $N_2O$ and NMVOC based on measured or estimated values reported in the literature. The emission factors are based on a recommendation by Schleiss (2017) based on Dinkel et al. (2012). They are based on measurements and taking into account the predominantly non-industrial (ban on refuse composting) origin of composted material in Switzerland resulting in a rotting process as aerobic as possible to produce compost of marketable quality. This yields a lower emission factor for $CH_4$ compared to reference values (IPCC 2006).

**Activity data (5B1)**

Activity data for source category 5B1 Composting are shown in Table 7-12 and documented in detail in EMIS 2022/5B1 Kompostierung.

Activity data for industrial composting are based on waste surveys (Schleiss 2017). For 2013 reliable data on waste quantities are available (FOEN 2016m). All cantons were addressed and data on the amounts of organic waste quantities, according to their respective treatment option, have been collected. Data on waste quantities are also available from surveys in 1989, 1993 and 2000. Activity data between these years were interpolated. The time series were validated with additional data sets from the years 2002 and 2010. After 1993 digesting of organic waste was also becoming a relevant treatment option and therefore respective amounts were subtracted. In addition, also waste wood quantities were subtracted, in order to get the amount of organic waste treated in industrial composting plants. As of 2014, activity data for industrial composting are adopted from the annual statistical reports by the inspectorate system for the composting and fermentation industry in Switzerland (CVIS) as recommended by Schleiss (2017).

Activity data for backyard composting were reassessed in 2017 (Schleiss 2017). Basically, amounts of organic waste composted in backyards are based on expert assessments and are derived from data from a small number of cities and villages. The experts took into account different parameters affecting waste amounts composted in backyards over time, i.e. urban or rural situation, communication e.g. by community authorities and incentive programmes, and on the availability of separate door-to-door collection of organic wastes. As of 2008, activity data for backyard composting are assumed to be constant as recommended by Schleiss (2017). The unit of activity data and emission factors are reported as mass of dry matter according to the Guidelines reference for CRF tables. A transfer factor from wet to dry matter of 54.5% has been suggested by CVIS (2019).

#### 7.3.2.2. Anaerobic digestion at biogas facilities (5B2)

**Methodology (5B2)**

In source category 5B2 Anaerobic digestion at industrial and agricultural biogas facilities are considered. The produced biogas is used for combined heat and power generation or upgraded to natural gas quality. Accordingly, biogas upgrading is considered as a separate process in 5B2. However, emissions from the use of biogas as fuel for combined heat and power generation are reported under sector 1 Energy, in accordance with the IPCC Guidelines (IPCC 2006).

For the emissions from 5B2 Anaerobic digestion at biogas facilities, a Tier 2 method is used. While industrial and agricultural biogas facilities are separately considered, the same emission factors are used (see below). As mentioned above, emissions from biogas upgrading are estimated separately, based on the amount of biogas upgraded.

Emissions of greenhouse gases from industrial and agricultural biogas facilities are estimated using a constant emission factor for each biogas facility. This is based on an evaluation of measurement data for $CH_4$ losses that has shown that those losses are not dependent on the amount of substrate processed in a particular facility. Therefore, $CH_4$ emissions are calculated based on an emission factor per plant multiplied by the number of industrial and agricultural biogas facilities, respectively.

In contrast, emissions of air pollutants are calculated based on estimates from up to seven different process steps (such as pre-storage, primary and secondary digester, interim storage, maturing, handling of biogas etc.), as documented in EMIS 2022/1A1a & 5 B 2 Vergärung LW and EMIS 2022/1A1a & 5 B 2 Vergärung IG. However, as $CH_4$, CO and NMVOC emissions from source category 5B are of biogenic origin, no indirect $CO_2$ emissions from this source category are included in CRF Table6 as documented in chp. 9.

$N_2O$ emissions from source category 5B2 are considered to be negligible according to the IPCC Guidelines (IPCC 2006, vol. 5, chp. 4.1.3), and are therefore set to zero.

### Emission factors (5B2)

Table 7-11 presents the emission factors used in 5B2 Anaerobic digestion at biogas facilities. As documented in FOEN (2015n), the emission factor for $CH_4$ for anaerobic digestion at industrial and agricultural biogas facilities is based on investigations performed in the framework of the greenhouse gas emission compensation projects. Field measurements indicate that there is no correlation between the produced amount of biogas and the amount of biogas lost to the atmosphere. The investigated data show that on average each biogas facility loses 1.23 t $CH_4$ per year to the atmosphere. This value is used to estimate the emissions from industrial and agricultural biogas facilities in Switzerland.

The emission factor for losses of $CH_4$ from biogas upgrading is based on official regulations regarding maximal $CH_4$ leakage, as well as studies focussing on $CH_4$ emissions from biogas upgrading. Accordingly, regulations by the Swiss Gas and Water Association (SGWA 2016a) set an emission limit value for $CH_4$ losses from biogas upgrading. In 1990, such losses were allowed to be 5% of the upgraded amount, in 2014 the limit was lowered to 2.5%. Measurements in a few biogas upgrade installations in 2007, 2013 and 2014 showed the following losses: 2007 one plant: 2.6%, 2013 one plant: 1%, 2014 three plants: 1.3%, 1.8%, and 3.5%. The measurements showed that the emission limits were respected (with the exception of one plant in 2014) and therefore Switzerland decided to set the losses from biogas upgrading to the emission limit value with the assumption of a linear improvement between the 1990 and the 2014 value. The continuous improvement seems plausible, as newer plants show fewer losses and values of less than 1%–2.5% are state of the art.

### Activity data (5B2)

Activity data for 5B2 Anaerobic digestion at biogas facilities, as shown in Table 7-12, are based on data from the Swiss renewable energy statistics (SFOE 2021a). Relevant are the number of industrial and agricultural biogas facilities, as well as the total amount of biogas upgraded.

Table 7-11 Emission factors for 5B Biological treatment of solid waste in 2020.

| 5B Biological treatment of solid waste | Unit | $CH_4$ | $N_2O$ | $NO_x$ | CO | NMVOC | $SO_2$ |
|---|---|---|---|---|---|---|---|
| Composting (industrial) | g/t composted waste | 1'835 | 92 | NA | NA | 550 | NA |
| Composting (backyard) | g/t composted waste | 1'835 | 92 | NA | NA | 550 | NA |
| Digestion (industrial biogas facilities) | t/facility | 1.23 | NA | NA | NA | NA | NA |
| Digestion (agricultural biogas facilities) | t/facility | 1.23 | NA | NA | NA | NA | NA |
| Biogas up-grade | g/GJ | 500 | NA | NA | NA | NA | NA |

Table 7-12 Activity data in 5B Biological treatment of solid waste.

| 5B Biological treatment of solid waste | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Composting (industrial) | kt (dry) | 131 | 196 | 283 | 287 | 289 |
| Composting (backyard) | kt (dry) | 60 | 84 | 98 | 93 | 65 |
| Digestion (industrial biogas facilities) | number | NO | 4 | 11 | 14 | 22 |
| Digestion (agricultural biogas facilities) | number | 102 | 76 | 68 | 72 | 72 |
| Biogas up-grade | GJ | NO | NO | 19'866 | 40'637 | 121'627 |

| 5B Biological treatment of solid waste | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Composting (industrial) | kt (dry) | 290 | 291 | 292 | 261 | 234 | 274 | 267 | 259 | 296 | 285 |
| Composting (backyard) | kt (dry) | 60 | 55 | 55 | 55 | 55 | 55 | 55 | 55 | 55 | 55 |
| Digestion (industrial biogas facilities) | number | 28 | 26 | 26 | 25 | 26 | 27 | 28 | 28 | 29 | 27 |
| Digestion (agricultural biogas facilities) | number | 80 | 89 | 97 | 98 | 99 | 98 | 106 | 111 | 112 | 119 |
| Biogas up-grade | GJ | 168'170 | 236'074 | 277'700 | 337'415 | 408'038 | 442'665 | 456'665 | 473'538 | 551'924 | 600'094 |

To improve transparency the $CH_4$ and $N_2O$ emissions of source category 5B Biological treatment of solid waste are shown on a completely disaggregated level in Table 7-13.

Table 7-13 $CH_4$ and $N_2O$ emissions of 5B Biological treatment of solid waste.

| 5B Biological treatment of solid waste | Gas | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|---|
| Composting (industrial) | $CH_4$ | t | 240.2 | 360.3 | 519.3 | 526.3 | 529.7 |
| | $N_2O$ | t | 12.0 | 18.1 | 26.0 | 26.4 | 26.6 |
| Composting (backyard) | $CH_4$ | t | 110.0 | 155.0 | 180.0 | 170.0 | 120.0 |
| | $N_2O$ | t | 5.5 | 7.8 | 9.0 | 8.5 | 6.0 |
| Digestion (industrial) | $CH_4$ | t | NO | 4.9 | 13.6 | 17.2 | 27.1 |
| Digestion (agricultural) | $CH_4$ | t | 125.5 | 93.5 | 83.6 | 88.6 | 88.6 |
| Biogas up-grade | $CH_4$ | t | NO | NO | 15.7 | 28.0 | 70.9 |

| 5B Biological treatment of solid waste | Gas | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Composting (industrial) | $CH_4$ | t | 531.7 | 533.7 | 535.6 | 478.5 | 429.9 | 502.7 | 489.8 | 475.2 | 543.9 | 522.7 |
| | $N_2O$ | t | 26.7 | 26.8 | 26.9 | 24.0 | 21.6 | 25.2 | 24.6 | 23.8 | 27.3 | 26.2 |
| Composting (backyard) | $CH_4$ | t | 110.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | $N_2O$ | t | 5.5 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Digestion (industrial) | $CH_4$ | t | 34.5 | 32.0 | 32.0 | 30.8 | 32.0 | 33.2 | 34.5 | 34.5 | 35.7 | 33.2 |
| Digestion (agricultural) | $CH_4$ | t | 98.4 | 109.5 | 119.4 | 120.6 | 121.8 | 120.6 | 130.5 | 136.6 | 137.9 | 146.5 |
| Biogas up-grade | $CH_4$ | t | 94.7 | 128.0 | 144.7 | 168.7 | 204.0 | 221.3 | 228.3 | 236.8 | 276.0 | 300.0 |

## 7.3.3. Uncertainties and time-series consistency

### Uncertainty in $CH_4$ emissions from composting and digestion

The uncertainty of all emission factors in source category 5B1 Composting is estimated at 30% for industrial composting and at 100% for backyard composting. The uncertainty of the related activity data is estimated at 30% for industrial composting and at 100% for backyard composting (EMIS 2022/5B1 Kompostierung).

For 5B2 Anaerobic digestion at biogas facilities the uncertainty takes into account the different process steps on one hand and emission factors on the other hand (EMIS 2022/1A1a & 5 B 2 Vergärung LW and EMIS 2022/1A1a & 5 B 2 Vergärung IG).

The overall uncertainty for 5B Biological treatment of solid waste for activity data as well as for emission factor is 30%.

Consistency: Time series for 5B Biological treatment of solid waste are all considered consistent.

### 7.3.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

### 7.3.5. Category-specific recalculations

The following recalculations were implemented in submission 2022:

- 5B1 Composting (industrial and backyard): The unit of activity data and emission factors are now reported in the unit mass of dry matter instead of mass of wet matter according to the Guidelines reference for CRF tables. A transfer factor from wet to dry matter of 54.5% has been suggested by CVIS (2019). Thus, activity data for the years 1990–2019 have decreased by 45.5% while emission factors for $CH_4$, $N_2O$ and NMVOC have increased by the same factor (increase of 83.5%). This leads to small changes in emissions from 5B1 Composting, due to rounding effects.

### 7.3.6. Category-specific planned improvements

- 5B: A research project in the framework of a joint European research programme is investigating the $CH_4$ emissions from agricultural biogas facilities. Results will be implemented in the greenhouse gas inventory, if applicable, after completion of the project.

## 7.4. Source category 5C – Incineration and open burning of waste

### 7.4.1. Source category description

Table 7-14 Key categories of 5C Incineration and open burning of waste. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 5C | Incineration and Open Burning of Waste | N2O | L2 |

There is a long tradition in Switzerland to incinerate waste. The heat generated during the incineration has to be recovered in accordance with the Ordinance on the Avoidance and Disposal of Waste (Swiss Confederation 2015). Following the IPCC Guidelines (IPCC 2006) emissions from waste-to-energy activities are dealt with in 1A1a Public electricity and heat production.

5C1 encompasses incineration of hospital wastes, illegal waste incineration, incineration of insulation material from cables, of sewage sludge and cremations.

5C2 consists of emissions from open burning of branches in agriculture and gardening. Natural agricultural and gardening residues consist of fallen fruit trees, part of diseased residue which are cut up, collected and burnt off-site. Field burning of agricultural residues does not occur in Switzerland. Emissions from open burning of natural residues in forestry are reported in LULUCF sector 4V (chp. 6.4.2.12).

Table 7-15 Overview of waste incineration sources reported under 5C.

| 5C | Source category | Specification |
|---|---|---|
| 5C1 | Hospital waste incineration | Emissions from incinerating hospital waste in hospital incinerators |
| | Municipal waste incineration (illegal) | Emissions from illegal incineration of municipal solid wastes at home.<br>Emissions from waste incineration at construction sites (open burning) |
| | Industrial waste incineration | Emissions from incinerating cable insulation materials |
| | Sewage sludge incineration | Emissions from sewage sludge incineration plants |
| | Cremation | Emissions from the burning of  bodies in crematoria |
| 5C2 | Open burning of natural residues in agriculture and private households | Open burning of branches in agriculture and gardening. |

## 7.4.2. Methodological issues

**Methodology (5C)**

Emissions are calculated using Tier 2 methods based on the IPCC Guidelines (IPCC 2006, vol. 5, chp. 5.2). In general, the greenhouse gas emissions are calculated by multiplying the waste quantity incinerated by emission factors. For crematoria, the greenhouse gas emissions are calculated by multiplying the number of cremations by emission factors.

For sewage sludge incineration plants the respective waste quantities are based on reliable statistical data. The emission factors are based on emission declarations from three incineration plants in 2002 and 2015, respectively that covered approximately one third of the Swiss capacities. Due to the lack of better or newer data these emission factors are kept constant since then and no improvement in flue gas cleaning standards is assumed.

For hospital waste incineration, municipal waste incineration (illegal) and industrial waste incineration (consists of cable insulation materials), the waste quantities used are based on expert estimates.

Emissions from burning of residues in agriculture and gardening are calculated using a Tier 1 method based on the IPCC Guidelines (IPCC 2006, vol. 5, chp. 5.2). Emission factors are taken from the EMEP/EEA guidebook (EMEP/EEA 2019, EMEP/EEA 2002).

Indirect $CO_2$ emissions resulting from fossil $CH_4$, CO and NMVOC emissions from hospital waste incineration, municipal waste incineration (illegal) and industrial waste incineration (consists of cable insulation materials) are included in CRF Table6 as documented in chp. 9.

**Emission factors (5C)**

Table 7-16 presents an overview of the emission factors for 5C for the latest inventory year. Documentation and sources are given in: EMIS 2022/5 C 1 (5 C 1 b iii UNECE)_Spitalabfallverbrennung, EMIS 2022/5 C 1 (5 C 1 a UNECE)_ Abfallverbrennung illegal, EMIS 2022/5 C 1 (5 C 1 b i UNECE)_Kabelabbrand, EMIS2022/5 C 1_(5 C 1 b iv UNECE)_Klärschlammverbrennung, EMIS2022/ 5 C 2_4 V A 1_Abfallverbrennung Land- und Forstwirtschaft and EMIS 2022/5 C 1 (5 C 1 b v UNECE)_Krematorien.

Table 7-16 Emission factors for 5C Waste incineration and open burning of waste in 2020.

| 5C Waste incineration and open burning of waste | $CO_2$ | $CH_4$ | $N_2O$ | $NO_x$ | CO | NMVOC | $SO_2$ |
|---|---|---|---|---|---|---|---|
| | t/t | kg/t | | | | | |
| Hospital waste incineration | 0.90 | NA | 0.06 | 1.5 | 1.4 | 0.30 | 1.3 |
| Municipal waste incineration (illegal) | 0.52 | 6.0 | 0.15 | 2.5 | 50 | 16 | 0.75 |
| Industrial waste incineration | 1.3 | NA | NA | 1.3 | 2.5 | 0.50 | 6.0 |
| Sewage sludge incineration | NA | 0.10 | 1.85 | 0.40 | 0.10 | 0.1890 | 0.16 |
| Open burning of natural residues in agriculture | NA | 6.8 | 0.18 | 1.4 | 49 | 1.5 | 0.030 |
| Open burning of natural residues in private households | NA | 6.8 | 0.18 | 1.4 | 49 | 1.5 | 0.030 |
| | $CO_2$ | $CH_4$ | $N_2O$ | $NO_x$ | CO | NMVOC | $SO_2$ |
| | t/crem. | kg/crem. | | | | | |
| Cremation | NA | NA | NA | 0.21 | 0.041 | 0.0060 | NA |

Comments on $CO_2$ emission factors:

- For all waste incineration categories, only $CO_2$ emissions from non-biogenic waste are taken into account.
- Hospital waste incineration: The waste is mainly of fossil origin. The default value for the $CO_2$ emission factor is taken from SAEFL (2000). Since 2002 no emissions from hospital waste incineration have occurred, as all hospital waste incinerator plants have been closed and hospital waste is incinerated in municipal solid waste incineration plants (accounted for in 1A1a).
- Municipal waste incineration (illegal): The $CO_2$ emission factor is estimated by using the same assumption as in case of municipal solid waste incineration: The C-content is based on the study by FOEN (2014l) and the fossil carbon fraction was determined by Rytec (2014). See also chp. 3.2.5.2 and detailed information in EMIS 2022/1A1a Kehrichtverbrennungsanlagen (pp. 5–7).
- Industrial waste incineration (consists of cable insulation materials): The $CO_2$ emission factor is based on measurements of the flue gas treatment of a cable disassembling site where $O_2$ was measured in the flue gas. Assuming that the ratio of $CO_2/O_2$ is the same as in municipal solid waste incineration plants, a fraction of 7% of $CO_2$ results. Based on these assumptions, an emission factor of 1.3 kg/kg cable can be derived. Since 1995 no emissions from incinerating cable insulation materials have occurred.
- Sewage sludge incineration plants: As sewage sludge is biogenic waste, the emission factor for $CO_2$ is zero. It is assumed that the share of fossil fuel used during the start-ups is negligible.

Additional information on emission factors of all other (non-$CO_2$) gases:

- Hospital waste incineration: All emission factors are taken from SAEFL (2000).
- Municipal waste incineration (illegal): The emission factor for $N_2O$ is taken from the IPCC Guidelines (IPCC 2006, vol. 5), the emission factors for $CH_4$, $NO_x$, NMVOC and $SO_2$ from SAEFL (2000) and USEPA (1995a).
- Industrial waste incineration (consists of cable insulation materials): All emission factors are adopted from SAEFL (2000).
- Sewage sludge incineration plants: For 1990, emission factors are taken from SAEFL (2000). From 2002 to 2015, constant emission factors are used, which are deduced from measurements (LHA 2004) taken at the largest sewage sludge incineration plant incinerating at that time roughly one third of Switzerland's sewage sludge. In 2015 new emission factors for all pollutants other than $CO_2$ and $CH_4$ have been deduced based on measurements on three sewage sludge incineration plants (EMIS 2022/5C1 Klärschlammverbrennung). Between 1990 and 2002 as well as between 2002 and 2015, the emission factors are interpolated. Emission factors for $CH_4$, $NO_x$, CO and $SO_2$ decrease due to gradual technical improvements. Emission factors for $N_2O$ have been deduced differently (EMIS 2022/5C1 Klärschlammverbrennung): From 1990 to 2014, the evaluation of results from 7 emissions measurements over the years 2005–2013 on three sewage sludge incineration plants yielded an $N_2O$ emission factor of 4.10 kg/t (Meyer 2016, Wunderlin 2013). No indications suggested changes in emissions reductions technology over this period. In 2015, one plant accounting for incinerating 30% of the total sewage sludge in Switzerland applied a new emissions reduction technology resulting in $N_2O$ emissions of only 0.03 kg/t (TBF 2021). By accounting for this improvement, the $N_2O$ emission factor for 2015–2016 was reduced to 3.3 kg/t. TBF (2021) investigated that as of 2017 two additional sewage sludge incineration plants, accounting for the incineration of additional 30% of Switzerland's sewage sludge, have implemented emissions reductions measures. This led to the implementation of a new $N_2O$ emission factor of 1.85 kg/t from 2017 onwards.
- Crematoria: NMVOC and CO emissions were reduced by technical improvements. A large number of measurements were analysed (crematoria as well as other types of installations are obliged to monitor their emissions by the Swiss Federal Ordinance on Air Pollution Control (Swiss Confederation 1985) such that plant-specific emission factors are available for installations with retrofitted flue gas treatment as well as non-retrofitted installations. The emission factors are calculated as weighted averages of cremations taking place in retrofitted and non-retrofitted cremation plants (EMIS 2022/5C1 Krematorien).
- The emission factors of burning of branches in agriculture and gardening are calculated based on the EMEP/EEA guidebook (EMEP/EEA 2019) except for $CH_4$ and $N_2O$ for which emission factors are based on EMEP/CORINAIR (EMEP/EEA 2002), see also documentation in EMIS 2022/5C2 & 4VA1 Abfallverbrennung in der Land- und Forstwirtschaft.
- General remark: In years with no specific data for activity data or emission factors the respective data are interpolated.
- General remark: Indirect $CO_2$ emissions resulting from fossil $CH_4$, CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

### Activity data (5C)

The activity data for 5C Waste incineration are the quantities of waste incinerated, see Table 7-17. Activity data for open burning are split into open burning of natural residues in agriculture as well as into open burning of natural residues in private households, while respective activity data in CRF Table5.C are aggregated.

Table 7-17 Activity data for the different emission sources within source category 5C Waste incineration and open burning of waste.

| 5C Incineration and open burning of waste | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Hospital waste incineration | kt | 15.0 | 8.8 | 2.5 | NO | NO |
| Municipal waste incineration (illegal) | kt | 32.3 | 26.2 | 24.9 | 21.7 | 21.0 |
| Industrial waste incineration | kt | 7.5 | NO | NO | NO | NO |
| Sewage sludge incineration | kt (dry) | 57.0 | 50.2 | 64.3 | 94.9 | 89.8 |
| Open burning of natural residues in agriculture | kt | 16.5 | 15.2 | 14.0 | 12.8 | 11.5 |
| Open burning of natural residues in private households | kt | 6.1 | 4.9 | 3.6 | 2.4 | 1.2 |
| Total | kt | 134.3 | 105.2 | 109.3 | 131.7 | 123.6 |
| | | | | | | |
| Cremation | Numb. | 37'513 | 40'968 | 44'821 | 48'169 | 52'813 |

| 5C Incineration and open burning of waste | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hospital waste incineration | kt | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Municipal waste incineration (illegal) | kt | 20.3 | 20.3 | 19.9 | 19.3 | 19.3 | 19.0 | 18.3 | 17.9 | 17.3 | 17.0 |
| Industrial waste incineration | kt | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Sewage sludge incineration | kt (dry) | 83.1 | 75.5 | 93.7 | 92.8 | 97.3 | 99.4 | 102.0 | 97.9 | 100.4 | 97.4 |
| Open burning of natural residues in agriculture | kt | 11.4 | 11.3 | 11.2 | 11.1 | 11.0 | 10.8 | 10.7 | 10.6 | 10.5 | 10.4 |
| Open burning of natural residues in private households | kt | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| Total | kt | 116.0 | 108.2 | 125.9 | 124.3 | 128.7 | 130.4 | 132.1 | 127.6 | 129.3 | 125.9 |
| | | | | | | | | | | | |
| Cremation | Numb. | 52'530 | 50'567 | 53'205 | 55'616 | 59'664 | 54'634 | 57'694 | 54'842 | 57'746 | 68'148 |

Hospital waste incineration: Does not occur anymore in specific hospital waste incineration plants since 2002. Such waste is nowadays incinerated in municipal solid waste incineration plants and is therefore reported under sector 1 Energy. The amount of hospital waste burnt in 1990 stems from BUS (1988).

Municipal waste incineration (illegal): As waste incineration outside incineration plants is forbidden in Switzerland, no data is available. Illegal incineration of waste e.g. in wood stoves, garden fires, construction sites etc. is decreasing due to surveillance by authorities but also by citizens that would report open burning. However, there still are cases of illegal waste incineration. It is assumed that 1% of all waste in Switzerland has been burnt illegally in 1990 and that this value linearly decreases to 0.25% in 2030 (and then remains constant).

Industrial waste incineration (consists of cable insulation materials): Does not occur anymore since 1995. Such waste is nowadays incinerated in municipal solid waste incineration plants and is therefore reported under sector 1 Energy. The amount burnt in 1990 is estimated by the amount reported by a company that was supposed to burn approx. 1/3 of all cable insulation materials in Switzerland.

Sewage sludge incineration: Activity data for sewage sludge incineration for the years 1990, 1994, and 1999 are taken from Külling et al. (2002a). As of 2000 the total amount of sewage sludge produced in Switzerland is calculated by multiplying the sludge production per person and year as reported by VBSA (2017) with the total population. The per capita sewage sludge production for 2000, 2004, 2008, 2012, 2016 and 2017 (VBSA 2017) have been derived by compiling the respective amounts of sewage sludge incinerated in municipal solid waste incineration plants, sewage sludge incineration plants and used as alternative fuel in the cement industry and dividing it by the total population count (VBSA 2017). Per capita sludge productions for the intervening years were interpolated linearly. As of 2016, annual per capita sludge production amounted to 21.2 kg (VBSA 2017).

Open burning of natural residues: The amount of natural residues burnt openly has been estimated in a study (INFRAS 2014) as briefly described in the following. Open burning of such residues is regulated in the Ordinance on Air Pollution Control (Swiss Confederation 1985), Article 26b. In Switzerland, cantonal authorities are responsible for the implementation of these regulations. Since there is no nationwide data available for the activity data of open burning of natural residues, cantonal authorities have been interviewed. Based on the available statistics for many cantons on the number of permitted fires and sanctions due to non-permitted fires, the amount of burnt material in those cantons has been quantified. Since there is also a significant number of unreported cases, it has been assumed that the actual amount of material burnt is three times as large as the amount approved by the authorities. Based on the evaluated numbers from the cantons, an extrapolation to the amount burnt in Switzerland has been made. For the extrapolation the statistics on the harvesting of wood has been used (FOEN 2012i). For the determination of a time series of natural residues burnt, senior experts with historical knowledge in agriculture and forestry have been interviewed. Furthermore, statistical data on agricultural and forestry activities has been used to estimate the potential of material available for burning at a certain time. With this approach a time series since 1900 has been compiled. Emissions from open burning of natural residues in forestry (5C2ii) are reported in LULUCF sector 4V (chp. 6.4.2.12).

Cremations: Activity data is reported by the Swiss Cremation Association. These statistics are updated every year.

### 7.4.3. Uncertainties and time-series consistency

The uncertainty assessment, based on expert judgment, results in high uncertainties for $CO_2$, $CH_4$ and $N_2O$ of 40%, 60% and 150% of emission estimates, respectively (see Table 1-10 for quantification of “high”).

Consistency: Time series for 5C Waste incineration and open burning of waste are all considered consistent.

### 7.4.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

### 7.4.5. Category-specific recalculations

The following recalculations were implemented in submission 2022:

- 5C1 sewage sludge incineration: The emission factor for $N_2O$ has decreased from 2015 to 2020 in the framework of a study evaluating reports of emission reduction measures carried out in the period 2015–2020 on several sewages sludge incineration plants in Switzerland (TBF 2021). The decrease occurred in two steps due to an implementation of an emission reduction technique in several sewage sludge incineration plants in 2015 and 2017, respectively. Roughly 2/3 of Switzerland's sewages sludge is incinerated in plants applying the technique for low $N_2O$ emissions leading to a reduction of the emission factor by 55% (from 4.10 kg $N_2O$/t in 2014 to 1.85 kg $N_2O$/t in 2017). This leads to the following reductions in $N_2O$ emissions: 2015: -19.5%, 2016: -37.2%, 2017–2019: -54.8%).

### 7.4.6. Category-specific planned improvements

No category-specific improvements are planned.

## 7.5. Source category 5D – Wastewater treatment and discharge

### 7.5.1. Source category description

Table 7-18 Key categories of 5D Wastewater treatment and discharge. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| Code | IPCC category | Gas | Identification criteria |
|---|---|---|---|
| 5D | Wastewater Treatment and Discharge | CH4 | L1, T1, L2 |
| 5D | Wastewater Treatment and Discharge | N2O | L2 |

Source category 5D1 Domestic wastewater comprises all emissions from liquid waste handling and sludge from housing and commercial sources (including grey water and night soil). In Switzerland, municipal wastewater treatment (WWT) plants treat wastewater from single cities or several cities and municipalities together. Wastewater in general is treated in three steps:

- Mechanical treatment
- Biological treatment
- Chemical treatment

The treated wastewater flows into a receiving system (lake, river or stream). Pre-treated industrial effluents are also handled for final treatment in municipal wastewater treatment plants (see Figure 7-6). In the following, these are called "domestic wastewater treatment plants" according to the terminology of 5D1 Domestic wastewater.

Switzerland's wastewater management infrastructure – comprising about 850 wastewater treatment plants and 40'000–50'000 km of public sewers – is now practically complete (FOEN 2017l). The vast majority of wastewater treatment plants apply an anaerobic sludge treatment with sewage gas recovery, and use the sewage gas for heat production. About

290 wastewater treatment plants also apply combined heat and power units. See also EMIS 2022/5D1 Wastewater Treatment Plants.

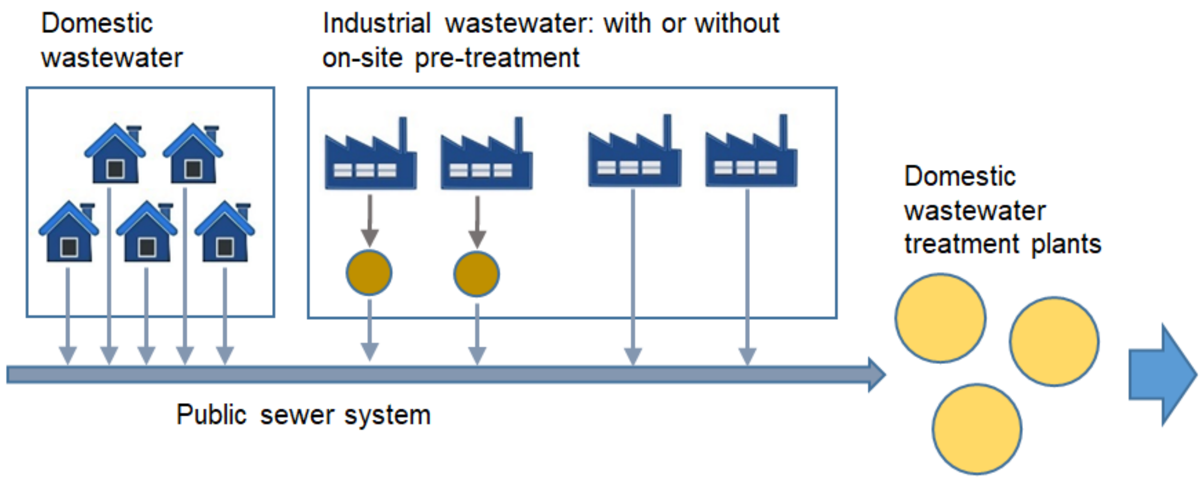



Figure 7-6 Graphical representation of domestic and industrial wastewater streams.

Source category 5D2 Industrial wastewater comprises all emissions from liquid waste handling and sludge from industrial processes such as food processing, textiles, car-washing places, electroplating plants, and pulp/paper production. These processes may result in effluents with a high load of organics. Depending on the contaminants, an on-site pre-treatment is necessary in order to reduce the load of pollutants in the wastewater to meet the regulatory standards (which are in place to preclude disruptions of the domestic wastewater treatment plants) and to reduce discharge fees. The on-site pre-treatment is generally anaerobic, in order to use the sewage gas as source for heat and power production. Currently, about 20 industrial wastewater treatment plants pre-treat wastewater before its discharge to the domestic sewage system, where the industrial wastewater is additionally treated together with domestic wastewater in domestic wastewater treatment plants (see Figure 7-6 and Figure 7-7). Due to this strong connection with domestic wastewater treatment, industrial wastewater is not identified as separate wastewater stream for the calculation of GHG emissions, but joined to the domestic wastewater treatment. For the calculation of emissions of other gases ($NO_x$, CO, NMVOC, $SO_2$), domestic and industrial wastewater streams are distinguished (i.e. different emission factors relative to population are applied, see below). See also EMIS 2022/5D2 Pre-treatment of industrial wastewater.

Table 7-19 Specification of source category 5D Wastewater treatment and discharge.

| 5D | Source category | Specification |
|---|---|---|
| 5D1 | Domestic wastewater | Emissions from liquid waste handling and sludge from housing and commercial sources |
| 5D2 | Industrial wastewater | Emissions of precursors from handling of liquid wastes and sludge from industrial processes (emissions of $CH_4$ and $N_2O$ are implemented in 5D1) |
| 5D3 | Other | Not occurring in Switzerland |

Category 5D contains all direct emissions from wastewater handling, including direct emissions of sewage gas (leakage), torching and upgrading of sewage gas to natural gas quality (to be fed into the natural gas network and/or used as fuel). Emissions from the usage of sewage gas in combined heat and power (CHP) units and boilers (only heat production) are reported in sector 1 Energy in source category 1A2gviii Other (see Figure 3-18).

Wastewater treatment also leads to emissions reported in other categories, as illustrated in Figure 7-7. Emissions associated with sewage sludge drying are assumed to be negligible. The discharge of sewage sludge on agricultural soils has been phased out since 2003 and is generally forbidden since 2009. Therefore, this process is crossed out in Figure 7-7. The same applies to solid waste disposal on land (5A). All sewage sludge is incinerated either in municipal solid waste incineration plants (1A1a), sewage sludge incineration plants (5C) or used as alternative fuel in the cement industry (1A2f).

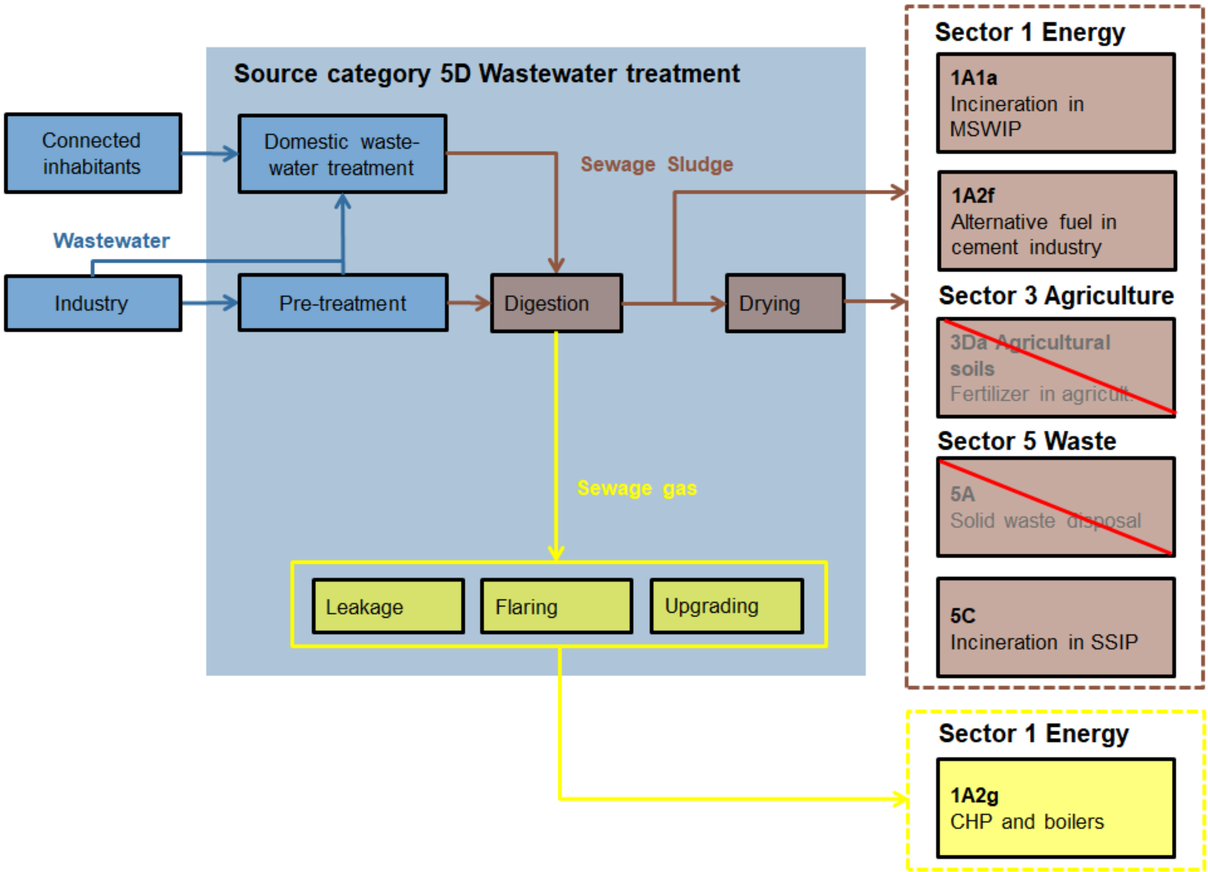



Figure 7-7 System boundaries of processes related to wastewater treatment. CHP = Combined heat and power generation. MSWIP = Municipal solid waste incineration plant. SSIP = Sewage sludge incineration plant.

## 7.5.2. Methodological issues

$CH_4$ emissions are calculated by a Tier 2 method based on the decision tree of the IPCC Guidelines (IPCC 2006, vol. 5, chp. 6, Fig. 6.2 and Fig. 6.3). $N_2O$ emissions are calculated using a country-specific method according to IPCC (2006). Details regarding the calculation of $CH_4$ and $N_2O$ emissions are provided in the following.

### 7.5.2.1. $CH_4$ emissions

**Methodology (5D, $CH_4$)**

$CH_4$ emissions from wastewater treatment and discharge take into account emissions stemming from organically degradable material in wastewater and emissions related to sewage gas production (and recovery) from sewage sludge (in domestic as well as industrial installations). Accordingly, the contribution of industrial wastewater is taken into account in the calculation of $CH_4$ emissions from domestic wastewater by means of a correction factor for additional industrial biochemical oxygen demand (BOD) discharged into the domestic sewer system. Industries handling wastewater with high biochemical oxygen demand usually use anaerobic digesters to produce sewage gas. The emissions related to sewage gas production (and recovery) during industrial pre-treatment of wastewater are also taken into account in the calculation of emissions from domestic wastewater treatment plants, because the underlying Swiss renewable energy statistics (see below) does not differentiate between sewage gas production in domestic and industrial wastewater treatment plants.

Accordingly, total $CH_4$ emissions from domestic and industrial wastewater treatment and discharge are calculated as the sum of two terms:

$$CH_{4,total} = CH_{4,wastewater} + CH_{4,sewage\ gas}$$

(1) Wastewater

In accordance with the IPCC Guidelines (IPCC 2006) the contribution of wastewater sewered to wastewater treatment plants is determined by:

$$CH_{4,wastewater} = EF_{wastewater} * T_{Plant} * TOW$$

$EF_{wastewater}$ corresponds to the emission factor (see below), $T_{Plant}$ to the fraction of population connected to domestic wastewater treatment plants in each year and TOW to the total organically degradable material in the wastewater per year.

From all inhabitants (urban and rural) 90% were connected to wastewater treatment plants in 1990, and this percentage reached 97% in 2006, remaining constant thereafter. Switzerland reports emissions only from wastewater discharged to the public sewer system, without taking into account potential emissions from wastewater of unconnected inhabitants. However, emissions from the small fraction of wastewater not treated in wastewater treatment plants (since 2006 the wastewater from 3% of the population) are negligible. Federal law only permits alternative treatment systems in remote and sparsely populated regions. Some of such alternative systems treat wastewater very similar to centralized wastewater treatment plants, often under aerobic conditions. The sewage sludge from these small scale treatment installations is either dealt with by centralized wastewater treatment plants or municipal solid waste incineration plants. Simpler systems are e.g. septic tanks with at least three chambers. However, the production of $CH_4$ in an anaerobic environment is strongly temperature dependent and significant $CH_4$ production is unlikely below 15°C due to the inactivity of methanogens (IPCC 2006). As in Switzerland alternative systems are typically buried, the wastewater reaches the rather constant temperature of the surrounding soil, approximately corresponding to the mean annual air temperature. At Grono, the warmest place in Switzerland, the mean annual temperature is 12.4°C. Accordingly, in alternative treatment systems the temperature of the wastewater is too low to produce substantial $CH_4$ emissions. $CH_4$ emissions from wastewater produced by inhabitants not connected to domestic wastewater treatment plants are thus currently considered insignificant and set to zero in the Swiss greenhouse gas inventory. However, as detailed under the category-specific planned improvements (see chp. 7.5.6), the emissions from the small fraction of wastewater not discharged to the public sewer system are currently reconsidered.

(2) Sewage gas

The $CH_4$ emissions resulting from sewage gas treatment (aiming at stabilizing the sewage sludge and producing sewage gas) are calculated based on a country-specific implied emission factor ($EF_{sewage\ gas}$, see below), which is normalized with population (P):

$$CH_{4,sewage\ gas} = EF_{sewage\ gas} * P$$

**Emission factors (5D, $CH_4$)**

(1) Wastewater

The wastewater of all connected inhabitants, i.e. virtually all wastewater generated in Switzerland, is sewered to wastewater treatment plants using closed sewer systems. The emission factor according to the IPCC Guidelines (IPCC 2006, vol. 5, chp. 6, Equation 6.2) is represented by the product of the maximum $CH_4$ producing potential ($B_o$, default value 0.60 kg $CH_4$/kg BOD) and the methane correction factor (MCF) for the wastewater treatment and discharge system. For the wastewater sewered to centralized wastewater treatment plants, the IPCC Guidelines (IPCC 2006) propose that the MCF is zero (range 0.0–0.1) for well managed aerobic wastewater treatment plants. While wastewater treatment plants are generally well managed in Switzerland and mostly operated aerobically (with the exception of sewage sludge treatment, which is considered separately, see below), some $CH_4$ emissions may still occur. Therefore, the MCF is set to 0.05 (corresponding to the mid-value of the range of well managed aerobic wastewater treatment plants), which also brings total $CH_4$ emissions from wastewater treatment in Switzerland to similar values as estimated by Hiller et al. (2014) in their peer-reviewed study. This leads to the following constant emission factor:

$$EF_{wastewater} = B_0 * MCF = 0.60 \frac{kgCH_4}{kgBOD} * 0.05 = 0.03 \frac{kgCH_4}{kgBOD}$$

As mentioned above the maximum $CH_4$ producing capacity of the wastewater not treated in wastewater treatment plants is zero, as the wastewater has a temperature most likely too low to produce significant amounts of $CH_4$. Accordingly, the emission factor for wastewater not treated in wastewater treatment plants is zero and the corresponding emissions are zero, too.

(2) Sewage gas

To calculate the country-specific implied emission factor $EF_{sewage\ gas}$ for $CH_4$ emissions from sewage gas treatment the total sewage gas production (in domestic and industrial systems) is taken into account based on detailed Swiss renewable energy statistics (SFOE 2021a). These statistics provide the amount of sewage gas used in furnaces and combined heat and power installations, as well as the amount of sewage gas upgraded to natural gas quality. It is assumed that 2% of the total amount of sewage gas is flared and 0.75% of the total amount is leaking. It is further assumed that the leakage of upgraded gas linearly decreases from 5% in 1990 to 2.5% in 2014, remaining constant thereafter. The emission factor is adapted on a yearly basis due to the respective annual changes in population and the total production of sewage gas.

(3) Values of emission factors referred to the number of inhabitants

The $CH_4$ emission factors for 5D Wastewater treatment and discharge are summarized in Table 7-20.

Table 7-20 Country-specific $CH_4$ emission factors for source category 5D Wastewater treatment and discharge in 2020 referred to the number of inhabitants. Detailed information is given in EMIS 2022/5D1 5D2 Kläranlagen GHG (Wastewater Handling – Emissions of Nitrous Oxide ($N_2O$) and Methane ($CH_4$), Update to the 2006 IPCC Guidelines).

| **5D Wastewater treatment and discharge** | **Unit** | **2020** |
|---|---|---|
| Population | inhabitants in 1000 | 8'638 |
| Emissions from WW sewered to WWT plants | kg $CH_4$/person/a | 0.80 |
| Emissions from WW not sewered to WWT plants | kg $CH_4$/person/a | NA |
| Emissons from losses during sludge treatment | kg $CH_4$/person/a | 0.090 |

**Activity data (5D, $CH_4$)**

(1) Wastewater

In correspondence with the emission factor $EF_{wastewater}$ given above, the activity data is the fraction of population connected to domestic wastewater treatment plants ($T_{plant}$), as well as the total organically degradable material (*TOW*) in domestic and industrial wastewater. According to the IPCC Guidelines (IPCC 2006), the total organically degradable material is calculated by

$$TOW = P * BOD * 0.001 * I * 365$$

TOW is given in kg BOD/yr (BOD: biochemical oxygen demand) and P is the population (see Table 7-21). For the biochemical oxygen demand the default value for Europe given by the IPCC Guidelines (IPCC 2006) is used for Switzerland (60 g/inhabitant/day). The parameter I corresponds to the correction factor for additional industrial biochemical oxygen demand discharged into domestic sewers with default value 1.25. While the amount of sewage sludge removed from wastewater treatment plants is known, detailed information about its biochemical oxygen demand content is not available. Therefore, the amount of biochemical oxygen demand removed with sewage sludge is set to zero, in accordance with the default value given by the IPCC Guidelines (IPCC 2006).

Time series of the activity data are shown in Table 7-21.

(2) Sewage gas

As elaborated above, a per capita $CH_4$ emission factor ($EF_{sewage\ gas}$) is calculated for $CH_4$ emissions from separate sewage sludge treatment, and the respective activity data is population (Table 7-21).

### 7.5.2.2. $N_2O$ emissions

**Methodology (5D, $N_2O$)**

Direct $N_2O$ emissions from centralized wastewater treatment plants and $N_2O$ emissions from wastewater effluent are calculated in accordance with the IPCC Guidelines (IPCC 2006).

(1) $N_2O$ emissions from wastewater treatment plants

Direct $N_2O$ emissions from wastewater treatment plants are determined with equation 6.9 of the IPCC Guidelines (IPCC 2006):

$$N_2O_{PLANTS} = EF_{PLANT} * P * T_{PLANT} * F_{IND-COM}$$

$N_2O_{PLANTS}$ corresponds to the total $N_2O$ emissions from wastewater treatment plants in kg $N_2O$/yr, $P$ to the population, $T_{PLANT}$ to the degree of utilization of modern, centralized wastewater treatment plants (%),
$F_{IND-COM}$ to the correction factor for industrial (and commercial) co-discharged protein, and $EF_{PLANT}$ to the emission factor from the plants.

(2) $N_2O$ emissions from wastewater effluents

The following equation from the IPCC Guidelines (IPCC 2006) for the $N_2O$ emissions from wastewater effluent is used:

$$N_2O_{EFFLUENT} = EF_{EFFLUENT} * N_{EFFLUENT} * 44/28$$

$N_2O_{Effluent}$ corresponds to the total $N_2O$ emissions from effluents (kg $N_2O$/yr), $N_{EFFLUENT}$ to the total amount of nitrogen discharged to the aquatic environment (kg N/yr), and $EF_{EFFLUENT}$ to the emission factor for $N_2O$ emissions from discharged wastewater (kg $N_2O$-N/kg N). The following equation allows for the calculation of the total amount of nitrogen in the wastewater ($N_{EFFLUENT}$, kg N/yr, IPCC 2006):

$$N_{EFFLUENT} = (P * Protein * F_{NPR} * F_{NON-CON} * F_{IND-COM}) - N_{SLUDGE} - N_{WWT}$$

P corresponds to the population, Protein to the annual per capita protein consumption (kg protein/inhabitant/yr), and $F_{NPR}$ to the fraction of nitrogen in protein. $F_{NON-CON}$ is a factor accounting for non-consumed protein added to the wastewater. $F_{IND-COM}$ is a factor accounting for industrial (and commercial) co-discharged protein into the sewer system. $N_{SLUDGE}$ is the amount of nitrogen removed with sewage sludge (kg N/yr), calculated as the product of sludge amount per year and its nitrogen concentration. The default value according to the 2006 IPCC Guidelines would be zero, but detailed data about sewage sludge removal as well as the nitrogen content of the sewage sludge is available for Switzerland (Külling et al. 2002a, VBSA 2017). In Switzerland sewage sludge is mostly burnt today in waste incineration plants and (cement) industry, previously it has also been used as fertiliser (now forbidden). $N_{WWT}$ corresponds to the amount of nitrogen directly emitted by wastewater treatment plants in form of $N_2O$ ($N_2O_{Plants}$, see calculation above).

**Emission factors (5D, $N_2O$)**

(1) $N_2O$ emissions from wastewater treatment plants

The IPCC default emission factor is applied: $EF_{PLANT}$ = 3.2 g $N_2O$/inhabitant/yr (IPCC 2006).

(2) $N_2O$ emissions from wastewater effluents

The IPCC default emission factor is applied: $EF_{EFFLUENT}$ = 0.005 kg $N_2O$-N/kg N (IPCC 2006).

**Activity data (5D, $N_2O$)**

(1) $N_2O$ emissions from wastewater treatment plants

The needed time-dependent and country-specific activity data are summarized in Table 7-21:

- Population (P)
- Degree of utilization of modern, centralized wastewater treatment plants ($T_{PLANT}$ )
- In addition, the following constant factor is used: Industrial (and commercial) co-discharged protein, within IPCC (2006) range: $F_{IND\text{-}COM}$ = 1.0 (EAWAG 2018)

(2) $N_2O$ emissions from wastewater effluents

The time-dependent and country-specific activity data are also summarized in Table 7-21:

- Population (P)
- Annual per capita protein consumption (Protein) (SBV 2021)
- Mass of nitrogen contained in the removed sludge ($N_{SLUDGE}$)

In addition, the following constant factors are used:

- Fraction of nitrogen in protein, IPCC default value: $F_{NPR}$ = 0.16 kg N/kg protein (IPCC 2006).
- Factor accounting for non-consumed protein added to the wastewater, within IPCC (2006) range: $F_{NON\text{-}CON}$ = 1.0 (EAWAG 2018). This value is appropriate for Switzerland as it is illegal to discharge solid and liquid garbage with the wastewater, according to Article 10 of the Waters Protection Ordinance (Swiss Confederation 1998a).
- Industrial (and commercial) co-discharged protein, IPCC default value: $F_{IND\text{-}COM}$ = 1.25 (IPCC 2006).

Table 7-21 Activity data for source category 5D Wastewater treatment and discharge (source EMIS 2022/5D1 Wastewater Treatment Plants and EMIS 2022/5D2 Pre-treatment of industrial wastewater).

| 5D Wastewater treatment and discharge | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Population | persons in 1000 | 6'712 | 7'041 | 7'184 | 7'437 | 7'825 |
| Fraction of population connected to wastewater treatment plants | % | 90.0 | 93.7 | 95.4 | 96.8 | 97.2 |
| Connected persons | persons in 1000 | 6'041 | 6'597 | 6'854 | 7'199 | 7'606 |
| Protein consumption | kg/inhab./a | 39 | 37 | 37 | 37 | 38 |
| N removed with sludge ($N_{sludge}$) | N in t/a | 9'465 | 9'009 | 9'374 | 9'222 | 8'578 |
| N directly emitted ($N_{WWT}$) | N in t/a | 12.3 | 13.4 | 14.0 | 14.7 | 15.5 |
| Total org. degr. material (TOW) | t/a | 183'741 | 192'747 | 196'662 | 203'588 | 214'209 |

| 5D Wastewater treatment and discharge | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Population | persons in 1000 | 7'912 | 7'997 | 8'089 | 8'189 | 8'282 | 8'373 | 8'452 | 8'514 | 8'575 | 8'638 |
| Fraction of population connected to wastewater treatment plants | % | 97.3 | 97.3 | 97.3 | 97.3 | 97.3 | 97.3 | 97.3 | 97.3 | 97.3 | 97.3 |
| Connected persons | persons in 1000 | 7'698 | 7'781 | 7'871 | 7'968 | 8'058 | 8'147 | 8'224 | 8'284 | 8'343 | 8'405 |
| Protein consumption | kg/inhab./a | 39 | 37 | 37 | 37 | 38 | 36 | 36 | 36 | 35 | 35 |
| N removed with sludge ($N_{sludge}$) | N in t/a | 8'295 | 8'034 | 7'952 | 7'908 | 7'817 | 7'721 | 7'795 | 7'852 | 7'908 | 7'965 |
| N directly emitted ($N_{WWT}$) | N in t/a | 15.7 | 15.8 | 16.0 | 16.2 | 16.4 | 16.6 | 16.7 | 16.9 | 17.0 | 17.1 |
| Total org. degr. material (TOW) | t/a | 216'591 | 218'918 | 221'436 | 224'174 | 226'720 | 229'211 | 231'374 | 233'071 | 234'741 | 236'465 |

### 7.5.2.3. Other gases

The sewage gas production generates emissions of further gases from flaring: $CO_2$ (biogenic), $NO_x$, CO, NMVOC, and $SO_2$. The emissions are calculated by multiplying population (as activity data, see Table 7-21) with country-specific emission factors based on measurements and expert estimates, documented in EMIS 2022/5D1 Wastewater Treatment Plants and EMIS 2022/5D2 Pre-treatment of industrial wastewater. The emission factors used are summarized in Table 7-22.

Table 7-22 Emission factors of $CO_2$ (biogenic), $CH_4$, $N_2O$, $NO_x$, CO, NMVOC and $SO_2$ for 5D Wastewater treatment and discharge in 2020.

| 5D Wastewater treatment and discharge | $CO_2$ biog. | $N_2O$ | $CH_4$ | $NO_x$ | CO | NMVOC | $SO_2$ |
|---|---|---|---|---|---|---|---|
| | kg/person | g/person | | | | | |
| 5D1 Domestic wastewater | 0.41 | 40 | 889 | 0.56 | 0.28 | 0.011 | 0.0028 |
| 5D2 Industrial wastewater | 0.08 | IE | IE | 0.12 | 0.061 | 0.0024 | 0.00061 |

## 7.5.3. Uncertainties and time-series consistency

**Uncertainty in $CH_4$ and $N_2O$ emissions from 5D**

### 7.5.3.1. $CH_4$ emissions

The default values of the IPCC Guidelines (IPCC 2006) are adopted to estimate the uncertainty of $CH_4$ emissions. The following specifications are given:

- Activity data: Uncertainties of the single factors U(population) = 5%, U(BOD) = 30%, U(I) = 20% lead to an aggregated uncertainty of U(AD) = 36%.
- $CH_4$ emission factor: Uncertainties of the single factors U($B_0$) = 30%, U(MCF) = 10% (well managed plants) lead to an aggregated uncertainty of U(EF) = 32%.
- Combined uncertainty U(Em $CH_4$) = 48% (according to uncertainty computation approaches 1 and 2, see Annexes A2.2 and A2.3, respectively).

### 7.5.3.2. $N_2O$ emissions

By applying the default uncertainties of the IPCC Guidelines (IPCC 2006, vol. 5, chp. 6, table 6.11) for the activity data (population, protein consumption etc.) a total uncertainty of 32% results.

For the emission factor the 2006 IPCC Guidelines provide default values, too. However, the range for $EF_{EFFLUENT}$ covers a range of 0.0005–0.25 kg $N_2O$-N/kg N (with default value 0.005 kg $N_2O$-N/kg N). If this range is interpreted as the 95% uncertainty interval, a symmetrised uncertainty of 2'500% would result, which is not considered appropriate. The IPCC Guidelines (IPCC 2006) do not explain how to apply the range, wherefore the default uncertainty is not adopted. Instead, the uncertainty is based on expert judgments assuming a high uncertainty of $N_2O$ emissions from 5D Wastewater treatment and discharge in Switzerland. By means of Table 1-10 this qualitative estimation corresponds to 150% for the combined uncertainty. For the uncertainty computation using Monte Carlo simulations, the emission factor is modelled using a gamma distribution to reflect the fact that only positive values are possible.

Consistency: Time series for 5D Wastewater treatment and discharge are all considered consistent.

## 7.5.4. Category-specific QA/QC and verification

To check the quality of the assumptions and calculations for 5D Wastewater treatment and discharge and their accordance with the 2006 IPCC Guidelines, a review by Eawag (Swiss Federal Institute of Aquatic Science and Technology) has been performed in 2018 (EAWAG 2018). No major issues have been found and recommendations by the authors have already been implemented in submission 2019.

In 2020, a project at the School of Agricultural, Forest and Food Sciences (HAFL) was completed, measuring $CH_4$ emissions on two wastewater treatment plants in Switzerland using an inverse dispersion method (Kupper et al. 2021). In their report, the results from the inverse dispersion method are compared to literature data, to a country-specific method proposed by Eawag (EAWAG 2018), and to $CH_4$ emission estimates from 5D Wastewater treatment and discharge as of 2016 (FOEN 2018). The comparison denotes considerable uncertainties and some differences for measurements and emission estimates, but all values are within the range given in the literature review (Kupper et al. 2021).

### 7.5.5. Category-specific recalculations

The following recalculations were implemented in submission 2022: Major recalculations which contribute significantly to the total differences emissions of sector 5D between the latest and the previous submissions are presented also in chp. 10.1.2.5.

- 5D1 Domestic wastewater treatment: Changes in the underlying statistics by the Swiss Farmers Association from 2014 to 2019 of less than ±1% lead to changes of the annual per capita protein consumption and thus to changes in the nitrogen content of wastewater effluent as well as in the $N_2O$ emission factor. Consequently, $N_2O$ emissions from domestic wastewater treatment change by +0.36% to -1.2%.

### 7.5.6. Category-specific planned improvements

Long-term and representative measurements of $N_2O$ emissions from wastewater treatment plants in Switzerland were ongoing. Results for estimating representative emission factors of $N_2O$ for wastewater treatment are now available by Gruber et al. (2021) and it is planned to implement the findings in the next inventory and NIR.

In order to address the recommendations from the UNFCCC review process (UNFCCC 2022, issues W.5, W.6, W.7) concerning $CH_4$ emissions from domestic wastewater treatment outside the public sewer system, a study has been commissioned by FOEN. Results will be implemented in the greenhouse gas inventory after completion of the study as appropriate.

## 7.6. Source category 5E – Other

### 7.6.1. Source category description

Source category 5E Other is not a key category.

The source category 5E Other comprises NMVOC and CO emissions from car shredding stemming from residues of fuels (gasoline, diesel oil) and motor oil in the tanks and motors of the shredded vehicles. Direct GHG emissions do not occur.

Table 7-23 Specification of source category 5E Other (car shredding)

| 5E | Source category | Specification |
|---|---|---|
| 5E | Car shredding plants | Emissions from car shredding plants |

## 7.6.2. Methodological issues

### Methodology (5E)

For the emissions from car shredding a Tier 1 method is used.

Indirect $CO_2$ emissions resulting from fossil CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

### Emission factors (5E)

An emission factor of 100 g NMVOC per tonne of shredded vehicle is applied for the period 1990–1995. From 2000 onward, 200 g/t are used. Between 1995 and 2000 the values are linearly interpolated. The NMVOC emission factor are based on measurements at four plants in the years from 2002 to 2008 (EMIS 2022/5E Shredder Anlagen). For CO a constant emission factor is applied over the entire reporting period.

Table 7-24 CO and NMVOC emission factors for 5E Other (car shredding) in 2020.

| 5E Other waste | Unit | $CH_4$ | $N_2O$ | $NO_x$ | CO | NMVOC | $SO_2$ |
|---|---|---|---|---|---|---|---|
| Shredding | g/t scrap | NA | NA | NA | 5.0 | 200 | NA |

### Activity data (5E)

The waste quantities from 1990 to 1999 are provided by the Swiss Shredding Association. The data from 2000 to 2007 are taken from Swiss waste statistics. From then onwards the quantities are assumed to remain constant due to the lack of data (see also EMIS 2022/5E Shredder Anlagen).

Table 7-25 Activity data 5E Other (car shredding).

| 5E Other waste | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Shredding | kt | 280 | 300 | 300 | 300 | 300 |

| 5E Other waste | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Shredding | kt | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 300 |

## 7.6.3. Uncertainties and time-series consistency

Uncertainties of 20% for the emission factor and 10% for the activity data are assumed (see detailed input uncertainties in Annex A2.1).

Consistency: Time series for 5E Other are all considered consistent.

## 7.6.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

### 7.6.5. Category-specific recalculations

There were no recalculations implemented in submission 2022.

### 7.6.6. Category-specific planned improvements

No category-specific improvements are planned.

# 8. Other

| Responsibilities for chapter Other | |
|---|---|
| Overall responsibility | Michael Bock (FOEN) |
| Authors | Michael Bock (FOEN), Rainer Kegel (FOEN), Daiana Leuenberger (FOEN) |
| EMIS data base operation | Rainer Kegel (FOEN), Daiana Leuenberger (FOEN) |
| Annual updates (NIR text, tables, figures) | Beat Rihm (Meteotest) |
| Quality control (NIR annual updates) | Michael Bock (FOEN), Dominik Eggli (Meteotest), Adrian Schilt (FOEN) |
| Internal review | Rainer Kegel (FOEN), Daiana Leuenberger (FOEN), Adrian Schilt (FOEN) |

## 8.1. Overview

Within the sector 6 Other emissions from two sources are considered:

- Fire damage estates
- Fire damage motor vehicles

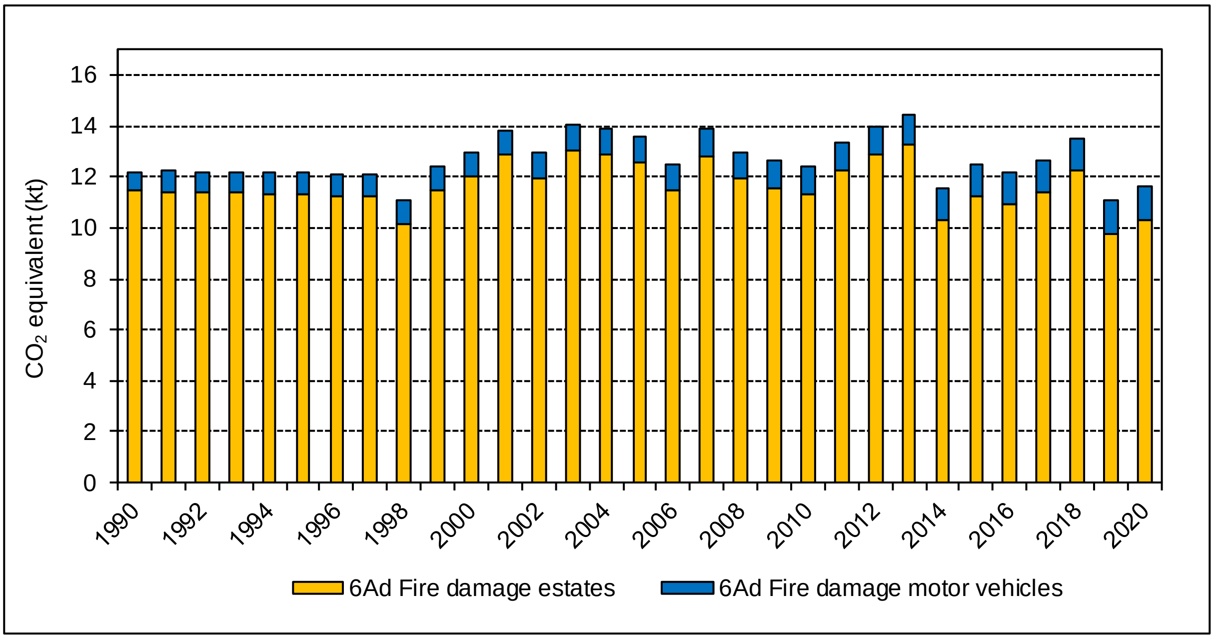



Figure 8-1 Switzerland's greenhouse gas emissions in sector 6 Other.

Table 8-1 Trend of total GHG emissions from sector 6 Other in Switzerland.

| Gas | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | |
| $CO_2$ | 11 | 11 | 12 | 12 | 11 |
| $CH_4$ | 0.66 | 0.62 | 0.62 | 0.65 | 0.60 |
| $N_2O$ | 0.60 | 0.55 | 0.54 | 0.57 | 0.51 |
| Sum | 12 | 12 | 13 | 14 | 12 |

| Gas | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | | | | | | |
| $CO_2$ | 12 | 13 | 13 | 10 | 11 | 11 | 12 | 12 | 10 | 11 |
| $CH_4$ | 0.64 | 0.67 | 0.69 | 0.56 | 0.60 | 0.59 | 0.61 | 0.65 | 0.54 | 0.57 |
| $N_2O$ | 0.55 | 0.58 | 0.60 | 0.47 | 0.51 | 0.50 | 0.51 | 0.55 | 0.44 | 0.47 |
| Sum | 13 | 14 | 14 | 12 | 12 | 12 | 13 | 14 | 11 | 12 |

In sector 6 Other, Fire damage estates account for most of the emissions, the rest originates from Fire damage motor vehicles. The total greenhouse gas emissions of this sector show variations around 12 kt $CO_2$ eq during the reporting period. Consequently, sector 6 Other is an emission source of minor importance for the national total.

## 8.2. Source category 6 – Other

### 8.2.1. Source category description

Source category 6 – Other is not a key category.

The sources reported in source category 6 Other are shown in Table 8-2.

Table 8-2 Specification of source category 6 Other.

| 6 | Source category | Specification |
|---|---|---|
| 6Ad | Fire damage estates | Emissions from fires in buildings. |
| 6Ad | Fire damage motor vehicles | Emissions from fires in motor vehicles. |

### 8.2.2. Methodological issues

**Methodology (6 Other)**

$CO_2$ emissions are calculated by a Tier 1 method based on the decision tree of the IPCC Guidelines (IPCC 2006, vol. 5, chp. 5, Fig. 5.1). Emission factors are country-specific.

$CH_4$ emissions are calculated by a Tier 1 method based on the decision tree of the IPCC Guidelines (IPCC 2006, vol. 5, chp. 5, Fig. 5.2). Emission factors are taken from a US study (FM Global 2010) (“OTH”, fire damage estates) and from USEPA 1992 (“OTH”, fire damage motor vehicles).

$N_2O$ emissions are calculated by a Tier 1 method based on the decision tree of the IPCC Guidelines (IPCC 2006, vol. 5, chp. 5, Fig. 5.2). Emission factors are taken from a US study (FM Global 2010) ("OTH", fire damage estates). $N_2O$ emissions from fire damages of motor vehicles have not been estimated.

The estimation of GHG emissions are based on damage sums and fires reported from insurance companies.

**Emission factors (6 Other)**

a) Fire damage estates

Emission factors for $CO_2$, CO, $NO_x$ and $SO_2$ are country-specific based on measurements and expert estimates originally gained for illegal waste incineration. It is assumed that for fire damage in estates emission factors are the same as for illegal waste incineration (EMIS 2022/6Ad Brand- und Feuerschäden Immobilien).

The fraction between fossil and biogenic $CO_2$ emissions is assumed to remain constant since 2000 with 80% being fossil and 20% being biogenic $CO_2$ emissions. Before 2000, it is assumed that the fraction of fossil $CO_2$ emissions from burnt goods has been increasing linearly from 20% in 1950 to 80% in 2000. The interpolated emission factors for fossil $CO_2$ were thus between 400 and 1500 t $CO_2$ / kt burnt good between 1950 and 2000, respectively. Vice versa, the emission factors for biogenic $CO_2$ were between 1500 and 400 t $CO_2$ / kt burnt good between 1950 and 2000, respectively.

Indirect $CO_2$ emissions resulting from fossil $CH_4$, CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

b) Fire damage motor vehicles

Emission factors for $CO_2$, $NO_x$, CO and $SO_2$ are country-specific based on measurements and expert estimates originally gained for the combustion of cable insulation materials, documented in EMIS 2022/6Ad Brand- und Feuerschäden Motorfahrzeuge.

The emission factor for $CH_4$ from fire damage in motor vehicles is based on USEPA (1992), while $N_2O$ emissions have not been estimated for this source category.

Indirect $CO_2$ emissions resulting from fossil $CH_4$, CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

Table 8-3 Emission factors for fire damages in 2020 (EMIS 2022/6Ad).

| 6A Other | Unit | $CO_2$ biogenic | $CO_2$ fossil | $CH_4$ | $N_2O$ | $NO_x$ | CO | NMVOC | $SO_2$ |
|---|---|---|---|---|---|---|---|---|---|
| 6Ad Fire damage estates | t / kt burnt good | 400 | 1'500 | 3 | 0.25 | 2 | 100 | 16 | 1 |
| 6Ad Fire damage motor vehicles | t / kt burnt good | NO | 1'500 | 5 | NE | 1.3 | 2 | 2 | 5 |

**Activity data (6 Other)**

a) Fire damage estates

Activity data are estimated yearly based on annually published information by the fire insurance association of the cantons (Vereinigung kantonaler Feuerversicherungen, VKF). VKF publishes the number of fire incidents in buildings each year and the total sum of monetary damage.

Statistical insurance data from 1992 to 2001 show that the average damage sum per fire incident in buildings amounts to approximately CHF 15’600. This corresponds – based on the assumption of typical damage costs of CHF 20’000 per 1000 kg of burnt material – to 780 kg of flammable material per case. It is further assumed that on average 50% of the flammable material gets destroyed during an incident because of the intervention of the fire brigade, yet without actually being set on fire. Thus, an average amount of 400 kg of burnt material per fire case is estimated and held constant throughout the time series. With these assumptions, the amount of burnt material for each year can be estimated using the total sum of monetary damage published by VKF (EMIS 2022/6Ad Brand- und Feuerschäden Immobilien), divided by the average damage sum (CHF 20’000) and multiplied by the burnt material (400 kg) per fire incident. The resulting value of 8 kt is used for the year 1990. Additional statistical data published annually by the fire insurance association is available for the years 1996–2020. They are used to calculate the activity data on an annual basis starting from 1996. Between 1990 and 1996 activity data are interpolated linearly.

b) Fire damage motor vehicles

Activity data are estimated yearly based on vehicle numbers published annually by the Swiss Federal Statistical Office SFSO (EMIS 2022/6Ad Brand- und Feuerschäden Motorfahrzeuge).

Based on data from a Swiss insurance company with 25% market share in 2002, the number of reported cases of fire damage to vehicles was extrapolated to the total vehicle number in Switzerland. This results in one fire case per 790 vehicles for the year 2002. It is assumed that this ratio has remained constant during the reporting period. By applying this ratio to the actual vehicle number published annually by the SFSO, the total number of vehicles with fire damages in Switzerland can be calculated for each year.

During a car fire incident, a car burns down only partially. It is assumed that approximately 100 kg of material burns down during a car fire. With these assumptions, the total number of material burnt is calculated from the total number of car fire incidents in Switzerland.

Table 8-4 Activity data of burnt goods (documented in EMIS 2022/6Ad).

| 6A | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| 6Ad Fire damage estates | kt | 8.0 | 7.3 | 7.3 | 7.6 | 6.8 |
| 6Ad Fire damage motor vehicles | kt | 0.48 | 0.52 | 0.58 | 0.64 | 0.68 |

| 6A | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6Ad Fire damage estates | kt | 7.4 | 7.8 | 8.0 | 6.3 | 6.8 | 6.6 | 6.9 | 7.4 | 5.9 | 6.3 |
| 6Ad Fire damage motor vehicles | kt | 0.69 | 0.71 | 0.72 | 0.73 | 0.75 | 0.76 | 0.77 | 0.77 | 0.78 | 0.79 |

### 8.2.3. Uncertainties and time series consistency

Uncertainties of $CO_2$, $CH_4$ and $N_2O$ emissions are estimated to be high (according to Table 1-10).

Consistency: Time series for 6Ad Fire damages are all considered consistent.

### 8.2.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

### 8.2.5. Category-specific recalculations

The following recalculation was implemented in submission 2022:

- 6Ad Fire damage estates: Activity data for 2019 (amount of burnt material) decreased by 15.9% (1'122 t), due to a change in the underlying statistics by the fire insurance association of the cantons (Vereinigung kantonaler Feuerversicherungen, VKF).

### 8.2.6. Category-specific planned improvements

No category-specific improvements are planned.

# 9. Indirect $CO_2$ and $N_2O$ emissions

| Responsibilities for chapter Indirect $CO_2$ and $N_2O$ emissions | |
|---|---|
| Overall responsibility | Adrian Schilt (FOEN) |
| Authors & sector experts | Sabine Schenker (FOEN), Adrian Schilt (FOEN) |
| EMIS database operation | Anouk-Aimée Bass (FOEN) |
| Annual updates (NIR text, tables, figures) | Dominik Eggli (Meteotest), Felix Weber (INFRAS) |
| Quality control (NIR annual updates) | Dominik Eggli (Meteotest), Adrian Schilt (FOEN) |
| Internal review | Anouk-Aimée Bass (FOEN), Daniel Bretscher (Agroscope), Rainer Kegel (FOEN), Sabine Schenker (FOEN), Adrian Schilt (FOEN) |

## 9.1. Overview

In this chapter, indirect $CO_2$ emissions that result from the atmospheric oxidation of $CH_4$, CO and NMVOC as well as indirect $N_2O$ emissions that are induced by the deposition of $NO_x$ and $NH_3$ are documented. While indirect $CO_2$ emissions of fossil origin reported in this chapter are accounted for in the national total, indirect $N_2O$ emissions are not.

Indirect emissions of $CO_2$ and $N_2O$ are shown in CRF Table6, together with the emissions of the precursor gases $CH_4$, CO, NMVOC, $NO_x$ and $NH_3$. While all emissions of precursor gases are shown in both CRF Table6 and in the respective sectors, the indirect emissions of $CO_2$ and $N_2O$ shown in CRF Table6 only represent emissions not already included in direct emissions in other sectors (in order to avoid double counting). Further, in the case of indirect $CO_2$ emissions, only carbon of fossil origin is considered. Accordingly, while $CH_4$, CO and NMVOC of biogenic origin are shown as precursor gases in CRF Table6, they are not included for the calculation of indirect $CO_2$ emissions. Consequently, the implied emission factors may vary from sector to sector and also from year to year.

Chapter 9.2 explains in detail the methodological issues to derive indirect $CO_2$ and $N_2O$ emissions based on the emissions of the precursor gases $CH_4$, CO and NMVOC as well as $NO_x$ and $NH_3$ from the different sectors. As an overview, the resulting indirect $CO_2$ emissions are shown in Table 9-1, as well as in Figure 9-1 and Figure 9-2. The resulting indirect $N_2O$ emissions are shown in Table 9-2, as well as in Figure 9-3 and Figure 9-4.

To provide further details with regard to the $CH_4$, CO and NMVOC emissions relevant for the indirect $CO_2$ emissions as shown in CRF Table6, the emissions of these precursor gases are shown for each sector, disaggregated by source category, in Table 9-3 (for sector 1 Energy), in Table 9-4 (for sector 2 Industrial processes and product use), in Table 9-5 (for sector 5 Waste) and in Table 9-6 (for sector 6 Other). In these tables, the percentages provided in brackets reflect the share of emissions of precursor gases that are relevant for indirect $CO_2$ emissions, i.e. the share of fossil emissions of precursor gases not already considered under the direct $CO_2$ emissions. This information – together with the factors for the stoichiometric conversion of $CH_4$, CO and NMVOC to indirect $CO_2$ as provided in chp. 9.2.1 – allows for an interpretation of the implied emission factors.

Indirect $CO_2$ emissions are considered for both the uncertainty analysis (see chp. 1.6) and the key category analysis (see chp. 1.5).

Indirect $N_2O$ emissions are neither considered for the uncertainty analysis (see chp. 1.6), nor for the key category analysis (see chp. 1.5).

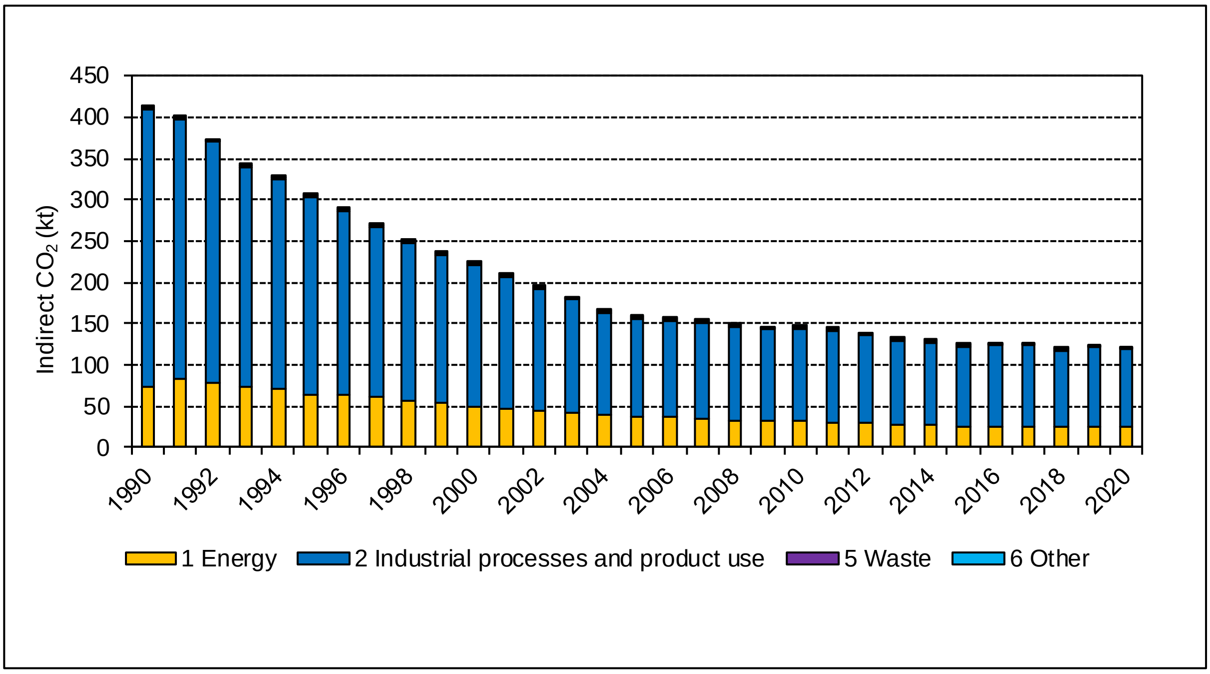



Figure 9-1 Switzerland's indirect fossil $CO_2$ emissions.

Table 9-1 Indirect fossil $CO_2$ emissions.

| Indirect fossil $CO_2$ emissions by source category | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | kt $CO_2$ | | | | |
| **1 Energy** | **74** | **65** | **50** | **38** | **32** |
| 1B Fugitive emissions from fuels | 74 | 65 | 50 | 38 | 32 |
| **2 Industrial processes and product use** | **336** | **238** | **171** | **119** | **113** |
| 2A Mineral industry | 0.15 | 0.12 | 0.11 | 0.11 | 0.12 |
| 2B Chemical industry | 8.0 | 6.8 | 8.4 | 7.3 | 8.1 |
| 2C Metal industry | 3.4 | 2.4 | 2.2 | 1.3 | 0.93 |
| 2D Non-energy products from fuels and solvent use | 193 | 126 | 91 | 50 | 48 |
| 2G Other product manufacture and use | 129 | 101 | 67 | 60 | 54 |
| 2H Other | 2.8 | 2.0 | 1.9 | 1.3 | 2.3 |
| **5 Waste** | **2.2** | **1.9** | **1.8** | **1.6** | **1.5** |
| 5C Waste incineration and open burning of waste | 2.2 | 1.7 | 1.7 | 1.4 | 1.3 |
| 5E Other | 0.064 | 0.10 | 0.13 | 0.13 | 0.13 |
| **6 Other** | **1.1** | **1.1** | **1.2** | **1.2** | **1.1** |
| 6Ad Fire damages | 1.1 | 1.1 | 1.2 | 1.2 | 1.1 |
| **Total** | **414** | **306** | **224** | **160** | **147** |

| Indirect fossil $CO_2$ emissions by source category | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| | kt $CO_2$ | | | | | | | | | |
| **1 Energy** | **31** | **29** | **28** | **27** | **26** | **25** | **25** | **25** | **24** | **24** |
| 1B Fugitive emissions from fuels | 31 | 29 | 28 | 27 | 26 | 25 | 25 | 25 | 24 | 24 |
| **2 Industrial processes and product use** | **111** | **107** | **102** | **100** | **96** | **99** | **99** | **92** | **97** | **94** |
| 2A Mineral industry | 0.12 | 0.11 | 0.10 | 0.10 | 0.09 | 0.09 | 0.094 | 0.094 | 0.094 | 0.089 |
| 2B Chemical industry | 8.0 | 7.7 | 6.1 | 6.6 | 7.1 | 14 | 14 | 8.1 | 13 | 11 |
| 2C Metal industry | 1.1 | 0.81 | 0.80 | 0.78 | 0.67 | 0.63 | 0.65 | 0.64 | 0.46 | 0.41 |
| 2D Non-energy products from fuels and solvent use | 46 | 44 | 43 | 41 | 38 | 36 | 36 | 35 | 35 | 34 |
| 2G Other product manufacture and use | 53 | 52 | 50 | 49 | 48 | 47 | 47 | 47 | 47 | 47 |
| 2H Other | 2.5 | 2.1 | 2.0 | 2.0 | 1.9 | 1.0 | 1.0 | 1.1 | 0.94 | 0.9 |
| **5 Waste** | **1.41** | **1.4** | **1.4** | **1.3** | **1.3** | **1.3** | **1.3** | **1.2** | **1.2** | **1.2** |
| 5C Waste incineration and open burning of waste | 1.3 | 1.3 | 1.2 | 1.2 | 1.2 | 1.2 | 1.1 | 1.1 | 1.1 | 1.1 |
| 5E Other | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 |
| **6 Other** | **1.2** | **1.2** | **1.3** | **1.0** | **1.1** | **1.1** | **1.1** | **1.2** | **1.0** | **1.0** |
| 6Ad Fire damages | 1.2 | 1.2 | 1.3 | 1.0 | 1.1 | 1.1 | 1.1 | 1.2 | 1.0 | 1.0 |
| **Total** | **144** | **139** | **133** | **129** | **125** | **126** | **126** | **120** | **123** | **121** |

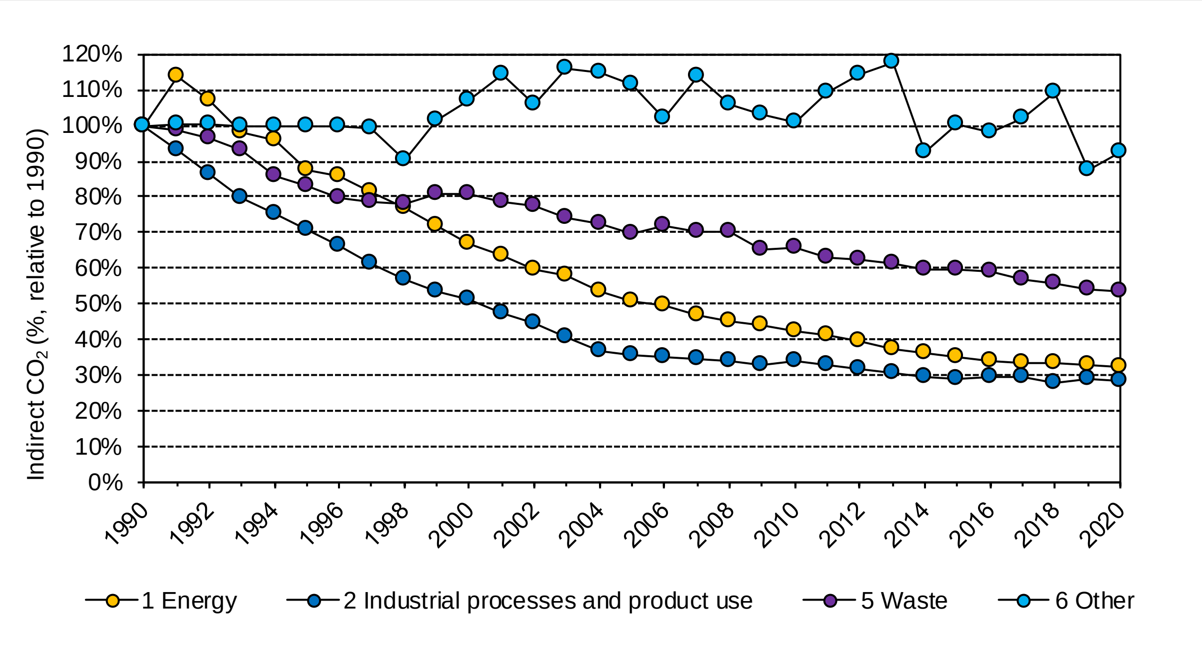



Figure 9-2 Relative trends of the indirect fossil $CO_2$ emissions by sector. The base year 1990 represents 100%.

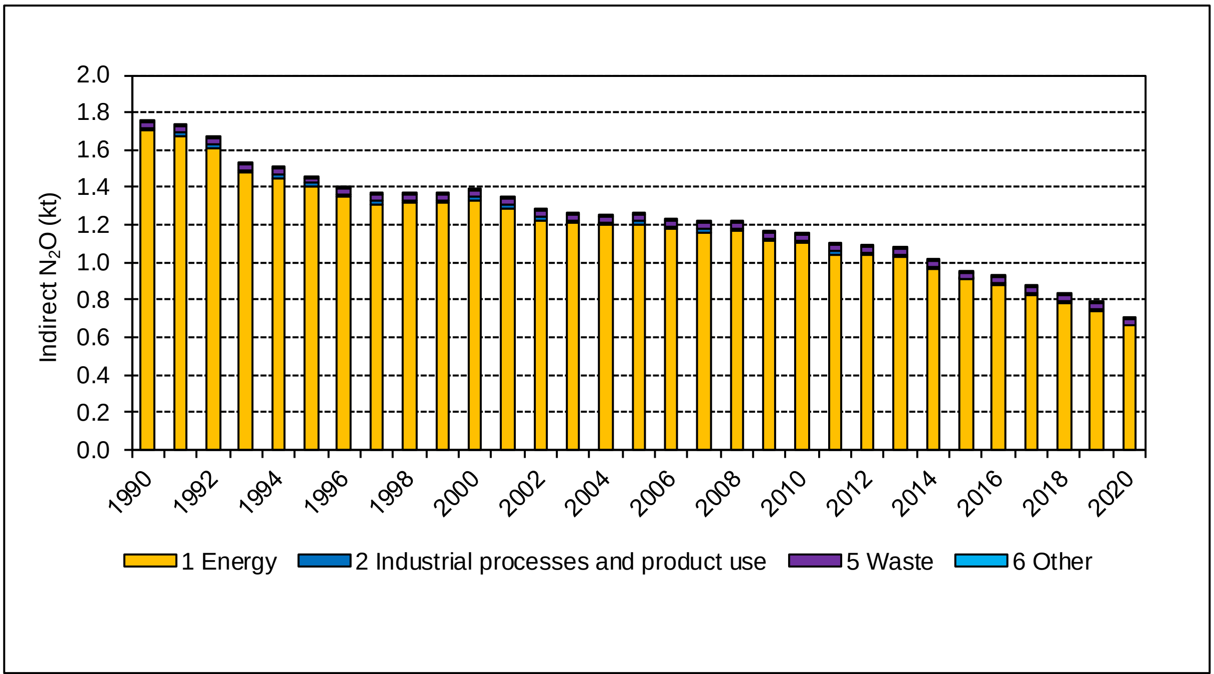



Figure 9-3 Switzerland's indirect $N_2O$ emissions.

Table 9-2 Indirect $N_2O$ emissions.

| Indirect $N_2O$ emissions by source category | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | kt $N_2O$ | | | | |
| **1 Energy** | **1.7** | **1.4** | **1.3** | **1.2** | **1.1** |
| 1A Fuel combustion activities | 1.7 | 1.4 | 1.3 | 1.2 | 1.1 |
| 1B Fugitive emissions from fuels | 0.0025 | 0.0038 | 0.0038 | 0.0035 | 0.0014 |
| **2 Industrial processes and product use** | **0.018** | **0.014** | **0.017** | **0.015** | **0.012** |
| 2A Mineral industry | 0.00021 | 0.00017 | 0.00015 | 0.00016 | 0.00018 |
| 2B Chemical industry | 0.0014 | 0.0012 | 0.0012 | 0.0011 | 0.0012 |
| 2C Metal industry | 0.0038 | 0.0023 | 0.0024 | 0.0025 | 0.0026 |
| 2G Other product manufacture and use | 0.0069 | 0.0068 | 0.0080 | 0.0081 | 0.0035 |
| 2H Other | 0.0054 | 0.0037 | 0.0051 | 0.0034 | 0.0043 |
| **5 Waste** | **0.033** | **0.030** | **0.031** | **0.032** | **0.032** |
| 5A Solid waste disposal | 0.020 | 0.015 | 0.014 | 0.014 | 0.012 |
| 5B Biological treatement of solid waste | 0.0059 | 0.0086 | 0.012 | 0.012 | 0.014 |
| 5C Waste incineration and open burning of waste | 0.0040 | 0.0030 | 0.0026 | 0.0027 | 0.0027 |
| 5D Wastewater handling and discharge | 0.0032 | 0.0034 | 0.0035 | 0.0036 | 0.0040 |
| **6 Other** | **0.00020** | **0.00018** | **0.00018** | **0.00019** | **0.00018** |
| 6Ad Fire damages | 0.00020 | 0.00018 | 0.00018 | 0.00019 | 0.00018 |
| **Total** | **1.8** | **1.5** | **1.4** | **1.3** | **1.2** |

| Indirect $N_2O$ emissions by source category | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| | kt $N_2O$ | | | | | | | | | |
| **1 Energy** | **1.0** | **1.0** | **1.0** | **1.0** | **0.91** | **0.88** | **0.83** | **0.79** | **0.74** | **0.66** |
| 1A Fuel combustion activities | 1.0 | 1.0 | 1.0 | 1.0 | 0.91 | 0.88 | 0.83 | 0.79 | 0.74 | 0.66 |
| 1B Fugitive emissions from fuels | 0.0012 | 0.0008 | 0.00094 | 0.0011 | 0.00065 | 0.000038 | 0.000029 | 0.000031 | 0.000021 | 0.000022 |
| **2 Industrial processes and product use** | **0.013** | **0.012** | **0.010** | **0.011** | **0.010** | **0.0091** | **0.010** | **0.0091** | **0.0087** | **0.0080** |
| 2A Mineral industry | 0.00017 | 0.00016 | 0.00016 | 0.00016 | 0.00015 | 0.00015 | 0.00015 | 0.00015 | 0.00015 | 0.00014 |
| 2B Chemical industry | 0.0011 | 0.0011 | 0.00082 | 0.00094 | 0.00070 | 0.00094 | 0.0010 | 0.00045 | 0.00025 | 0.00022 |
| 2C Metal industry | 0.0028 | 0.0026 | 0.0026 | 0.0027 | 0.0027 | 0.0026 | 0.0026 | 0.0027 | 0.0024 | 0.0023 |
| 2G Other product manufacture and use | 0.0031 | 0.0033 | 0.0027 | 0.0025 | 0.0023 | 0.0024 | 0.0026 | 0.0029 | 0.0029 | 0.0028 |
| 2H Other | 0.0056 | 0.0047 | 0.0040 | 0.0051 | 0.0040 | 0.0030 | 0.0035 | 0.0029 | 0.0030 | 0.0025 |
| **5 Waste** | **0.032** | **0.032** | **0.032** | **0.032** | **0.031** | **0.032** | **0.031** | **0.031** | **0.032** | **0.032** |
| 5A Solid waste disposal | 0.011 | 0.011 | 0.011 | 0.010 | 0.010 | 0.009 | 0.0088 | 0.0083 | 0.0078 | 0.0075 |
| 5B Biological treatement of solid waste | 0.014 | 0.014 | 0.015 | 0.014 | 0.014 | 0.016 | 0.016 | 0.016 | 0.018 | 0.018 |
| 5C Waste incineration and open burning of waste | 0.0026 | 0.0025 | 0.0028 | 0.0028 | 0.0029 | 0.0026 | 0.0022 | 0.0018 | 0.0018 | 0.0018 |
| 5D Wastewater handling and discharge | 0.0040 | 0.0041 | 0.0041 | 0.0042 | 0.0042 | 0.0043 | 0.0043 | 0.0043 | 0.0044 | 0.00439 |
| **6 Other** | **0.00020** | **0.00021** | **0.00021** | **0.00017** | **0.00018** | **0.00018** | **0.00019** | **0.00020** | **0.00016** | **0.00017** |
| 6Ad Fire damages | 0.00020 | 0.00021 | 0.00021 | 0.00017 | 0.00018 | 0.00018 | 0.00019 | 0.00020 | 0.00016 | 0.00017 |
| **Total** | **1.1** | **1.1** | **1.1** | **1.0** | **0.95** | **0.92** | **0.87** | **0.83** | **0.79** | **0.70** |

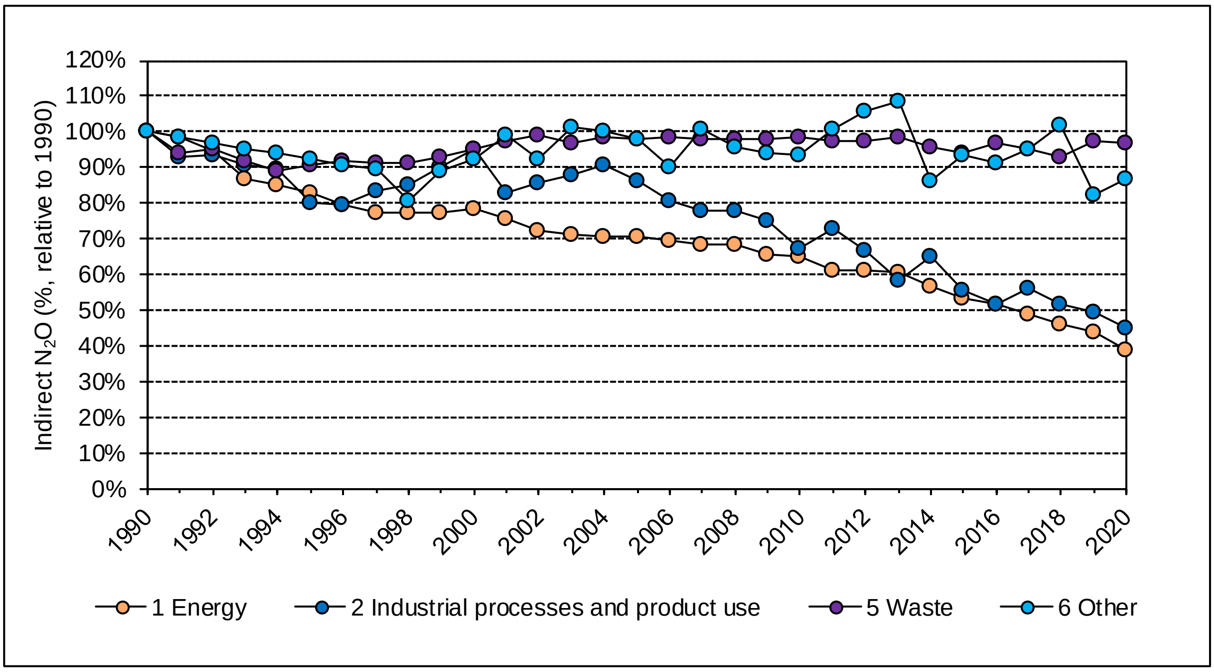



Figure 9-4 Relative trends of the indirect $N_2O$ emissions by sector. The base year 1990 represents 100%.

Table 9-3 Switzerland's emissions of the precursor gases $CH_4$, CO and NMVOC in the source categories of sector 1 Energy, together with the respective indirect $CO_2$ emissions. The numbers in brackets indicate the fractions of precursor gases that are relevant for indirect $CO_2$, i.e. the share of fossil emissions of precursor gases not already considered under the direct $CO_2$ emissions. To derive the indirect $CO_2$ emissions, the emissions of precursor gases need to be multiplied by the provided fractions as well as by the factors for the stoichiometric conversion of $CH_4$, CO and NMVOC to indirect $CO_2$ as given in the text (chp. 9.2.1). As an illustrative example, an emission of NMVOC indicated as "150 (40.0%)" leads to indirect $CO_2$ emissions of 132 kt (150 kt * 40.0% * 0.6 * 44/12 = 132 kt).

| **Emissions of NMVOC, CO and $CH_4$ as well as indirect $CO_2$** | **1990** | **1995** | **2000** | **2005** | **2010** |
|---|---|---|---|---|---|
| | kt | | | | |
| **1 Energy: NMVOC** | **134 (12.7%)** | **82.1 (12.2%)** | **62.1 (10.7%)** | **42.3 (10.6%)** | **29.7 (9.2%)** |
| 1A Fuel combustion | 117 (0.0%) | 72.0 (0.0%) | 55.5 (0.0%) | 37.7 (0.0%) | 27.0 (0.0%) |
| 1B Fugitive emissions from fuels | 17.1 (99.9%) | 10.1 (99.8%) | 6.7 (99.7%) | 4.5 (99.6%) | 2.7 (99.7%) |
| **1 Energy: CO** | **802 (0.0%)** | **521 (0.0%)** | **406 (0.0%)** | **309 (0.0%)** | **245 (0.0%)** |
| 1A Fuel combustion | 802 (0.0%) | 521 (0.0%) | 406 (0.0%) | 309 (0.0%) | 245 (0.0%) |
| 1B Fugitive emissions from fuels | 0.1 (0.0%) | 0.1 (0.0%) | 0.1 (0.0%) | 0.1 (0.0%) | 0.0 (0.0%) |
| **1 Energy: $CH_4$** | **24.7 (54.3%)** | **24.5 (63.7%)** | **20.0 (63.7%)** | **16.5 (61.4%)** | **14.6 (63.7%)** |
| 1A Fuel combustion | 11.3 (0.0%) | 8.9 (0.0%) | 7.3 (0.0%) | 6.4 (0.0%) | 5.3 (0.0%) |
| 1B Fugitive emissions from fuels | 13.4 (99.9%) | 15.6 (99.9%) | 12.8 (99.8%) | 10.2 (99.8%) | 9.3 (99.9%) |
| **1 Energy: Indirect $CO_2$** | **74.5** | **65.0** | **49.6** | **37.8** | **31.6** |
| 1A Fuel combustion | NO | NO | NO | NO | NO |
| 1B Fugitive emissions from fuels | 74.5 | 65.0 | 49.6 | 37.8 | 31.6 |
| *from NMVOC* | *37.6* | *22.1* | *14.6* | *9.9* | *6.0* |
| *from CO* | *NO* | *NO* | *NO* | *NO* | *NO* |
| *from $CH_4$* | *36.9* | *42.9* | *35.0* | *27.9* | *25.6* |

| **Emissions of NMVOC, CO and $CH_4$ as well as indirect $CO_2$** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
|---|---|---|---|---|---|---|---|---|---|---|
| | kt | | | | | | | | | |
| **1 Energy: NMVOC** | **27.0 (10.1%)** | **25.7 (10.8%)** | **24.4 (11.3%)** | **21.9 (12.2%)** | **20.3 (11.5%)** | **19.4 (10.3%)** | **18.4 (10.2%)** | **17.7 (10.9%)** | **17.0 (10.6%)** | **15.3 (11.0%)** |
| 1A Fuel combustion | 24.2 (0.0%) | 22.9 (0.0%) | 21.6 (0.0%) | 19.2 (0.0%) | 17.9 (0.0%) | 17.4 (0.0%) | 16.5 (0.0%) | 15.7 (0.0%) | 15.2 (0.0%) | 13.7 (0.0%) |
| 1B Fugitive emissions from fuels | 2.7 (99.8%) | 2.8 (99.9%) | 2.8 (99.8%) | 2.7 (99.8%) | 2.3 (99.9%) | 2.0 (100.0%) | 1.9 (100.0%) | 1.9 (100.0%) | 1.8 (100.0%) | 1.7 (100.0%) |
| **1 Energy: CO** | **221 (0.0%)** | **214 (0.0%)** | **207 (0.0%)** | **185 (0.0%)** | **176 (0.0%)** | **173 (0.0%)** | **166 (0.0%)** | **160 (0.0%)** | **157 (0.0%)** | **142 (0.0%)** |
| 1A Fuel combustion | 221 (0.0%) | 214 (0.0%) | 207 (0.0%) | 185 (0.0%) | 176 (0.0%) | 173 (0.0%) | 166 (0.0%) | 160 (0.0%) | 157 (0.0%) | 142 (0.0%) |
| 1B Fugitive emissions from fuels | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) |
| **1 Energy: $CH_4$** | **13.4 (67.3%)** | **12.9 (65.4%)** | **12.4 (63.5%)** | **11.3 (67.6%)** | **11.3 (67.1%)** | **11.4 (66.7%)** | **11.1 (67.4%)** | **10.9 (68.9%)** | **10.8 (68.9%)** | **10.5 (70.8%)** |
| 1A Fuel combustion | 4.4 (0.0%) | 4.5 (0.0%) | 4.5 (0.0%) | 3.7 (0.0%) | 3.7 (0.0%) | 3.8 (0.0%) | 3.6 (0.0%) | 3.4 (0.0%) | 3.3 (0.0%) | 3.1 (0.0%) |
| 1B Fugitive emissions from fuels | 9.0 (99.9%) | 8.5 (100.0%) | 7.9 (99.9%) | 7.7 (99.9%) | 7.6 (100.0%) | 7.6 (100.0%) | 7.5 (100.0%) | 7.5 (100.0%) | 7.4 (100.0%) | 7.4 (100.0%) |
| **1 Energy: Indirect $CO_2$** | **30.8** | **29.4** | **27.7** | **27.0** | **26.0** | **25.3** | **24.8** | **25.0** | **24.3** | **24.1** |
| 1A Fuel combustion | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1B Fugitive emissions from fuels | 30.8 | 29.4 | 27.7 | 27.0 | 26.0 | 25.3 | 24.8 | 25.0 | 24.3 | 24.1 |
| *from NMVOC* | *6.0* | *6.1* | *6.1* | *5.9* | *5.1* | *4.4* | *4.1* | *4.3* | *3.9* | *3.7* |
| *from CO* | *NO* | *NO* | *NO* | *NO* | *NO* | *NO* | *NO* | *NO* | *NO* | *NO* |
| *from $CH_4$* | *24.9* | *23.3* | *21.6* | *21.1* | *20.9* | *20.9* | *20.7* | *20.7* | *20.4* | *20.4* |

Table 9-4 Switzerland's emissions of the precursor gases $CH_4$, CO and NMVOC in the source categories of sector 2 Industrial processes and product use, together with the respective indirect $CO_2$ emissions. The numbers in brackets indicate the fractions of precursor gases that are relevant for indirect $CO_2$, i.e. the share of fossil emissions of precursor gases not already considered under the direct $CO_2$ emissions. To derive the indirect $CO_2$ emissions, the emissions of precursor gases need to be multiplied by the provided fractions as well as by the factors for the stoichiometric conversion of $CH_4$, CO and NMVOC to indirect $CO_2$ as given in the text (chp. 9.2.1). As an illustrative example, an emission of NMVOC indicated as "150 (40.0%)" leads to indirect $CO_2$ emissions of 132 kt (150 kt * 40.0% * 0.6 * 44/12 = 132 kt).

| Emissions of NMVOC, CO and $CH_4$ as well as indirect $CO_2$ | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | kt | | | | |
| **2 IPPU: NMVOC** | **151 (98.6%)** | **107 (98.0%)** | **75.4 (97.2%)** | **52.6 (95.9%)** | **49.3 (95.5%)** |
| 2A Mineral industry | 0.0 (100.0%) | 0.0 (146.1%) | 0.0 (148.0%) | 0.0 (148.8%) | 0.0 (147.9%) |
| 2B Chemical industry | 0.6 (96.5%) | 0.2 (90.7%) | 0.0 (30.9%) | 0.0 (21.4%) | 0.0 (32.9%) |
| 2C Metal industry | 1.1 (92.0%) | 0.8 (92.7%) | 0.7 (89.9%) | 0.5 (82.1%) | 0.3 (75.6%) |
| 2D Non-energy products from fuels and solvent use | 87.6 (100.0%) | 57.3 (100.0%) | 41.6 (100.0%) | 22.5 (100.0%) | 21.8 (100.0%) |
| 2G Other product manufacture and use | 58.7 (99.9%) | 45.9 (99.8%) | 30.6 (99.8%) | 27.2 (99.8%) | 24.6 (99.8%) |
| 2H Other | 2.7 (26.7%) | 2.6 (24.2%) | 2.4 (18.9%) | 2.4 (17.3%) | 2.5 (19.7%) |
| **2 IPPU: CO** | **11.1 (50.2%)** | **7.1 (66.2%)** | **9.1 (66.9%)** | **8.1 (58.8%)** | **7.2 (78.4%)** |
| 2A Mineral industry | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) |
| 2B Chemical industry | 4.0 (100.0%) | 3.7 (100.0%) | 4.9 (100.0%) | 4.2 (100.0%) | 4.6 (100.0%) |
| 2C Metal industry | 5.3 (13.3%) | 2.0 (26.7%) | 2.6 (19.0%) | 2.9 (9.8%) | 1.1 (20.7%) |
| 2D Non-energy products from fuels and solvent use | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) |
| 2G Other product manufacture and use | 0.9 (0.7%) | 0.9 (0.9%) | 0.9 (1.3%) | 0.7 (1.4%) | 0.7 (1.8%) |
| 2H Other | 0.9 (94.6%) | 0.4 (91.4%) | 0.6 (96.8%) | 0.3 (94.1%) | 0.8 (97.8%) |
| **2 IPPU: $CH_4$** | **0.1 (100.0%)** | **0.2 (100.0%)** | **0.2 (100.0%)** | **0.3 (100.0%)** | **0.3 (100.0%)** |
| 2B Chemical industry | 0.1 (100.0%) | 0.2 (100.0%) | 0.2 (100.0%) | 0.3 (100.0%) | 0.3 (100.0%) |
| **2 IPPU: Indirect $CO_2$** | **336** | **238** | **171** | **119** | **113** |
| 2A Mineral industry | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| *from NMVOC* | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| *from CO* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2B Chemical industry | 8.0 | 6.8 | 8.4 | 7.3 | 8.1 |
| *from NMVOC* | 1.3 | 0.4 | 0.0 | 0.0 | 0.0 |
| *from CO* | 6.3 | 5.8 | 7.8 | 6.6 | 7.3 |
| *from $CH_4$* | 0.4 | 0.6 | 0.6 | 0.7 | 0.8 |
| 2C Metal industry | 3.4 | 2.4 | 2.2 | 1.3 | 0.9 |
| *from NMVOC* | 2.3 | 1.6 | 1.4 | 0.8 | 0.6 |
| *from CO* | 1.1 | 0.9 | 0.8 | 0.4 | 0.3 |
| 2D Non-energy products from fuels and solvent use | 193 | 126 | 91.4 | 49.5 | 47.9 |
| *from NMVOC* | 193 | 126 | 91.4 | 49.5 | 47.9 |
| *from CO* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2G Other product manufacture and use | 129 | 101 | 67.2 | 59.7 | 54.0 |
| *from NMVOC* | 129 | 101 | 67.2 | 59.7 | 54.0 |
| *from CO* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2H Other | 2.8 | 2.0 | 1.9 | 1.3 | 2.3 |
| *from NMVOC* | 1.6 | 1.4 | 1.0 | 0.9 | 1.1 |
| *from CO* | 1.3 | 0.6 | 0.9 | 0.4 | 1.2 |

| Emissions of NMVOC, CO and $CH_4$ as well as indirect $CO_2$ | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| | kt | | | | | | | | | |
| **2 IPPU: NMVOC** | **48.1 (95.4%)** | **46.5 (95.3%)** | **45.2 (95.2%)** | **43.9 (95.0%)** | **42.2 (94.9%)** | **40.5 (94.8%)** | **40.5 (94.8%)** | **40.2 (94.7%)** | **40.0 (94.7%)** | **39.7 (94.6%)** |
| 2A Mineral industry | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) |
| 2B Chemical industry | 0.0 (16.0%) | 0.0 (10.8%) | 0.0 (11.1%) | 0.0 (22.6%) | 0.0 (12.4%) | 0.0 (5.6%) | 0.0 (8.7%) | 0.0 (10.0%) | 0.0 (13.2%) | 0.0 (15.3%) |
| 2C Metal industry | 0.4 (76.3%) | 0.3 (72.6%) | 0.3 (72.6%) | 0.3 (70.8%) | 0.3 (68.3%) | 0.3 (67.8%) | 0.3 (68.0%) | 0.3 (67.3%) | 0.2 (63.7%) | 0.2 (61.1%) |
| 2D Non-energy products from fuels and solvent use | 21.0 (100.0%) | 20.1 (100.0%) | 19.4 (100.0%) | 18.6 (100.0%) | 17.4 (100.0%) | 16.3 (100.0%) | 16.4 (100.0%) | 16.0 (100.0%) | 16.0 (100.0%) | 15.6 (100.0%) |
| 2G Other product manufacture and use | 24.1 (99.8%) | 23.5 (99.7%) | 23.0 (99.7%) | 22.5 (99.8%) | 22.0 (99.8%) | 21.6 (99.8%) | 21.5 (99.8%) | 21.5 (99.8%) | 21.5 (99.8%) | 21.5 (99.8%) |
| 2H Other | 2.5 (19.8%) | 2.5 (18.1%) | 2.4 (17.5%) | 2.4 (17.2%) | 2.4 (17.2%) | 2.3 (13.7%) | 2.3 (13.9%) | 2.3 (13.7%) | 2.3 (12.2%) | 2.2 (11.5%) |
| **2 IPPU: CO** | **7.4 (78.5%)** | **7.0 (77.1%)** | **6.0 (74.1%)** | **6.2 (75.4%)** | **6.5 (76.9%)** | **10.1 (85.5%)** | **10.1 (85.1%)** | **6.5 (77.2%)** | **9.5 (85.7%)** | **8.4 (83.5%)** |
| 2A Mineral industry | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) |
| 2B Chemical industry | 4.6 (100.0%) | 4.4 (100.0%) | 3.5 (100.0%) | 3.8 (100.0%) | 4.1 (100.0%) | 8.3 (100.0%) | 8.2 (100.0%) | 4.6 (100.0%) | 7.8 (100.0%) | 6.7 (100.0%) |
| 2C Metal industry | 1.2 (21.5%) | 1.1 (17.8%) | 1.1 (18.0%) | 1.1 (16.5%) | 1.1 (14.6%) | 1.0 (14.3%) | 1.0 (14.3%) | 1.0 (13.8%) | 0.9 (11.4%) | 0.9 (9.9%) |
| 2D Non-energy products from fuels and solvent use | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) |
| 2G Other product manufacture and use | 0.7 (2.2%) | 0.7 (2.0%) | 0.7 (2.5%) | 0.6 (2.2%) | 0.6 (2.1%) | 0.6 (1.5%) | 0.6 (2.1%) | 0.6 (2.3%) | 0.6 (1.3%) | 0.6 (1.3%) |
| 2H Other | 0.9 (98.2%) | 0.7 (97.7%) | 0.7 (97.7%) | 0.7 (97.5%) | 0.7 (97.5%) | 0.2 (92.5%) | 0.2 (93.1%) | 0.3 (93.8%) | 0.2 (92.6%) | 0.2 (92.2%) |
| **2 IPPU: $CH_4$** | **0.3 (100.0%)** | **0.3 (100.0%)** | **0.2 (100.0%)** | **0.2 (100.0%)** | **0.2 (100.0%)** | **0.3 (100.0%)** | **0.3 (100.0%)** | **0.3 (100.0%)** | **0.3 (100.0%)** | **0.3 (100.0%)** |
| 2B Chemical industry | 0.3 (100.0%) | 0.3 (100.0%) | 0.2 (100.0%) | 0.2 (100.0%) | 0.2 (100.0%) | 0.3 (100.0%) | 0.3 (100.0%) | 0.3 (100.0%) | 0.3 (100.0%) | 0.3 (100.0%) |
| **2 IPPU: Indirect $CO_2$** | **111** | **107** | **102** | **99.7** | **96.5** | **98.8** | **98.7** | **92.4** | **96.9** | **94.3** |
| 2A Mineral industry | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| *from NMVOC* | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| *from CO* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2B Chemical industry | 8.0 | 7.7 | 6.1 | 6.6 | 7.1 | 13.8 | 13.6 | 8.1 | 13.0 | 11.2 |
| *from NMVOC* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *from CO* | 7.3 | 7.0 | 5.5 | 6.0 | 6.5 | 13.0 | 12.8 | 7.2 | 12.3 | 10.5 |
| *from $CH_4$* | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.8 | 0.8 | 0.8 | 0.8 | 0.7 |
| 2C Metal industry | 1.1 | 0.8 | 0.8 | 0.8 | 0.7 | 0.6 | 0.6 | 0.6 | 0.5 | 0.4 |
| *from NMVOC* | 0.7 | 0.5 | 0.5 | 0.5 | 0.4 | 0.4 | 0.4 | 0.4 | 0.3 | 0.3 |
| *from CO* | 0.4 | 0.3 | 0.3 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 |
| 2D Non-energy products from fuels and solvent use | 46.2 | 44.2 | 42.8 | 41.0 | 38.3 | 35.9 | 36.0 | 35.3 | 35.1 | 34.4 |
| *from NMVOC* | 46.2 | 44.2 | 42.8 | 41.0 | 38.3 | 35.9 | 36.0 | 35.3 | 35.1 | 34.4 |
| *from CO* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2G Other product manufacture and use | 52.8 | 51.7 | 50.4 | 49.3 | 48.4 | 47.4 | 47.3 | 47.2 | 47.2 | 47.3 |
| *from NMVOC* | 52.8 | 51.7 | 50.4 | 49.3 | 48.3 | 47.4 | 47.3 | 47.2 | 47.2 | 47.3 |
| *from CO* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2H Other | 2.5 | 2.1 | 2.0 | 2.0 | 1.9 | 1.0 | 1.0 | 1.1 | 0.9 | 0.9 |
| *from NMVOC* | 1.1 | 1.0 | 0.9 | 0.9 | 0.9 | 0.7 | 0.7 | 0.7 | 0.6 | 0.6 |
| *from CO* | 1.4 | 1.1 | 1.1 | 1.0 | 1.0 | 0.3 | 0.4 | 0.4 | 0.3 | 0.3 |

Table 9-5 Switzerland's emissions of the precursor gases $CH_4$, CO and NMVOC in the source categories of sector 5 Waste, together with the respective indirect $CO_2$ emissions. The numbers in brackets indicate the fractions of precursor gases that are relevant for indirect $CO_2$, i.e. the share of fossil emissions of precursor gases not already considered under the direct $CO_2$ emissions. To derive the indirect $CO_2$ emissions, the emissions of precursor gases need to be multiplied by the provided fractions as well as by the factors for the stoichiometric conversion of $CH_4$, CO and NMVOC to indirect $CO_2$ as given in the text (chp. 9.2.1). As an illustrative example, an emission of NMVOC indicated as "150 (40.0%)" leads to indirect $CO_2$ emissions of 132 kt (150 kt * 40.0% * 0.6 * 44/12 = 132 kt).

| Emissions of NMVOC, CO and $CH_4$ as well as indirect $CO_2$ | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | kt | | | | |
| **5 Waste: NMVOC** | **1.1 (25.6%)** | **1.0 (25.8%)** | **1.0 (25.3%)** | **1.0 (22.7%)** | **1.2 (18.8%)** |
| 5A Solid waste disposal | 0.4 (0.0%) | 0.3 (0.0%) | 0.3 (0.0%) | 0.3 (0.0%) | 0.2 (0.0%) |
| 5B Biological treatment of solid waste | 0.2 (0.0%) | 0.2 (0.0%) | 0.3 (0.0%) | 0.3 (0.0%) | 0.5 (0.0%) |
| 5C Incineration and open burning of waste | 0.6 (47.4%) | 0.5 (47.3%) | 0.4 (48.1%) | 0.4 (47.0%) | 0.4 (45.2%) |
| 5D Waste water treatment and discharge | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) |
| 5E Other | 0.0 (100.0%) | 0.0 (100.0%) | 0.1 (100.0%) | 0.1 (100.0%) | 0.1 (100.0%) |
| **5 Waste: CO** | **2.8 (29.8%)** | **2.4 (27.7%)** | **2.2 (28.7%)** | **1.9 (28.6%)** | **1.7 (29.3%)** |
| 5A Solid waste disposal | 0.0 (0.0%) | 0.1 (0.0%) | 0.1 (0.0%) | 0.1 (0.0%) | 0.0 (0.0%) |
| 5B Biological treatment of solid waste | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) |
| 5C Incineration and open burning of waste | 2.8 (30.2%) | 2.3 (28.9%) | 2.1 (30.0%) | 1.9 (29.5%) | 1.7 (30.0%) |
| 5D Waste water treatment and discharge | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) |
| 5E Other | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) |
| **5 Waste: $CH_4$** | **36.8 (0.3%)** | **29.7 (0.3%)** | **28.0 (0.3%)** | **28.4 (0.2%)** | **25.2 (0.2%)** |
| 5A Solid waste disposal | 30.8 (0.0%) | 23.1 (0.0%) | 21.0 (0.0%) | 21.2 (0.0%) | 17.6 (0.0%) |
| 5B Biological treatment of solid waste | 0.5 (0.0%) | 0.6 (0.0%) | 0.8 (0.0%) | 0.8 (0.0%) | 0.8 (0.0%) |
| 5C Incineration and open burning of waste | 0.4 (27.1%) | 0.3 (26.4%) | 0.3 (27.8%) | 0.2 (27.1%) | 0.2 (27.7%) |
| 5D Waste water treatment and discharge | 5.2 (0.0%) | 5.6 (0.0%) | 5.9 (0.0%) | 6.2 (0.0%) | 6.6 (0.0%) |
| **5 Waste: Indirect $CO_2$** | **2.2** | **1.9** | **1.8** | **1.6** | **1.5** |
| 5A Solid waste disposal | NO | NO | NO | NO | NO |
| 5B Biological treatment of solid waste | NO | NO | NO | NO | NO |
| 5C Incineration and open burning of waste | 2.2 | 1.7 | 1.7 | 1.4 | 1.3 |
| *from NMVOC* | *0.6* | *0.5* | *0.5* | *0.4* | *0.4* |
| *from CO* | *1.3* | *1.1* | *1.0* | *0.9* | *0.8* |
| *from $CH_4$* | *0.3* | *0.2* | *0.2* | *0.2* | *0.2* |
| 5D Waste water treatment and discharge | NO | NO | NO | NO | NO |
| 5E Other | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| *from NMVOC* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* |
| *from CO* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* |

| Emissions of NMVOC, CO and $CH_4$ as well as indirect $CO_2$ | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| | kt | | | | | | | | | |
| **5 Waste: NMVOC** | **1.2 (17.8%)** | **1.3 (16.6%)** | **1.3 (15.7%)** | **1.4 (15.1%)** | **1.4 (14.7%)** | **1.5 (13.6%)** | **1.5 (13.1%)** | **1.6 (12.5%)** | **1.7 (11.5%)** | **1.7 (11.0%)** |
| 5A Solid waste disposal | 0.2 (0.0%) | 0.2 (0.0%) | 0.2 (0.0%) | 0.2 (0.0%) | 0.2 (0.0%) | 0.2 (0.0%) | 0.2 (0.0%) | 0.2 (0.0%) | 0.2 (0.0%) | 0.1 (0.0%) |
| 5B Biological treatment of solid waste | 0.6 (0.0%) | 0.7 (0.0%) | 0.7 (0.0%) | 0.8 (0.0%) | 0.8 (0.0%) | 0.9 (0.0%) | 1.0 (0.0%) | 1.0 (0.0%) | 1.1 (0.0%) | 1.2 (0.0%) |
| 5C Incineration and open burning of waste | 0.4 (44.7%) | 0.3 (44.4%) | 0.3 (44.1%) | 0.3 (43.9%) | 0.3 (43.8%) | 0.3 (43.4%) | 0.3 (42.8%) | 0.3 (42.4%) | 0.3 (42.2%) | 0.3 (42.3%) |
| 5D Waste water treatment and discharge | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) |
| 5E Other | 0.1 (100.0%) | 0.1 (100.0%) | 0.1 (100.0%) | 0.1 (100.0%) | 0.1 (100.0%) | 0.1 (100.0%) | 0.1 (100.0%) | 0.1 (100.0%) | 0.1 (100.0%) | 0.1 (100.0%) |
| **5 Waste: CO** | **1.7 (28.9%)** | **1.7 (28.9%)** | **1.7 (28.8%)** | **1.6 (28.7%)** | **1.6 (28.8%)** | **1.6 (28.8%)** | **1.5 (28.5%)** | **1.5 (28.4%)** | **1.5 (28.2%)** | **1.5 (28.1%)** |
| 5A Solid waste disposal | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) |
| 5B Biological treatment of solid waste | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) |
| 5C Incineration and open burning of waste | 1.7 (29.5%) | 1.6 (29.5%) | 1.6 (29.3%) | 1.6 (29.1%) | 1.6 (29.3%) | 1.6 (29.3%) | 1.5 (29.0%) | 1.5 (28.9%) | 1.4 (28.7%) | 1.4 (28.6%) |
| 5D Waste water treatment and discharge | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) | 0.0 (0.0%) |
| 5E Other | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) | 0.0 (100.0%) |
| **5 Waste: $CH_4$** | **24.6 (0.2%)** | **23.9 (0.2%)** | **23.4 (0.2%)** | **22.9 (0.2%)** | **22.4 (0.2%)** | **22.0 (0.2%)** | **21.4 (0.2%)** | **20.8 (0.2%)** | **20.3 (0.2%)** | **19.9 (0.2%)** |
| 5A Solid waste disposal | 16.8 (0.0%) | 16.0 (0.0%) | 15.3 (0.0%) | 14.7 (0.0%) | 14.1 (0.0%) | 13.4 (0.0%) | 12.8 (0.0%) | 12.1 (0.0%) | 11.4 (0.0%) | 10.9 (0.0%) |
| 5B Biological treatment of solid waste | 0.9 (0.0%) | 0.9 (0.0%) | 0.9 (0.0%) | 0.9 (0.0%) | 0.9 (0.0%) | 1.0 (0.0%) | 1.0 (0.0%) | 1.0 (0.0%) | 1.1 (0.0%) | 1.1 (0.0%) |
| 5C Incineration and open burning of waste | 0.2 (27.2%) | 0.2 (27.2%) | 0.2 (26.9%) | 0.2 (26.6%) | 0.2 (26.7%) | 0.2 (26.6%) | 0.2 (26.2%) | 0.2 (26.1%) | 0.2 (25.8%) | 0.2 (25.8%) |
| 5D Waste water treatment and discharge | 6.7 (0.0%) | 6.8 (0.0%) | 6.9 (0.0%) | 7.1 (0.0%) | 7.2 (0.0%) | 7.4 (0.0%) | 7.5 (0.0%) | 7.6 (0.0%) | 7.6 (0.0%) | 7.7 (0.0%) |
| **5 Waste: Indirect $CO_2$** | **1.4** | **1.4** | **1.4** | **1.3** | **1.3** | **1.3** | **1.3** | **1.2** | **1.2** | **1.2** |
| 5A Solid waste disposal | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 5B Biological treatment of solid waste | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 5C Incineration and open burning of waste | 1.3 | 1.3 | 1.2 | 1.2 | 1.2 | 1.2 | 1.1 | 1.1 | 1.1 | 1.1 |
| *from NMVOC* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* |
| *from CO* | *0.8* | *0.8* | *0.7* | *0.7* | *0.7* | *0.7* | *0.7* | *0.7* | *0.6* | *0.6* |
| *from $CH_4$* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* |
| 5D Waste water treatment and discharge | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 5E Other | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| *from NMVOC* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* |
| *from CO* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* |

Table 9-6 Switzerland's emissions of the precursor gases $CH_4$, CO and NMVOC in the source categories of sector 6 Other, together with the respective indirect $CO_2$ emissions. The numbers in brackets indicate the fractions of precursor gases that are relevant for indirect $CO_2$, i.e. the share of fossil emissions of precursor gases not already considered under the direct $CO_2$ emissions. To derive the indirect $CO_2$ emissions, the emissions of precursor gases need to be multiplied by the provided fractions as well as by the factors for the stoichiometric conversion of $CH_4$, CO and NMVOC to indirect $CO_2$ as given in the text (chp. 9.2.1). As an illustrative example, an emission of NMVOC indicated as "150 (40.0%)" leads to indirect $CO_2$ emissions of 132 kt (150 kt * 40.0% * 0.6 * 44/12 = 132 kt).

| Emissions of NMVOC, CO and $CH_4$ as well as indirect $CO_2$ | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | kt | | | | |
| **6 Other: NMVOC** | **0.1 (67.6%)** | **0.1 (73.4%)** | **0.1 (79.2%)** | **0.1 (79.2%)** | **0.1 (79.2%)** |
| **6 Other: CO** | **0.8 (67.4%)** | **0.7 (73.2%)** | **0.7 (79.0%)** | **0.8 (79.0%)** | **0.7 (79.0%)** |
| **6 Other: $CH_4$** | **0.0 (70.3%)** | **0.0 (76.0%)** | **0.0 (81.4%)** | **0.0 (81.5%)** | **0.0 (81.9%)** |
| **6 Other: Indirect $CO_2$** | **1.1** | **1.1** | **1.2** | **1.2** | **1.1** |
| *from NMVOC* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* |
| *from CO* | *0.8* | *0.8* | *0.9* | *0.9* | *0.9* |
| *from $CH_4$* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* |

| Emissions of NMVOC, CO and $CH_4$ as well as indirect $CO_2$ | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| | kt | | | | | | | | | |
| **6 Other: NMVOC** | **0.1 (79.2%)** | **0.1 (79.2%)** | **0.1 (79.2%)** | **0.1 (79.2%)** | **0.1 (79.2%)** | **0.1 (79.2%)** | **0.1 (79.2%)** | **0.1 (79.2%)** | **0.1 (79.3%)** | **0.1 (79.3%)** |
| **6 Other: CO** | **0.7 (79.0%)** | **0.8 (79.0%)** | **0.8 (79.0%)** | **0.6 (79.0%)** | **0.7 (79.0%)** | **0.7 (79.0%)** | **0.7 (79.0%)** | **0.7 (79.0%)** | **0.6 (79.0%)** | **0.6 (79.0%)** |
| **6 Other: $CH_4$** | **0.0 (81.8%)** | **0.0 (81.7%)** | **0.0 (81.7%)** | **0.0 (82.4%)** | **0.0 (82.2%)** | **0.0 (82.3%)** | **0.0 (82.2%)** | **0.0 (82.0%)** | **0.0 (82.7%)** | **0.0 (82.6%)** |
| **6 Other: Indirect $CO_2$** | **1.2** | **1.2** | **1.3** | **1.0** | **1.1** | **1.1** | **1.1** | **1.2** | **1.0** | **1.0** |
| *from NMVOC* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* |
| *from CO* | *0.9* | *1.0* | *1.0* | *0.8* | *0.8* | *0.8* | *0.9* | *0.9* | *0.7* | *0.8* |
| *from $CH_4$* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | *0.0* | *0.1* |

## 9.2. Indirect $CO_2$ and $N_2O$ emissions from all source categories of the GHG inventory

### 9.2.1. Methodological issues to derive indirect $CO_2$ emissions

Table 9-7 Key categories of indirect $CO_2$ emissions. Combined KCA results, level for 2020 and trend for 1990–2020, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

| **Code** | **IPCC category** | **Gas** | **Identification criteria** |
|---|---|---|---|
| 2D | Non-Energy Products from Fuels and Solvent Use; NMVOC (indirect) | CO2 | T1, L2, T2 |
| 2G | Other Product Manufacture and Use; NMVOC (indirect) | CO2 | L2 |

Indirect $CO_2$ emissions resulting from the atmospheric oxidation of $CH_4$ and CO are calculated based on the stoichiometric conversion (molecular weight of $CO_2$ divided by the molecular weight of $CH_4$ or CO, respectively). Indirect $CO_2$ emissions from the atmospheric oxidation of NMVOC are also calculated based on the stoichiometric conversion (carbon content fraction multiplied by the molecular weight of $CO_2$ divided by the molecular weight of carbon). Thereby, a constant carbon content of NMVOC of 60% is assumed, based on the IPCC Guidelines (IPCC 2006). Thus, indirect $CO_2$ emissions (Em) result from the following equations:

$$Em_{CO2,\ indirect\ from\ CH4} = Em_{CH4,\ fossil} * 44/16$$

$$Em_{CO2,\ indirect\ from\ CO} = Em_{CO,\ fossil} * 44/28$$

$$Em_{CO2,\ indirect\ from\ NMVOC} = Em_{NMVOC,\ fossil} * 0.6 * 44/12$$

*Activity data for the calculation of indirect $CO_2$ emissions*

Activity data to calculate indirect $CO_2$ emissions consists of $CH_4$, CO and NMVOC emissions as reported in each individual sector and source category, carefully excluding $CH_4$, CO and NMVOC emissions of biogenic origin and emissions already included as direct $CO_2$ emissions (e.g. when using an oxidation factor of 100%). For the different sectors and source categories, the situation is as follows:

**1A Energy:** Since according to the IPCC Guidelines (IPCC 2006) emission factors in source category 1A Energy are based on the assumption of complete oxidation (100%), $CO_2$ resulting from the atmospheric oxidation of $CH_4$, CO and NMVOC emitted from this source category is already accounted for in the corresponding emission factors for direct $CO_2$ emissions. The respective emissions are thus implicitly reported as direct $CO_2$ emissions in 1A and no indirect $CO_2$ emissions from 1A Energy are reported (see chp. 3.2.4.4.1).

**1B Fugitive emissions from fuels:** $CO_2$ resulting from the atmospheric oxidation of $CH_4$, CO and NMVOC emitted from source category 1B is reported as indirect $CO_2$ emissions unless it is already accounted for implicitly as direct $CO_2$ emissions in 1B (chp. 3.3). For 1B, Table 9-8 illustrates in which processes $CH_4$, CO and NMVOC emissions occur, and whether the related $CO_2$ emissions are reported as indirect $CO_2$ emissions or implicitly as direct $CO_2$ emissions. In summary, all $CO_2$ resulting from the atmospheric oxidation of CO emitted from 1B is implicitly included in 1B as direct $CO_2$ and is therefore not reported as indirect $CO_2$. $CO_2$ resulting from the atmospheric oxidation of $CH_4$ and NMVOC emitted from 1B is reported as indirect $CO_2$, except for source category 1B2c, where an oxidation factor of 100% is applied to calculate direct $CO_2$ emissions.

Table 9-8 Sources of indirect $CO_2$ emissions from source category 1B Fugitive emissions from fuels. Only relevant source categories are shown.

| Source categories: Fugitive emissions | | NMVOC | CO | $CH_4$ |
|---|---|---|---|---|
| Oil (1B2a) | Transport (1B2aiii) | $CO_2$ resulting from NMVOC reported as indirect $CO_2$ | NO | $CO_2$ resulting from $CH_4$ reported as indirect $CO_2$ |
| | Refining/storage (1B2aiv) | | | |
| | Distribution of oil products (1B2av) | | | NO |
| Natural gas (1B2b) | Production (1B2bii) | $CO_2$ resulting from NMVOC reported as indirect $CO_2$ | NO | $CO_2$ resulting from $CH_4$ reported as indirect $CO_2$ |
| | Transmission and storage (1B2biv) | | | |
| | Distribution (1B2bv) | | | |
| | Other leakage (1B2bvi) | | | |
| Venting and flaring (1B2c) | Flaring Oil (1B2ci) | $CO_2$ resulting from NMVOC included in direct $CO_2$ emissions ($CO_2$ EF assumes 100% oxidation) | $CO_2$ resulting from CO included in direct $CO_2$ emissions ($CO_2$ EF assumes 100% oxidation) | $CO_2$ resulting from $CH_4$ included in direct $CO_2$ emissions ($CO_2$ EF assumes 100% oxidation) |
| | $H_2$ Production refinery (1B2ci) | NO | NO | NO |
| | Flaring from gas production (1B2cii) | $CO_2$ resulting from NMVOC included in direct $CO_2$ emissions ($CO_2$ EF assumes 100% oxidation) | | $CO_2$ resulting from $CH_4$ included in direct $CO_2$ emissions ($CO_2$ EF assumes 100% oxidation) |

**2 Industrial processes and product use:** Except for NMVOC emissions from the cracker reported in source category 2B8b Ethylene, CO and NMVOC emissions from 2C1 Secondary steel production, electric arc furnaces and CO emissions from anode consumption in 2C3 Primary aluminium production, none of the $CO_2$ emissions resulting from the atmospheric oxidation of $CH_4$, CO and NMVOC emitted from sector 2 IPPU are already considered under the direct $CO_2$ emissions of this sector. The $CO_2$ emissions from the cracker reported in source category 2B8b Ethylene are based on a carbon mass balance considering all carbon sources and sinks of the process. Therefore, these NMVOC emissions are not accounted for as indirect $CO_2$ emissions from sector 2 IPPU. The $CO_2$ emissions from 2C1 Secondary steel production, electric arc furnace are based on a carbon mass balance considering all carbon sources and sinks of the process. Therefore, the emissions of both, CO and NMVOC, are not accounted for as indirect $CO_2$ emissions. For CO emissions from 2C3 Primary aluminium production full oxidation of the anodes is assumed and these emissions are therefore not included in the indirect emissions (see chp. 4.4.2.2). On the other hand, the NMVOC emissions from 2C3 Primary aluminium production originate solely from the production of the electrodes at the plants. Therefore, they have to be considered for the calculation of indirect $CO_2$ emissions.

In addition, before indirect $CO_2$ emissions are calculated, biogenic CO and NMVOC need to be subtracted from the total CO and NMVOC emissions from sector 2. Biogenic CO and

NMVOC emissions occur in the source categories 2H2 Food and beverages industry and 2G4 Other (tobacco consumption only), see chp. 4.2.

In source categories 2D3a and 2G4, direct $CO_2$ emissions from post-combustion of NMVOC as well as indirect $CO_2$ emissions from oxidation of NMVOC in the atmosphere occur. The $CO_2$ emissions from the NMVOC that are destroyed in post-combustion facilities are reported in the respective source categories 2D3a and 2G4. These NMVOC are not part of the reported NMVOC emissions of source categories 2D3a and 2G4 which are used to calculate indirect $CO_2$ emissions.

$CH_4$ emissions from sector 2 IPPU only stem from the source categories 2B5 (carbide production) and 2B10a (acetic acid production). These emissions are of fossil origin and have to be considered for the calculation of indirect $CO_2$ emissions.

**3 Agriculture and 4 LULUCF:** $CH_4$, CO and NMVOC emissions from the sectors 3 Agriculture and 4 LULUCF are of biogenic origin. Accordingly, no indirect $CO_2$ emissions are reported for these sectors.

**5 Waste:** $CH_4$, CO and NMVOC emissions from sector 5 Waste contain fossil and biogenic shares. Only indirect $CO_2$ resulting from the atmospheric oxidation of fossil $CH_4$, CO and NMVOC is included in CRF Table6. Emissions of fossil $CH_4$, CO and NMVOC originate from the following processes:

- Hospital waste incineration (CO and NMVOC emissions): Completely fossil, see chp. 7.4 Incineration and open burning of waste (5C1), since 2002 no emissions from hospital waste incineration have occurred.
- Municipal solid waste incineration (illegal) ($CH_4$, CO and NMVOC emissions): Partly fossil, fossil share is assumed to be the same as for waste incinerated in municipal solid waste incineration plants, see chp. 7.4 Incineration and open burning of waste (5C1).
- Industrial waste incineration (consists of cable insulation materials) (CO and NMVOC emissions): Completely fossil, see chp. 7.4 Incineration and open burning of waste (5C1), since 1995 no emissions from incinerating cable insulation materials have occurred.
- Shredding (CO and NMVOC emissions): Completely fossil, see chp. 7.6 Other (5E).

Further emissions of $CH_4$, CO and NMVOC from sector 5 Waste – such as from solid waste disposal (5A), biological treatment of solid waste (5B) and wastewater treatment and discharge (5D) – are of biogenic origin and therefore not considered for the calculation of indirect $CO_2$ emissions as presented in CRF Table6.

**6 Other:** $CH_4$, CO and NMVOC emissions from sector 6 Other contain fossil and biogenic shares. Only $CO_2$ resulting from the atmospheric oxidation of fossil $CH_4$, CO and NMVOC is reported as indirect $CO_2$. Emissions of fossil $CH_4$, CO and NMVOC originate from the following processes:

- Fire damage estate: The share of fossil $CH_4$, CO and NMVOC emissions is assumed to be equal to the share of fossil $CO_2$ emissions, which is 80% since the year 2000, see chp. 8.2 (6Ad).
- Fire damage motor vehicles: The share of fossil $CH_4$, CO and NMVOC emissions is assumed to be 100%, see chp. 8.2 (6Ad).

### 9.2.2. Methodological issues to derive indirect $N_2O$ emissions

Indirect $N_2O$ emissions are estimated using a country-specific method according to a study of indirect $N_2O$ emissions induced by nitrogen deposition in Switzerland (Bühlmann 2014, Bühlmann et al. 2015). In this study, ecosystem-specific emission factors for indirect $N_2O$ resulting from nitrogen deposition were developed, based on a comprehensive literature survey. Thereby, the land cover types forests, grassland and wetlands were distinguished. In a next step, the ecosystem-specific emission factors were combined with a highly-resolved nitrogen deposition map of Switzerland as well with the geo-referenced data set of the Swiss Land Use Statistics (allowing for the localisation and estimation of spatial extent of the different ecosystems). This resulted in detailed and spatially resolved indirect $N_2O$ emissions for Switzerland. To facilitate a simple application in the greenhouse gas inventory, the resulting total emissions were used to come up with a total emission factor expressed as indirect $N_2O$-N per N-deposition (deposited in form of $NO_x$ or $NH_3$, see also chp. 5.3.2.4). The resulting total emission factor is in the order of 2.5% and slightly varies with time as the shares of the different ecosystems are not constant over time. Based on this country-specific emission factor, higher indirect $N_2O$ emissions result compared to the emissions that would result by applying the IPCC Guidelines (IPCC 2006, see also Bühlmann et al. 2015).

To calculate indirect $N_2O$ emissions induced by the deposition of $NO_x$ and $NH_3$ according to Bühlmann (2014) and Bühlmann et al. (2015), total N-deposition is needed. It is derived from $NO_x$ (which is always reported in $NO_2$ equivalents) and $NH_3$ emissions using the stoichiometric conversion according to the following equation:

$$\text{Mass-N} = \text{Mass-NO}_{2,eq} * 14/46 + \text{Mass-NH}_3 * 14/17$$

Note: The emissions referred to as indirect $N_2O$ emissions in CRF Table3.B and in CRF Table3.D are not addressed in this chapter, as they are not reported as indirect $N_2O$ emissions in CRF Table6 and in CRF Table10 (these emissions are instead included in Sector 3 Agriculture along with direct $N_2O$ emissions).

*Activity data for the calculation of indirect $N_2O$ emissions*

The activity data to calculate indirect $N_2O$ emissions from a specific sector corresponds to the $NO_x$ and $NH_3$ emissions reported in the respective source categories. However, the following exceptions need to be considered:

- Indirect $N_2O$ emissions from sector 3 Agriculture are reported in the respective sector together with direct $N_2O$ emissions (chp. 5.3.2.5.4 Volatilisation of $NH_3$ and $NO_x$ from manure management systems, chp. 5.5.2.3 Indirect $N_2O$ emissions from atmospheric deposition of N volatilised from managed soils (3Db1) and chp. 5.5.2.4 Indirect $N_2O$ emissions from leaching and run-off from managed soils (3Db2)).
- For sector 6, the only indirect $N_2O$ emissions to be considered are those resulting from $NO_x$ emissions in source category 6Ad Fire damages.

### 9.2.3. Uncertainties and time series consistency

Indirect $CO_2$ emissions are included in the uncertainty analysis, but indirect $N_2O$ emissions are not included.

Uncertainties of indirect $CO_2$ emissions are based on respective uncertainties of $CH_4$, CO and NMVOC emissions. Uncertainties of $CH_4$ emissions are described in the respective chapters above. Uncertainties of CO and NMVOC emissions are documented in Switzerland's Informative Inventory Report 2022 (FOEN 2022b). The uncertainties of the emission factors are partly based on values provided by the EMEP/EEA guidebook (EMEP/EEA 2019, part A, chp. 5, Table 2-2) and expert judgements. The estimated uncertainties distinguish between fossil and biogenic shares.

Combined uncertainties of indirect $CO_2$ emissions, for each category, are given in Annex A2.1.

Consistency: Time series for indirect $CO_2$ and $N_2O$ emissions are all considered consistent.

### 9.2.4. Category-specific QA/QC and verification

The same QA/QC and verification procedures are conducted as for $CH_4$, CO, NMVOC, $NO_x$ and $NH_3$ related source categories in chp. 3 Energy, 4 Industrial processes and product use, 7 Waste and 8 Other.

### 9.2.5. Category-specific recalculations

- See $CH_4$ related recalculations reported in chp. 3 Energy, 4 Industrial processes and product use, 7 Waste and 8 Other.
- See CO related recalculations reported in chp. 4 Industrial processes and product use, 7 Waste and 8 Other in Switzerland's Informative Inventory Report 2022 (FOEN 2022b).
- See NMVOC related recalculations reported in chp. 3 Energy, 4 Industrial processes and product use, 7 Waste and 8 Other in Switzerland's Informative Inventory Report 2022 (FOEN 2022b).
- See $NO_x$ and $NH_3$ related recalculations reported in chp. 3 Energy, 4 Industrial processes and product use, 7 Waste and 8 Other in Switzerland's Informative Inventory Report 2022 (FOEN 2022b).

### 9.2.6. Category-specific planned improvements

No category-specific improvements are planned.

# 10. Recalculations and improvements

| Responsibilities for chapter Recalculations and improvements | |
|---|---|
| Overall responsibility | Regine Röthlisberger (FOEN) |
| Authors & annual updates (NIR text, tables, figures) | Michael Bock (FOEN), Regine Röthlisberger (FOEN), Nele Rogiers (FOEN), Andreas Schellenberger (FOEN), Daniel Bretscher (Agroscope) |
| EMIS database operation | Adrian Schilt (FOEN) |
| Quality control NIR (annual updates) | Adrian Schilt (FOEN) |
| Internal review | Anouk-Aimée Bass (FOEN), Rainer Kegel (FOEN), Daiana Leuenberger (FOEN), Sabine Schenker (FOEN), sector experts |

## 10.1. Explanations and justifications for recalculations and responses to the review process

The implementation of recommendations and encouragements from the UNFCCC review process are listed in chp. 10.1.1. Additionally, major recalculations are presented in chp. 10.1.2. In the relevant sectoral chapters, also minor recalculations are listed and a brief explanation for each is provided. A list with all recalculations and specifics of the recalculations is compiled by the EMIS experts and available to the reviewers on demand (partly in German).

### 10.1.1. Recommendations and encouragements from ERT and their implementation

The most recent in-depth review of the inventory was based on the submission of April 2021 (UNFCCC 2022). Some of the recommendations and encouragements could already be addressed and implemented in the submission at hand (see Table 10-1 and Table 10-2).

Table 10-1 Implementation of recommendations from the in-depth review in 2021 (UNFCCC 2022).

| ID | classification | Recommendation from ARR 2021 (UNFCCC 2022) | Answer including reference to chapter in NIR |
|---|---|---|---|
| **General** | | | |
| G.2 | QA/QC and verification | The ERT recommends that Switzerland ensure consistency in the data reported on recalculations of total emissions of CO2 eq including LULUCF between section 10 of the NIR and CRF table 8s4. | Consistency between chp. 10 and CRF Table8s4 ensured. |
| **Agriculture** | | | |
| A.5 | 3.B.1 Cattle – CH4 and N2O | The ERT recommends that the Party clearly explain the mass balance approaches developed to track VS and N flows excreted by cattle (by subcategory) and handled in each MMS and transparently describe the methods used to estimate CH4 and N2O emissions from manure management for cattle (for each subcategory) in the NIR. | A more detailed description of the methodological approach and additional data tables are provided in NIR Annex A3.3.4. |
| A.6 | 3.B.1 Cattle – N2O | The ERT recommends that Switzerland provide information in the NIR on the algorithms and background input data (e.g. crude protein intake, milk protein content and N retention, to the extent possible) used to evaluate the Nex rates for cattle (by subcategory). | Additional informatrion and references to literature are provided in NIR chp. 5.3.2.5.2. |
| A.7 | 3.D.a.4 Crop residues – N2O | The ERT recommends that the Party further clarify the model used to estimate N2O emissions from crop residues left on fields by including in the NIR information on the reference source for the model, the data sources and the calculation parameters used. | The description of the methodological approach in chp. 5.5.2.2.2 was revised in order to increase transparency. Additional information on data sources was included. |
| A.8 | 3.D.b.1 Atmospheric deposition – N2O | The ERT recommends that the Party justify the use of the country-specific N2O EF for atmospheric deposition by including information in the NIR on the calculation of the mean N2O EF for atmospheric deposition (e.g. reporting in tabular format the areas of land-use categories that were subject to N inputs and the relevant N2O EF for atmospheric deposition for each category of managed land) or use the IPCC default EF for N2O emissions from atmospheric deposition of N inputs to soil and water provided in table 11.3 of the 2006 IPCC Guidelines (vol. 4, chap. 11). | An aditional data table was included in NIR chp. 5.3.2.4. A more detailed description of the exact approach is provided in Bühlmann (2014) chp. 5.2.1. |
| **LULUCF** | | | |
| L.4 | 4.A Forest land – CO2 (L.8, 2019) Accuracy | Either include trees with a DBH of below 12 cm with branches, foliage and roots, in addition to non-tree understory vegetation, including shrubs, ferns, grasses, sedges and herbs, in the estimates of living biomass, deadwood and litter, or provide justification as to why these small trees and non-tree vegetation are not included in the calculation of living biomass, deadwood and litter. | A justification for not considering trees with a DBH of below 12 cm and non-tree vegetation in the calculation of living biomass, dead wood and litter was included in NIR chp. 6.4.2.1. |
| L.5 | 4.C.2 Land converted to grassland – CO2 | The ERT recommends that the Party include a justification for the use of a one-year conversion period for land converted to woody grassland types in its NIR. | A justification for the use of a one-year conversion period for land converted to woody grassland types was included in NIR chp. 6.6.4.5. |
| **Waste** | | | |
| W.2 | 5.B.1 Composting – CH4 | The ERT recommends that Switzerland describe in the NIR the process for composting of MSW to justify the low country-specific CH4 EF of 1.00 g/kg. | Justification of low country-specific CH4 EF documented in chp. 7.3.2.1 composting (5B1). |
| W.3 | 5.B.1 Composting – CH4 | The ERT recommends that the Party report correct AD for composting of MSW on a dry-weight basis (kt dm) in CRF table 5.B, instead of on a wet-weight basis, to ensure comparability of the resulting IEF across reporting Parties. | AD for composting of MSW is now reported in unit mass of dry matter as documented in chp. 7.3.2.1 composting (5B1). |
| W.4 | 5.C.1 Waste incineration – N2O | The ERT recommends that the Party improve the transparency of its reporting by referencing the sources used to obtain the country-specific N2O EF of 4.10 kg/t waste for sewage sludge incineration. | Improved reporting of deductiong of country-specific N2O EF in chp. 7.4.2 Methodological issues (5C). |
| **KP-LULUCF** | | | |
| KL.1 | General (KP-LULUCF) | The ERT recommends that the Party use the notation key “R” or, if technically feasible, “R, NR” (which appears to be possible for reporting in CRF table NIR-1, on the basis of input provided by the secretariat during the review), as this more accurately reflects the completeness of the Party’s reporting. | Both notation keys (R, NR) were inserted in CRF table NIR-1. An explanation is given in NIR chp. 11.3.1.2 |
| KL.2 | Article 3.4 activities – CO2, CH4 and N2O | The ERT recommends that the Party explain in the NIR (section 11.1.3) the reason for the expansion of the FM area over time owing to the inclusion of naturally regenerated forests that have achieved the forest definition. | An explanation was included in NIR chp. 11.1.3. |
| KL.3 | Deforestation – CO2, CH4 and N2O | The ERT recommends that the Party correct the error in the sum of the deforested areas under the information item of CRF table 4(KP-I)A.2, and implement a QA check to ensure that the total areas reported under the information item are consistent with the total areas reported for deforestation and with the deforested areas reported in CRF table NIR-2. | The error in the sum of the deforested areas under the information item of CRF table 4(KP-I)A.2 was corrected. An additional check to ensure that the total areas reported under the information item are consistent with the total areas reported for deforestation and with the deforested areas reported in CRF NIR-2 was implemented (see NIR chp. 11.1.3). |

Table 10-2 Implementation of encouragements from the in-depth review in 2021 (UNFCCC 2022).

| ID | classification | Encouragement from ARR 2021 (UNFCCC 2022) | Answer including reference to chapter in NIR |
|---|---|---|---|
| Agriculture | | | |
| A.4 | 3.A.1 Cattle – CH4 | The ERT encourages Switzerland to calculate the weighted average weight values for the growing cattle population and report the values in CRF table 3.As2 for the entire reporting period. | Weighted average weight values for the growing cattle are reported in CRF Table3.As2, Table3.B(a)s1 and Table3.B(b). |
| LULUCF | | | |
| L.6 | 4(I) Direct N2O emissions from N input to managed soils – | The ERT encourages the Party to include text in the documentation box of CRF table 4(I) indicating that direct N2O emissions from the fertilization of settlements are included under subcategories 3.D.a.1 (inorganic N fertilizers) and 3.D.a.7 (other). | The information was included in the documentation box of CRF Table4(I). |
| L.7 | 4(IV).1 Atmospheric deposition – N2O | The ERT encourages the Party to include text in the documentation box of CRF table 4(IV) indicating that indirect N2O emissions from managed soils (atmospheric deposition) from the fertilization of settlements are reported in CRF table 3.D under subcategory 3.D.b.1 (atmospheric deposition). | The information was included in the documentation box of CRF Table4(IV). |

## 10.1.2. Major recalculations and improvements implemented in the latest submission

In this chapter, the most important recalculations are presented. The figures show the differences between net emissions and removals in submission 2021 (previous) and submission 2022 (latest). Explanations are provided for categories that underwent recalculations larger than 2% of the corresponding category emissions and resulted in absolute changes larger than 5 kt $CO_2$ eq (approximately 0.01% of the national total emissions) for the Energy, IPPU, Agriculture and Waste sectors, and larger than approximately |25| kt $CO_2$ eq for the LULUCF and the KP-LULUCF sectors. Additional recalculations and corrections of minor errors, which had a smaller impact than the above thresholds, are listed in the relevant sectoral chapters.

### 10.1.2.1. Energy

The total changes in emissions in the energy sector due to all recalculations are shown in Figure 10-1 for $CO_2$, Figure 10-2 for $CH_4$ and Figure 10-3 for $N_2O$.

The largest recalculations in the energy sector resulted from the reassessment of the fugitive emissions from gasoline storage tanks, resulting in smaller NMVOC emissions in 1B2a and correspondingly higher $CO_2$ emissions in 1A3 of up to 10 kt $CO_2$ eq. In addition, the time series for marine bunkers has been harmonised with the data of the energy statistics, resulting in changes of the order of up to ±10 kt $CO_2$ eq. Consideration of the latest statistical data in the road transportation model led to small changes in the fuel allocation to sub-categories in 1A3b. While this has no effect on total $CO_2$ emissions, there was a small effect on $CH_4$ and $N_2O$ emissions in 1A3 of the order of a few kt $CO_2$ eq. All other recalculations had an impact that was smaller than 5 kt $CO_2$ eq (see Figure 10-1, Figure 10-2, Figure 10-3).

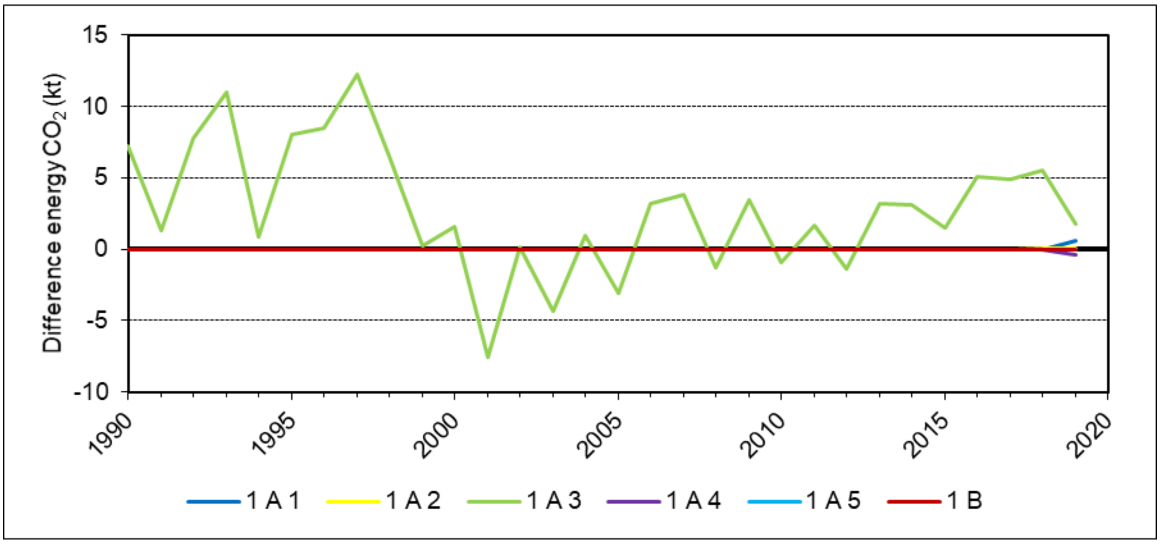



Figure 10-1 Differences in $CO_2$ emissions (in kt $CO_2$) between the latest and the previous submissions for various source categories in the energy sector. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

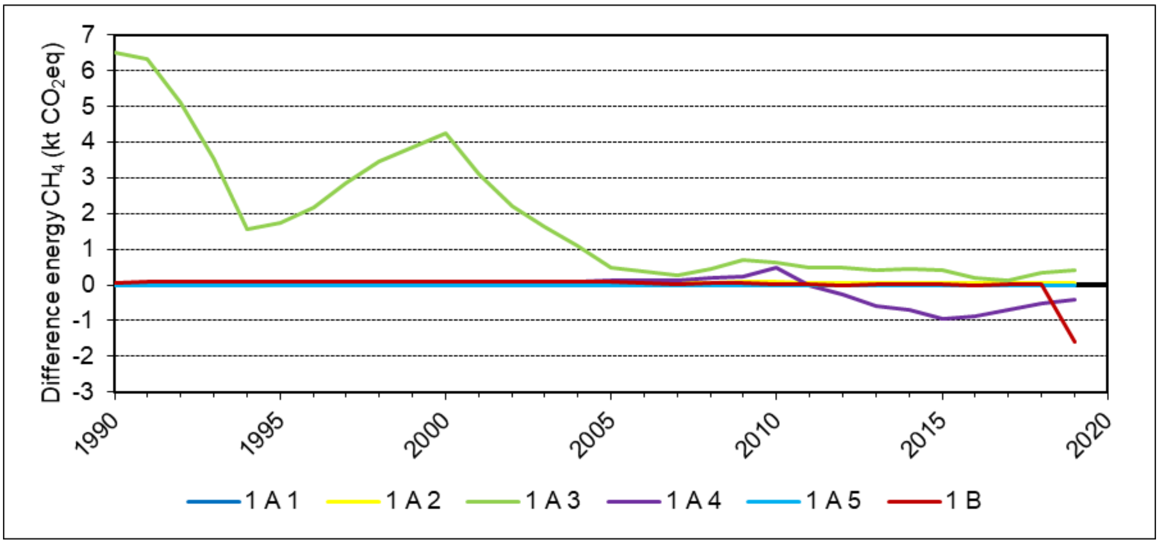



Figure 10-2 Differences in $CH_4$ emissions (in kt $CO_2$ eq) between the latest and the previous submissions for various source categories in the energy sector. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

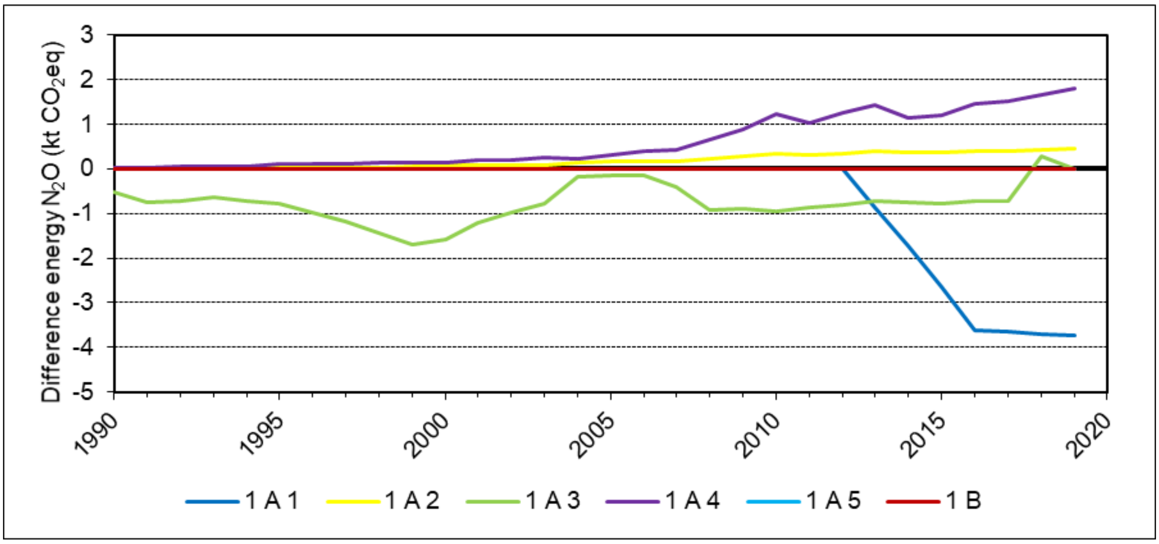



Figure 10-3 Differences in $N_2O$ emissions (in kt $CO_2$ eq) between the latest and the previous submissions for various source categories in the energy sector. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

### 10.1.2.2. Industrial processes and other product use

The total changes in emissions in the IPPU sector due to all recalculations are shown in Figure 10-4 for $CO_2$, $CH_4$, and $N_2O$, and in Figure 10-5 for HFCs, PFCs, $SF_6$, and $NF_3$.

The emission estimates for silicon carbide production was updated based on detailed industry data, resulting in a slight decrease in $CO_2$ of up to 12 kt $CO_2$ eq and a slight increase in $CH_4$ emissions of up to 5 kt $CO_2$ eq. For a specific application of $SF_6$ in category 2G, the emission factor has been adjusted based on information from the company, resulting in increasing emissions from when the application started up to + 30 kt $CO_2$ eq in the last years. Apart from that, there were only minor adjustments made to the model of foam production, refrigeration and air conditioning, resulting in changes of up to 6 kt $CO_2$ eq. All other recalculations had an impact that was smaller than 5 kt $CO_2$ eq (see Figure 10-4 and Figure 10-5).

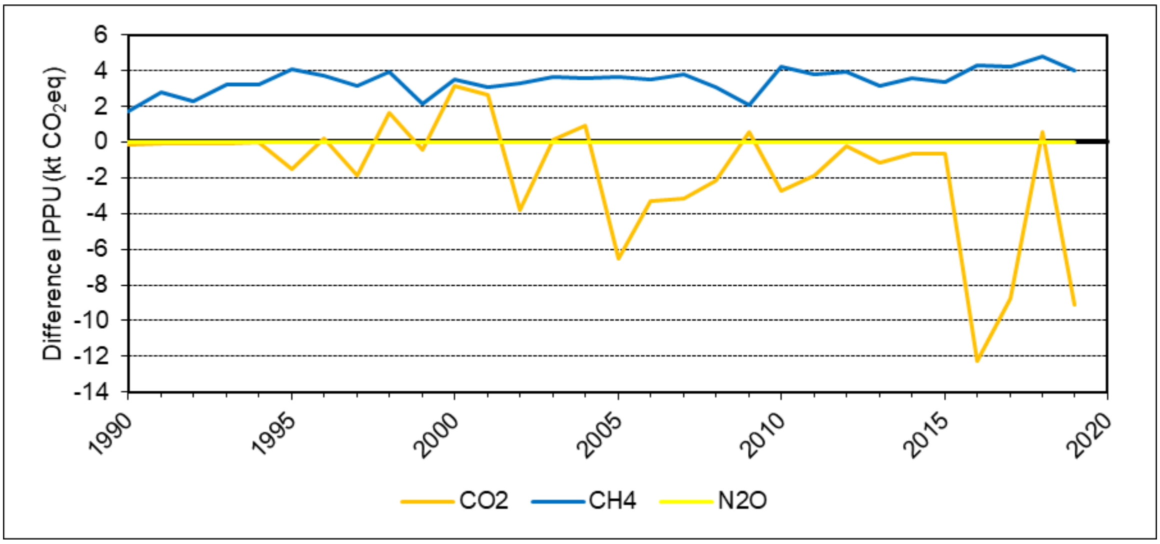



Figure 10-4 Differences in $CO_2$, $CH_4$, and $N_2O$ emissions (in kt $CO_2$ eq) between the latest and the previous submissions for sector IPPU. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

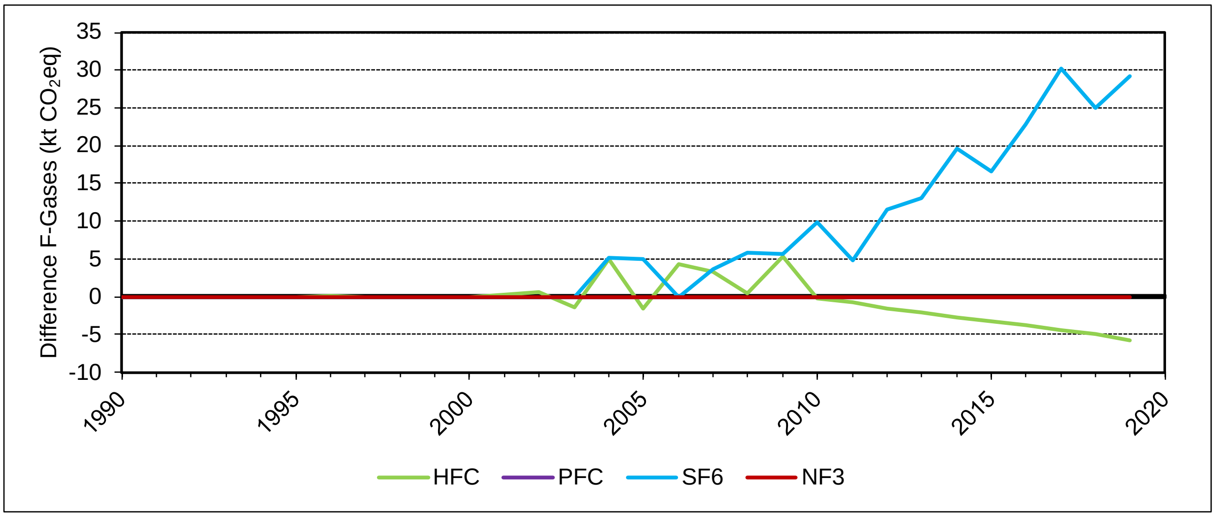



Figure 10-5 Differences in HFC, PFC, $SF_6$ and $NF_3$ emissions (in kt $CO_2$ eq) between the latest and the previous submissions for the sector IPPU. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

### 10.1.2.3. Agriculture

The total changes in emissions in the Agriculture sector due to all recalculations are shown in Figure 10-6 for $CO_2$, $CH_4$, and $N_2O$, and for the most important recalculations aggregated for all greenhouse gases in Figure 10-7.

The largest recalculations resulted from the revision of the live weight of mature dairy cattle (see chp. 5.2.5) and the deletion of the urea-energy content when estimating excretion of volatile solids (see chp. 5.3.5).

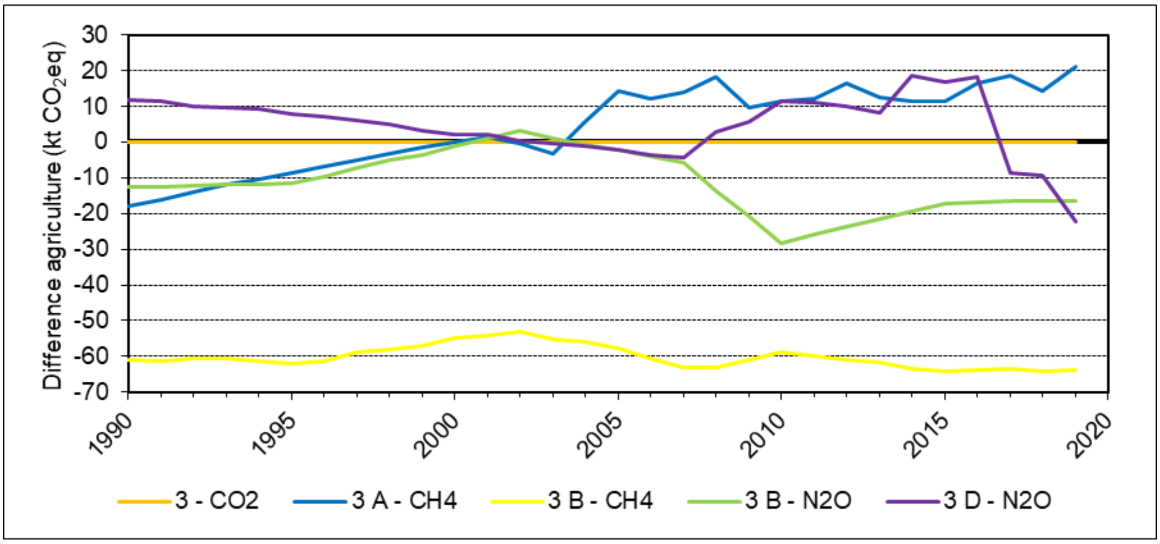



Figure 10-6 Differences in $CO_2$, $CH_4$, and $N_2O$ emissions (in kt $CO_2$ eq) between the latest and the previous submissions for sector Agriculture. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

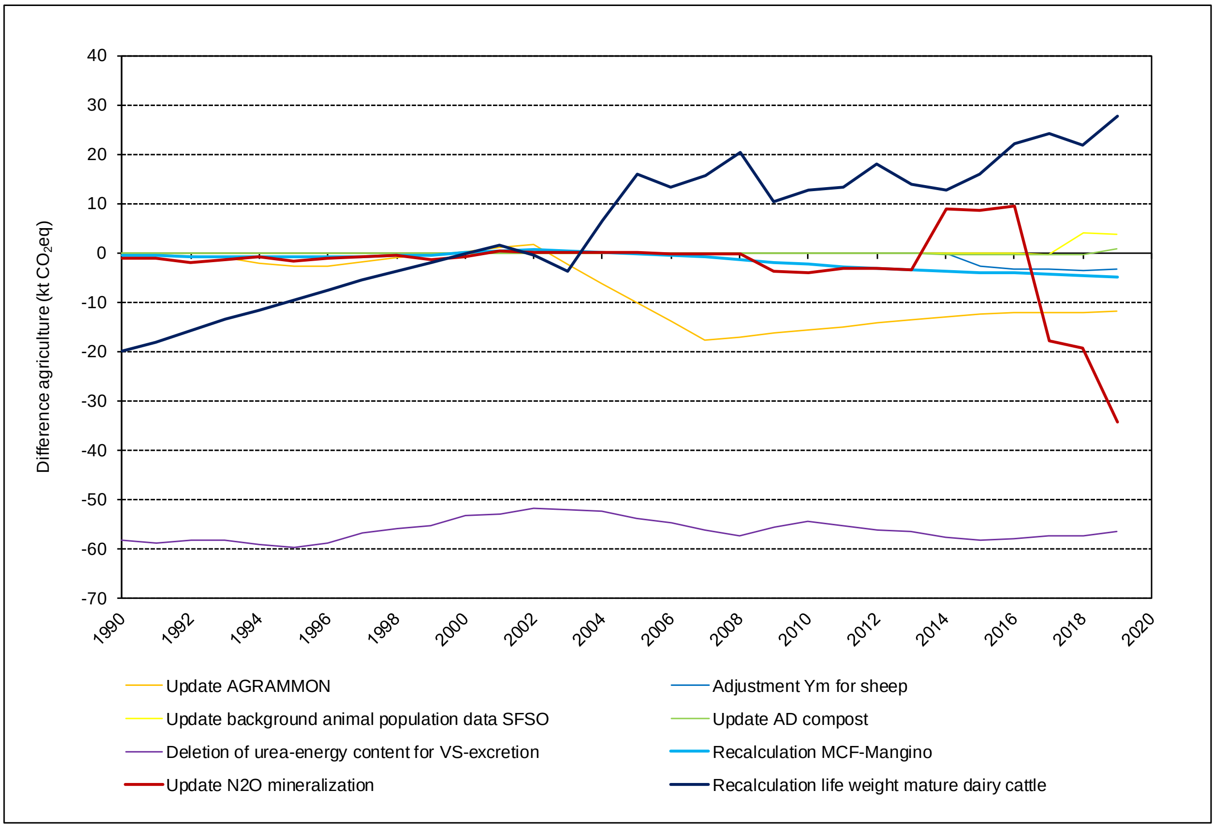



Figure 10-7 Differences in overall GHG emissions (in kt $CO_2$ eq) between the latest and the previous submissions for sector Agriculture due to the most important recalculations. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission. Note that due to the successive implementation of the different recalculations the amounts are not always exact but must be understood as approximations.

- $CH_4$ and $N_2O$ emissions from livestock were recalculated for the years 2017–2019 due to new background data of the SFSO for livestock population statistics for horses, fattening pigs and broilers (AD; SFSO 2021b). The impact on overall emissions is negligible for 2017 and approximately +4 kt $CO_2$ eq for 2018 and 2019.
- $CH_4$ emissions for mature dairy cattle were recalculated for the whole time series due to a new assessment of live weight (affecting IEF). A new time series of life weights was established by Burren et al. (2021) and was used for modelling GEI and VS-excretion rates instead of a constant weight of 650 kg. The impact on overall emissions ranges from -20 kt $CO_2$ eq in 1990 to +28 kt $CO_2$ eq in 2019.
- $CH_4$ emissions from enteric fermentation of sheep were recalculated for the years 2015–2019 due to an adjustment of the methane conversion rate ($Y_m$, affecting IEF). The weighting of the methane conversion rates for adult and young sheeps was adjusted based on new consistent time series of the number of young sheep (SFSO 2021b). The mean impact on overall emissions was -3.2 kt $CO_2$ eq for the period 2015–2019.
- $CH_4$ and $N_2O$ emissions from manure management and agricultural soils were recalculated for 1990–2019 due to new projections of the AGRAMMON-model. The main effects are presumably due to lower nitrogen excretion rates for mature dairy cattle and swine in later inventory years. The main impact on overall emissions is a decrease of 14 kt $CO_2$ eq for the period 2006–2019.
- $CH_4$ emissions from manure management of cattle, camels, deer and buffalo were revised for the whole time series. As recommended during the peer review with the German inventory compiling group (Fuß et al. 2021), urea energy was not accounted for when estimating VS excretion (affecting EF). According to Dämmgen et al. (2011) there is no indication for methane formation from urine energy. The mean impact on overall emissions is -56 kt $CO_2$ eq (-52 to -60 kt $CO_2$ eq).
- $CH_4$ emissions from manure management in liquid systems and anaerobic digesters were recalculated for 1990–2019. The MCF-value for liquid systems (EF) was revised due to revised model projections (Mangino et al. 2001) based on slightly recalculated AGRAMMON data for manure management system distribution (MS). The impact on overall emissions is negligible for the period 1990–2007 (<1 kt $CO_2$ eq) and subsequently increases to a maximum of almost -5 kt $CO_2$ eq.
- $N_2O$ emissions due to "N input from application of other organic fertilisers" were recalculated for the years 2014–2019. Nitrogen inputs from compost were revised (AD). The impact on overall emissions is negligible: <1.0 kt $CO_2$ eq.
- $N_2O$ emissions from mineralisation associated with loss of soil organic matter were recalculated for 1990–2019. The amount of mineralized nitrogen (AD) was revised due to new projections of soil carbon losses. The main effects are due to new meteodata (whole time series) and an error correction for 2019 in the Roth-C model (see chp. 6.5 and 6.6). The main impact on overall emissions are: negligible for the period 1990–2008 (<±2 kt $CO_2$ eq), approximately +9 kt $CO_2$ eq for the years 2014–2016 and -24 kt $CO_2$ eq for the years 2017–2019.
- Indirect $N_2O$ emissions from agricultural soils were revised according to the revised estimates of nitrogen volatilized or leached as a consequence of the recalculations mentioned above.

#### 10.1.2.4. Land Use, Land-Use change and Forestry

Overall changes in GHG emissions by sources and removals by sinks in the LULUCF sector due to all recalculations realised for the latest submission are shown in Figure 10-8.

The trends in net emissions and removals remain more or less the same (Figure 10-21). The pattern of the deviation of $CO_2$ eq net emissions and removals between the latest and the previous submissions (range from -182.7 kt $CO_2$ eq in 2019 to 99.8 kt $CO_2$ eq in 2016) is controlled by major recalculations in categories 4A, 4B, and 4C (Figure 10-9), which have an overall impact mainly from 2008 onwards (Figure 10-8).

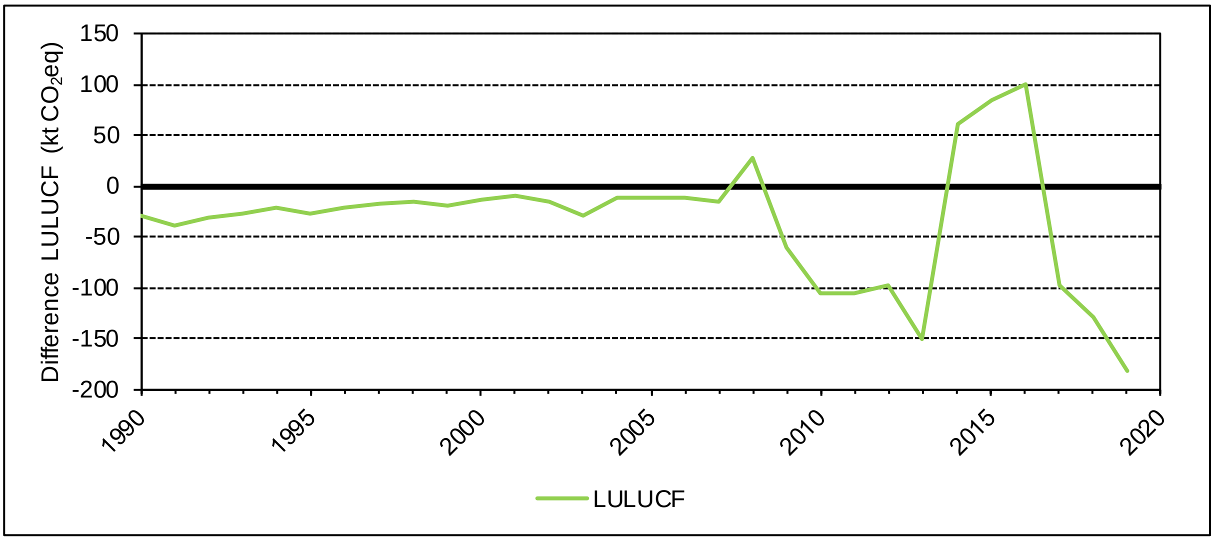



Figure 10-8 Differences in net emissions and removals (in kt $CO_2$ eq) between the latest and the previous submissions for the LULUCF sector. Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

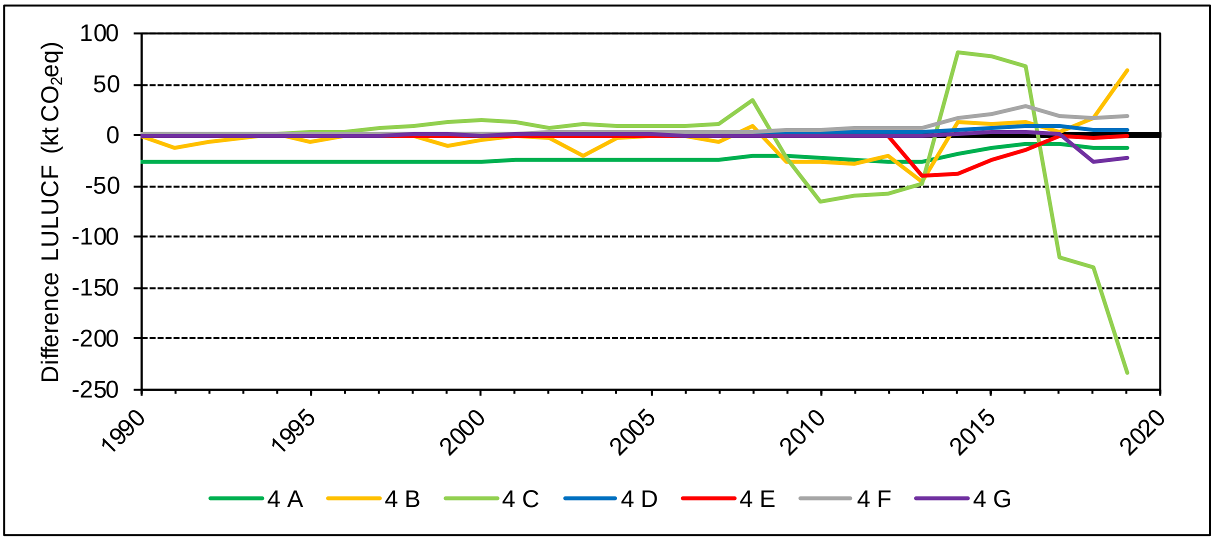



Figure 10-9 Differences in net emissions and removals (in kt $CO_2$ eq) between the latest and the previous submissions for categories 4A-4G in the LULUCF sector. Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

In category 4A Forest land one major recalculation dominated the changes in $CO_2$ eq net emissions and removals.

- 4A2: Updated estimates for soil carbon stocks in mineral soils were used (Nussbaum and Burgos 2021). The incorporation of this data set affected soil carbon stock changes of conversions from non-Forest land to Forest land and caused a systematic deviation between -28.1 (1992) and -20.5 (2016) kt $CO_2$ eq compared to the previous submission. (Included in these figures are associated $N_20$ emissions from category 4(III)A2, which roughly doubled, but at a very low level; annual differences are <0.001 kt). It is mainly responsible for the curve progression of category 4A shown in Figure 10-9. The resulting time series of net removals is 108 to 111 percent higher than in the previous submission (Figure 10-10)

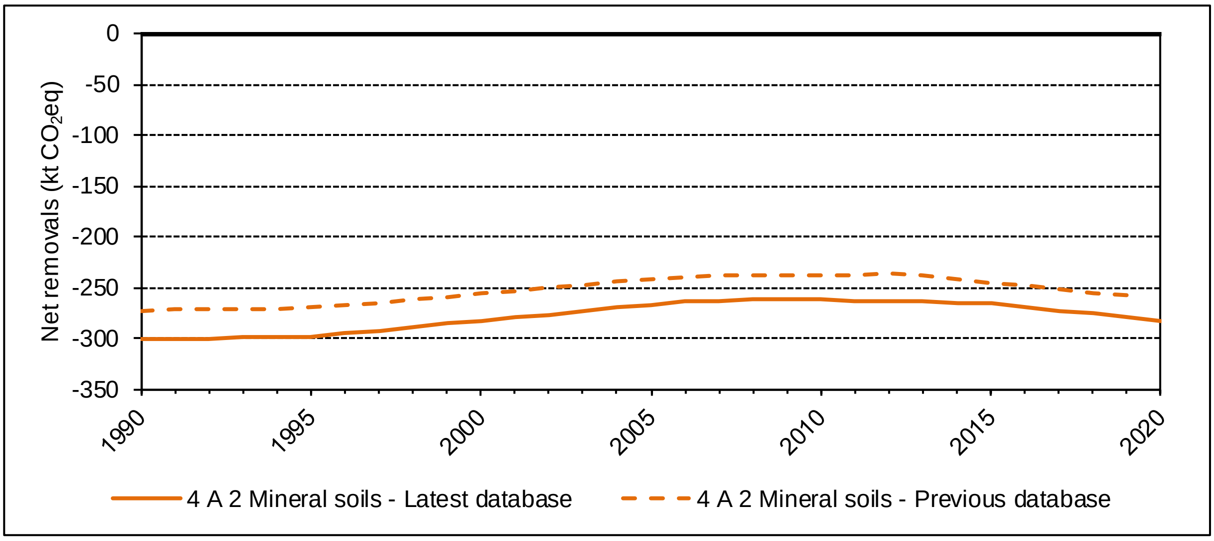



Figure 10-10 Comparison of net removals (negative values) from subcategory 4A2 Mineral soils on Land converted to forest land as reported in the previous and the latest submissions.

In category 4B Cropland one major recalculation dominated the changes in $CO_2$ eq net emissions and removals.

- 4B1: Carbon stocks and carbon stock changes in mineral soils of Cropland were recalculated using (1) updated crop yield data, (2) updated agricultural data, and (3) updated gridded climate data (see chp. 6.5.5). While the effect of the first two is very small, the last caused most of the differences in soil carbon stock changes between the latest and previous submissions. Although the absolute differences between the previous and latest climate data sets are relatively small, there are systematic differences (i.e. biases), for example that temperatures for regions at lower elevation had been slightly overestimated. More notable is a shift in the difference between the previous and latest temperature data at around 2011. The recalculation led to a difference between the latest and the previous submissions ranging from -27.6 kt $CO_2$ eq in 2011 to 77.4 kt $CO_2$ eq in 2019 (Figure 10-11). It is almost entirely responsible for the curve progression of category 4B shown in Figure 10-9. The resulting time series of net emissions and removals of reported five-year averages shows the most pronounced differences around the year 2011 and thereafter compared to the previous submission (Figure 10-12).

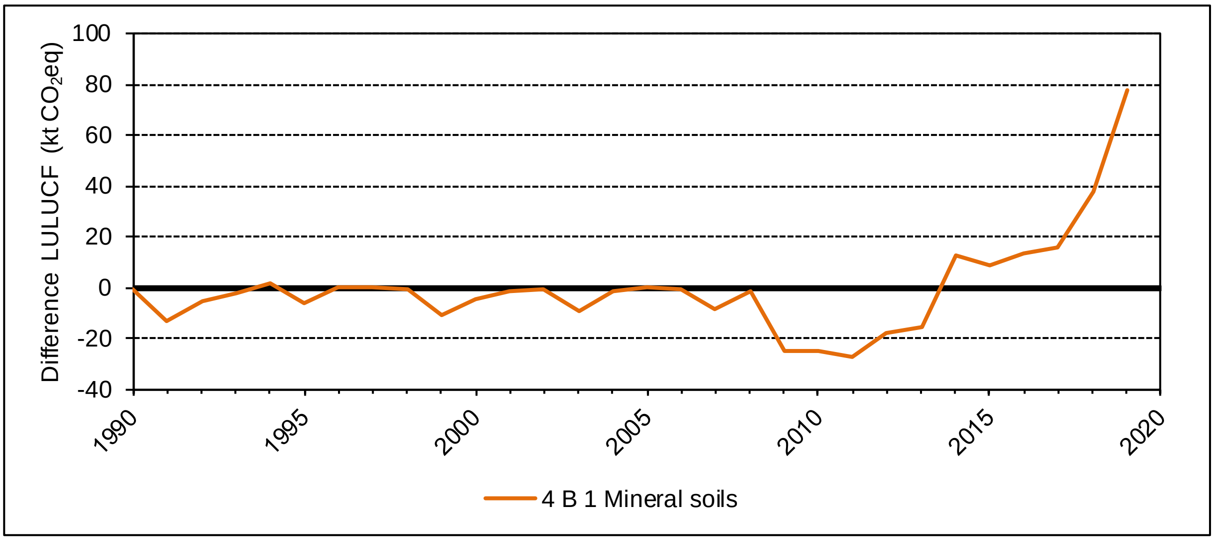



Figure 10-11 Differences in net emissions and removals (in kt $CO_2$ eq) between the latest and the previous submissions for subcategory 4B1 Net carbon stock change in mineral soils on Cropland remaining cropland ($CO_2$). Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

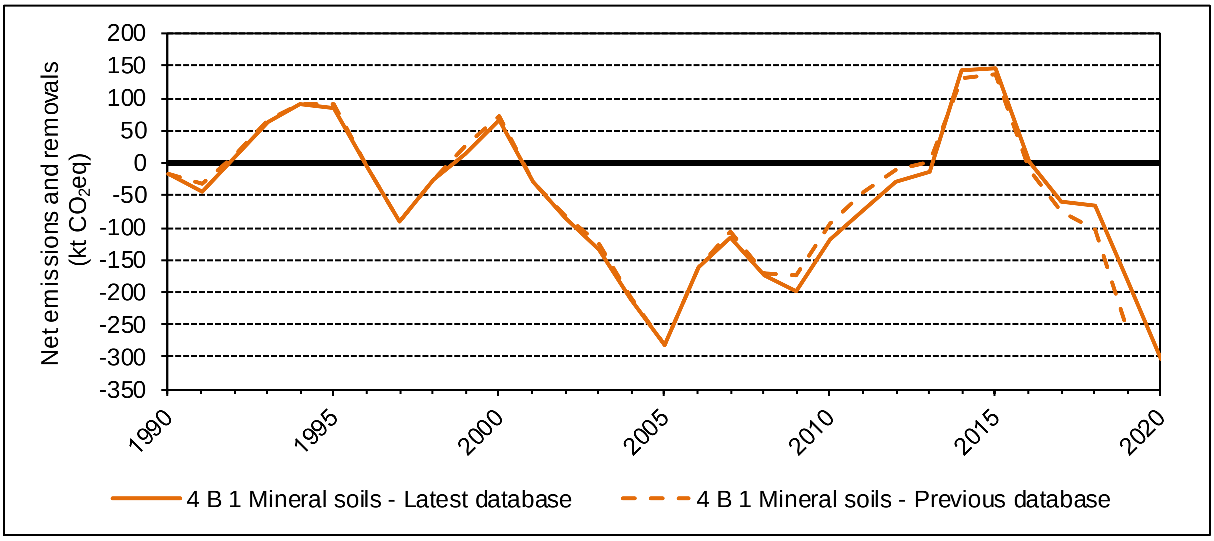



Figure 10-12 Comparison of net emissions (positive values) and net removals (negative values) from subcategory 4B1 Mineral soils on Cropland remaining cropland as reported in the previous and the latest submissions.

In category 4C Grassland one major recalculation dominated the changes in $CO_2$ eq net emissions and removals.

- 4C1: Carbon stocks and carbon stock changes in mineral soils of permanent grassland (CC31) were recalculated using (1) updated agricultural data and (2) updated gridded climate data (see chp. 6.6.5). While the effect of the first is very small, the last caused most of the differences in soil carbon stock changes between the latest and previous submissions around 2011 and partly in the years thereafter (see above in the section on category 4B1 for details on the climate data). The correction of an error in a script used to exclusively generate a 2019 import file for RothC resulted in a large reduction in emissions and due to multi-year averaging also dragged down the emissions for the years 2017 and 2018 (Figure 10-13). The overall recalculation (together with two other recalculations of Grassland mineral soil carbon stocks of negligible importance listed in chp. 6.6.5) led to a difference between the latest and the previous submissions ranging from -256.3 kt $CO_2$ eq in 2019 and 41.3 kt $CO_2$ eq in 2014 (Figure 10-13). It is mainly responsible for the curve progression of category 4C shown in Figure 10-9. The resulting time series of net emissions and removals of reported five-year averages shows the most pronounced differences around the year 2011 and especially thereafter compared to the previous submission (Figure 10-14).

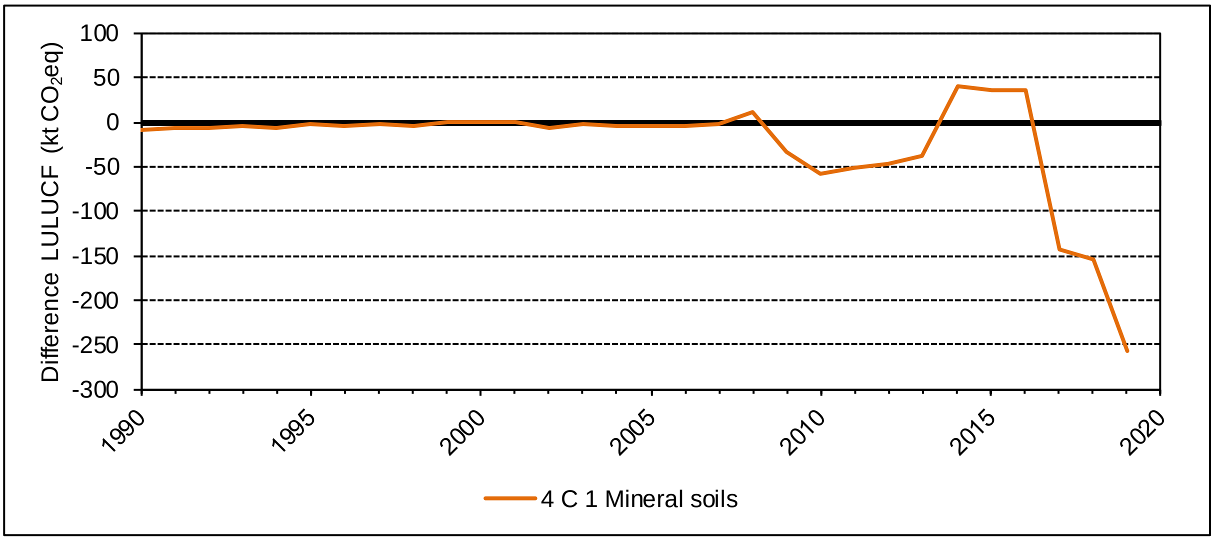



Figure 10-13 Differences in net emissions and removals (in kt $CO_2$ eq) between the latest and the previous submissions for the subcategory 4C1 Net carbon stock change in mineral soils on Grassland remaining grassland. Positive values refer to higher emissions/lower removals in the latest submission compared to the previous submission.

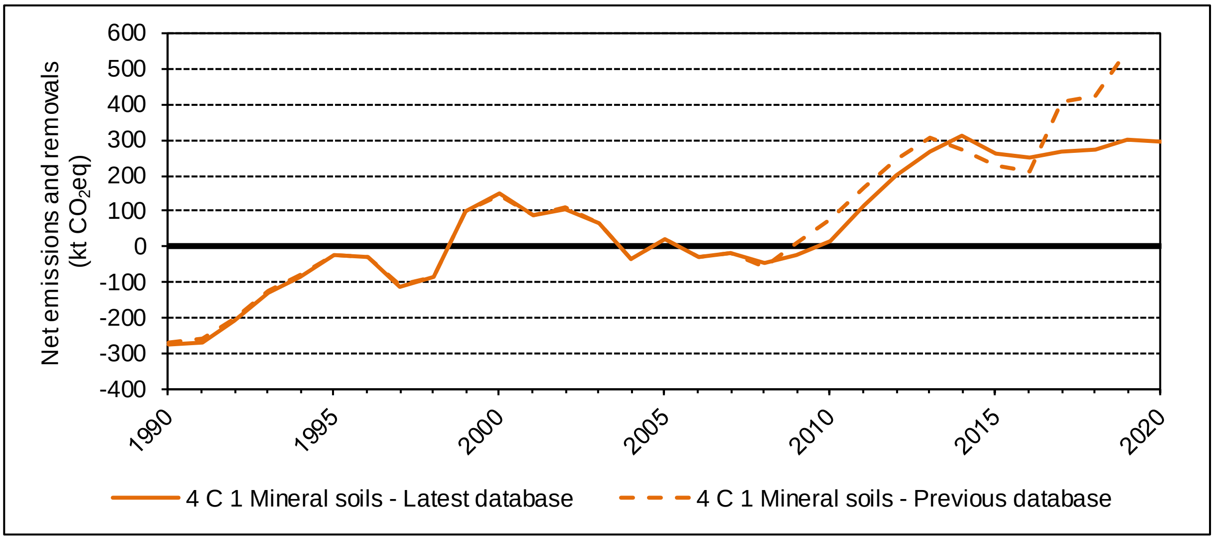



Figure 10-14 Comparison of net emissions (positive values) and net removals (negative values) from subcategory 4C1 Mineral soils on Grassland remaining grassland as reported in the previous and the latest submissions.

### 10.1.2.5. Waste

The total changes in emissions in the Waste sector due to all recalculations are shown in Figure 10-15 for $CO_2$, $CH_4$, and $N_2O$.

The only major recalculation is due to the reassessment of the $N_2O$ emission factor based on the evaluation of emission reports from sewage sludge incineration plants. The implementation of an emission reduction technique in several sewage sludge incineration plants in 2015 and 2017 led to a reduction of up to 70 kt $CO_2$ eq (see chp. 7.4.5). All other recalculations had an impact of less than 5 kt $CO_2$ eq (see Figure 10-15).

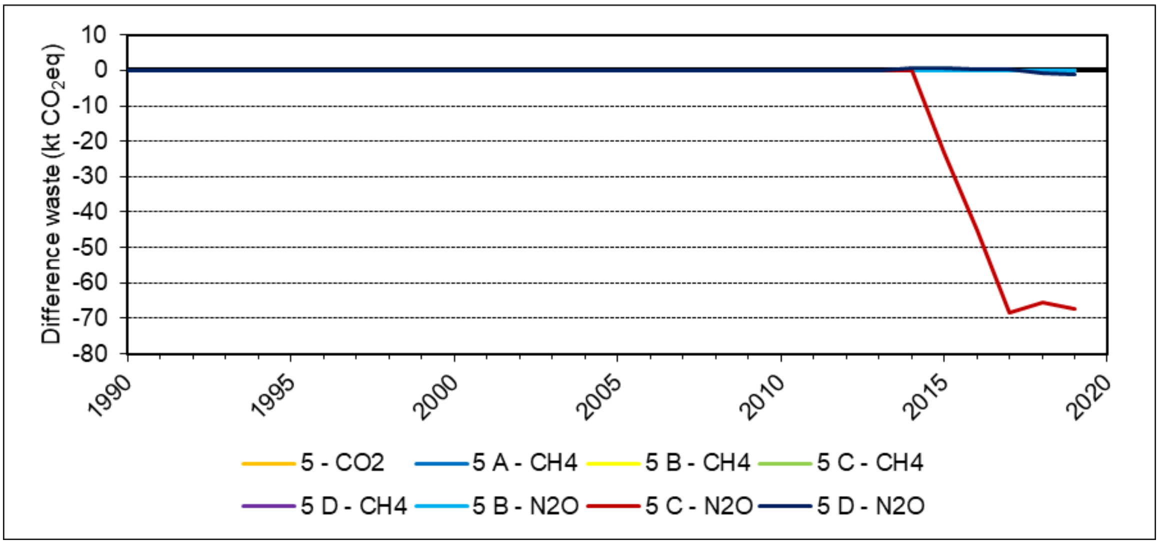



Figure 10-15 Differences in $CO_2$, $CH_4$, $N_2O$ emissions (in kt $CO_2$ eq) between the latest and the previous submissions for sector Waste. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

### 10.1.2.6. Other

There were no major recalculations implemented in submission 2022 for source category 6 Other.

### 10.1.2.7. Indirect $CO_2$ Emissions

The total changes in indirect $CO_2$ emissions due to all recalculations are shown in Figure 10-16.

The resulting recalculation is the sum of a decrease in NMVOC emissions in 1B2a (see chp. 3.3.3.5), an increase in CO emissions in 2B5 (see chp. 4.3.5) and the reassessment of VOC emissions in 2D and 2G (see chp. 4.5.5, 4.8.5).

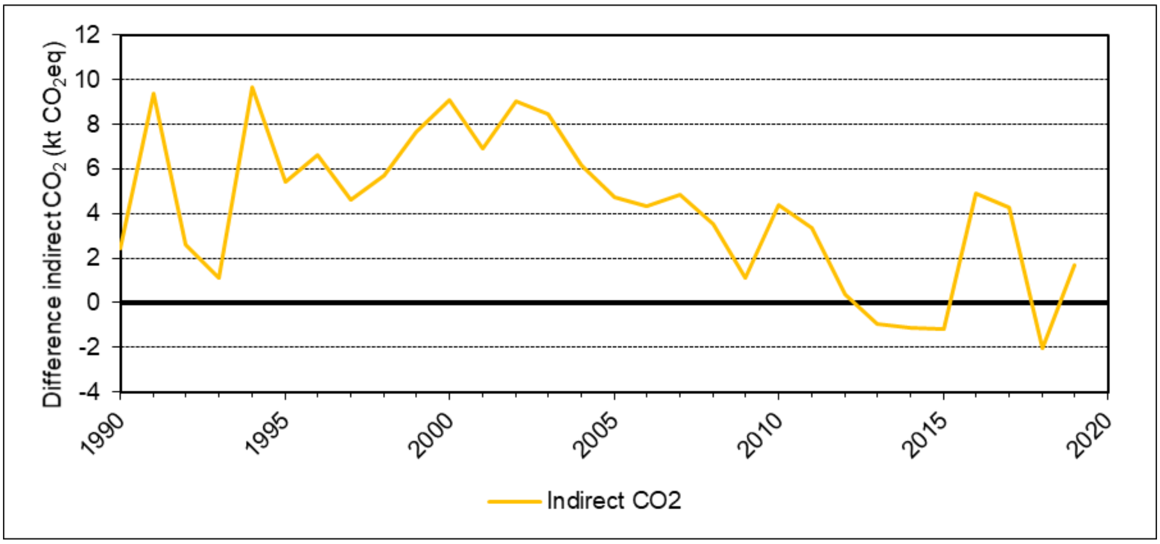



Figure 10-16 Differences in indirect $CO_2$ emissions (in kt $CO_2$ eq) between the latest and the previous submissions. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

### 10.1.2.8. KP-LULUCF Inventory

A technical correction of the FMRL (chp. 11.5.2.4) was performed.

All category-specific recalculations in categories 4A (chp. 6.4.5) and 4G (chp. 6.11.5), including the update of the activity data 1990–2019 (chp. 6.3.5), are relevant for the KP-LULUCF inventory. Figure 10-17 shows the differences in net emissions and removals for KP-LULUCF resulting from the recalculations. The overall pattern of the net emissions and removals remains unchanged (Figure 10-22).

- The incorporation of updated acitivity data (up to +11.7 kt $CO_2$ eq in year 2019) and the updated input data for HWP (up to -25.4 kt $CO_2$ eq in year 2018) were responsible for the recalculation of Forest management. They partly level out and lead to a maximum deviation of -15.2 kt $CO_2$ eq in 2018. Over most of the inventory period, the deviation is less than 3 kt $CO_2$ eq, mostly close to zero.
- Afforestation and Deforestation were hardly affected by the updated soil carbon stocks of mineral soil from Nussbaum and Burgos (2021). The incorporation of updated activity data were mainly responsible for the recalculations of Afforestation (-0.1–2.1 kt $CO_2$ eq) and Deforestation (0.4–29.0 kt $CO_2$ eq).

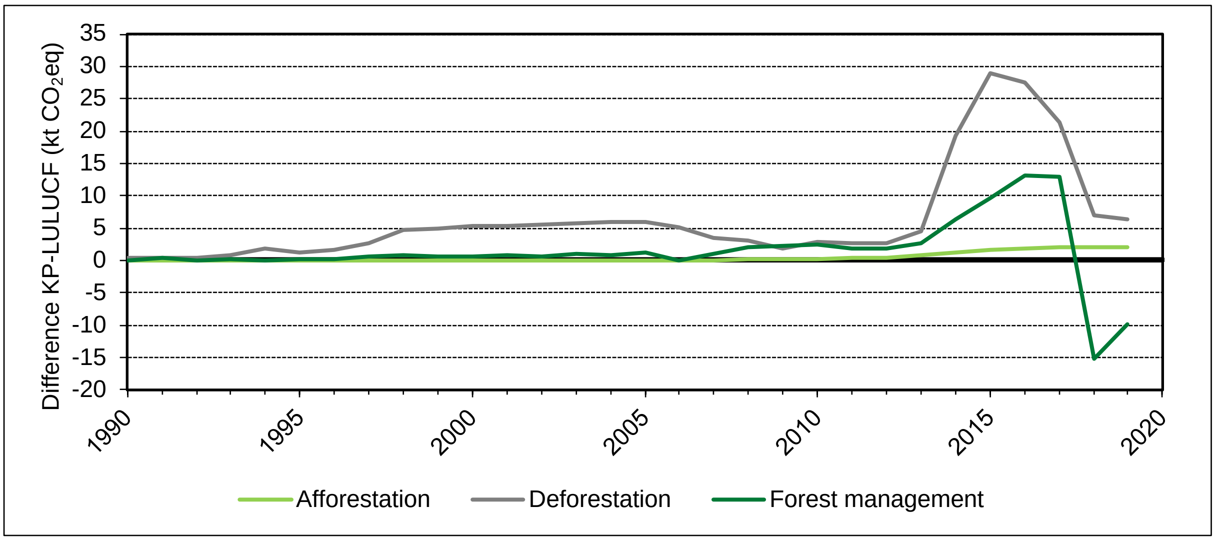



Figure 10-17 Differences in net emissions and removals (in kt $CO_2$ eq) between the latest and the previous submissions for Afforestation, Deforestation (Kyoto Protocol Art. 3.3), and Forest management (Kyoto Protocol Art. 3.4). Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

## 10.2. Implications for emission levels

Table 10-3 and Table 10-4 show the aggregated effect of all recalculations on the emission estimates for the base year 1990 and for the year 2019, respectively.

Table 10-3 Implications of recalculations for emission levels in 1990. Emissions (excluding indirect $CO_2$) are shown for the previous submission (FOEN 2021) and the latest submission. The difference refers to absolute values (Latest - Previous).

| Emissions for 1990 | $CO_2$ | | | $CH_4$ | | | $N_2O$ | | | F-Gases | | | Sum of all gases | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Latest | Previous | Difference | Latest | Previous | Difference | Latest | Previous | Difference | Latest | Previous | Difference | Latest | Previous | Difference |
| | $CO_2$ equivalent (kt) | | | | | | | | | | | | | | |
| 1 Energy | 40'907 | 40'900 | 7.3 | 617.9 | 611.4 | 6.6 | 317.3 | 317.8 | -0.5 | | | | 41'842 | 41'829 | 13.3 |
| 2 IPPU | 3'153 | 3'153 | -0.1 | 3.6 | 1.8 | 1.7 | 601.9 | 601.9 | 0.0 | 253.5 | 253.5 | 0.0 | 4'012 | 4'010 | 1.6 |
| 3 Agriculture | 48.9 | 48.9 | 0.0 | 4'250 | 4'329 | -78.9 | 2'283 | 2'284 | -0.9 | | | | 6'582 | 6'662 | -79.8 |
| 4 LULUCF | -2'128 | -2'098 | -29.4 | 28.3 | 28.3 | 0.0 | 55.2 | 54.2 | 1.0 | | | | -2'044 | -2'016 | -28.4 |
| 5 Waste | 40.2 | 40.2 | 0.0 | 919.5 | 919.5 | 0.0 | 158.5 | 158.5 | 0.0 | | | | 1'118 | 1'118 | 0.0 |
| 6 Other | 11.0 | 11.0 | 0.0 | 0.7 | 0.7 | 0.0 | 0.6 | 0.6 | 0.0 | | | | 12.2 | 12.2 | 0.0 |
| **Total including LULUCF** | **42'032** | **42'055** | **-22.3** | **5'820** | **5'891** | **-70.6** | **3'416** | **3'417** | **-0.4** | **253.5** | **253.5** | **0.0** | **51'522** | **51'616** | **-93** |
| | ***99.9%*** | ***100.0%*** | ***-0.1%*** | ***98.8%*** | ***100.0%*** | ***-1.2%*** | ***100.0%*** | ***100.0%*** | ***0.0%*** | ***100.0%*** | ***100.0%*** | ***0.0%*** | ***99.8%*** | ***100.0%*** | ***-0.2%*** |
| **Total excluding LULUCF** | **44'160** | **44'153** | **7.1** | **5'792** | **5'862** | **-70.6** | **3'361** | **3'362** | **-1.4** | **253.5** | **253.5** | **0.0** | **53'566** | **53'631** | **-64.9** |
| | ***100.0%*** | ***100.0%*** | ***0.0%*** | ***98.8%*** | ***100.0%*** | ***-1.2%*** | ***100.0%*** | ***100.0%*** | ***0.0%*** | ***100.0%*** | ***100.0%*** | ***0.0%*** | ***99.9%*** | ***100.0%*** | ***-0.1%*** |

| Emissions for 1990 | HFC | | | PFC | | | $SF_6$ | | | $NF_3$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Latest | Previous | Difference | Latest | Previous | Difference | Latest | Previous | Difference | Latest | Previous | Difference |
| | $CO_2$ equivalent (kt) | | | | | | | | | | | |
| 2 IPPU | 0.0 | 0.0 | 0.0 | 116.5 | 116.5 | 0.0 | 137.0 | 137.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Table 10-4 Implications of recalculations for emission levels in 2019. Emissions (excluding indirect CO2) are shown for the previous submission (FOEN 2021) and the latest submission. The difference refers to the absolute values (Latest - Previous)

| Emissions for 2019 | $CO_2$ | | | $CH_4$ | | | $N_2O$ | | | F-Gases | | | Sum of all gases | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Latest | Previous | Difference | Latest | Previous | Difference | Latest | Previous | Difference | Latest | Previous | Difference | Latest | Previous | Difference |
| | $CO_2$ equivalent (kt) | | | | | | | | | | | | | | |
| 1 Energy | 34'569 | 34'567 | 2.0 | 269.0 | 270.6 | -1.6 | 248.8 | 250.3 | -1.5 | | | | 35'087 | 35'088 | -1.0 |
| 2 IPPU | 2'099 | 2'108 | -9.1 | 6.9 | 2.9 | 4.0 | 685.7 | 685.7 | 0.0 | 1'614 | 1'590 | 23.5 | 4'406 | 4'387 | 18.3 |
| 3 Agriculture | 45.4 | 45.4 | 0.0 | 3'848 | 3'891 | -42.6 | 1'889 | 1'928 | -38.6 | | | | 5'783 | 5'864 | -81.2 |
| 4 LULUCF | -2'178 | -1'993 | -185.3 | 12.0 | 12.0 | 0.0 | 50.3 | 47.7 | 2.6 | | | | -2'116 | -1'933 | -182.7 |
| 5 Waste | 9.1 | 9.1 | 0.0 | 508.3 | 508.3 | 0.0 | 169.6 | 238.2 | -68.6 | | | | 687.1 | 755.6 | -68.6 |
| 6 Other | 10.1 | 11.7 | -1.7 | 0.5 | 0.6 | -0.1 | 0.4 | 0.5 | -0.1 | | | | 11.0 | 12.9 | -1.9 |
| **Total including LULUCF** | **34'555** | **34'749** | **-194.1** | **4'645** | **4'685** | **-40.2** | **3'044** | **3'150** | **-106.2** | **1'614** | **1'590** | **23.5** | **43'858** | **44'175** | **-317.0** |
| | ***99.4%*** | ***100.0%*** | ***-0.6%*** | ***99.1%*** | ***100.0%*** | ***-0.9%*** | ***96.6%*** | ***100.0%*** | ***-3.4%*** | ***101.5%*** | ***100.0%*** | ***1.5%*** | ***99.3%*** | ***100.0%*** | ***-0.7%*** |
| **Total excluding LULUCF** | **36'733** | **36'742** | **-8.8** | **4'633** | **4'673** | **-40.2** | **2'994** | **3'103** | **-108.8** | **1'614** | **1'590** | **23.5** | **45'974** | **46'108** | **-134.3** |
| | ***100.0%*** | ***100.0%*** | ***0.0%*** | ***99.1%*** | ***100.0%*** | ***-0.9%*** | ***96.5%*** | ***100.0%*** | ***-3.5%*** | ***101.5%*** | ***100.0%*** | ***1.5%*** | ***99.7%*** | ***100.0%*** | ***-0.3%*** |

| Emissions for 2019 | HFC | | | PFC | | | $SF_6$ | | | $NF_3$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Latest | Previous | Difference | Latest | Previous | Difference | Latest | Previous | Difference | Latest | Previous | Difference |
| | $CO_2$ equivalent (kt) | | | | | | | | | | | |
| 2 IPPU | 1'429 | 1'435 | -5.7 | 31.8 | 31.8 | 0.0 | 152.0 | 122.8 | 29.2 | 0.54 | 0.54 | 0.0 |

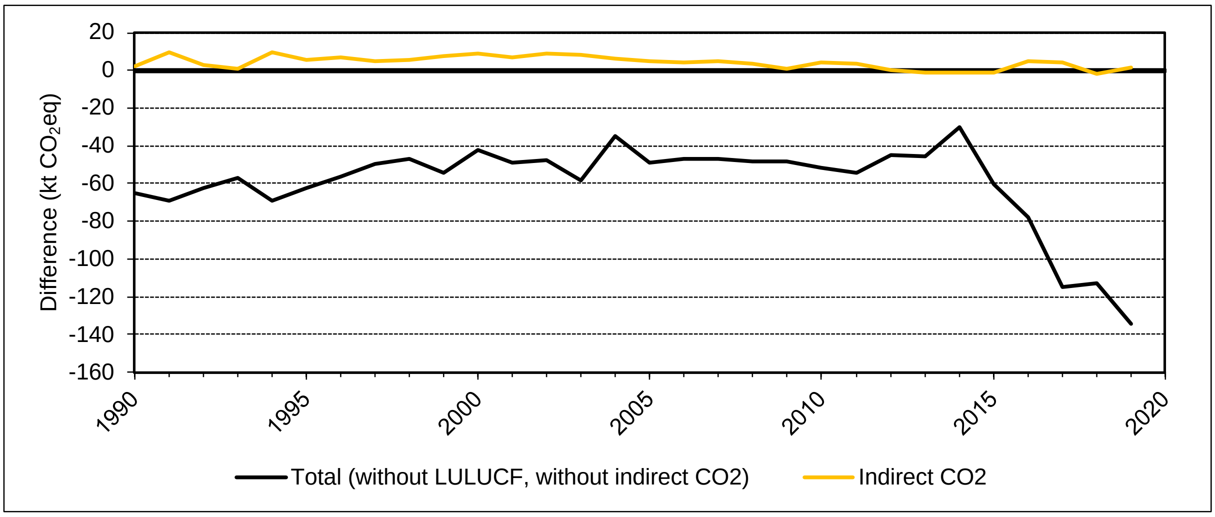



Figure 10-18 Implications of recalculations for the national total emissions (excluding LULUCF). The implications of recalculations for indirect $CO_2$ (in kt $CO_2$ eq) are shown separately (see also Figure 10-16). Positive values refer to higher emissions and negative values to lower emissions in the latest compared to the previous submission. For the implications of recalculations for LULUCF and KP-LULUCF see Figure 10-8 and Figure 10-17, respectively.

Figure 10-18 shows the aggregated effect of all the recalculations on national total emissions without LULUCF. The effect of the recalculations ranges from -65 kt $CO_2$ eq in 1990 to -134 kt $CO_2$ eq in 2019, corresponding to less than 0.3% of annual total emissions.

The aggregated effect of all recalculations on total net emissions and net removals from LULUCF are shown in Figure 10-8.

To further visualize the aggregated effect of all the recalculations, the following figures compare total emissions as reported in the previous and the latest submissions in absolute terms (instead of showing differences as in the figures above): Total emissions (without LULUCF, without indirect $CO_2$) in Figure 10-19, total indirect $CO_2$ emissions in Figure 10-20, total net emissions and net removals from LULUCF in Figure 10-21, and total net emissions and net removals from KP-LULUCF in Figure 10-22.

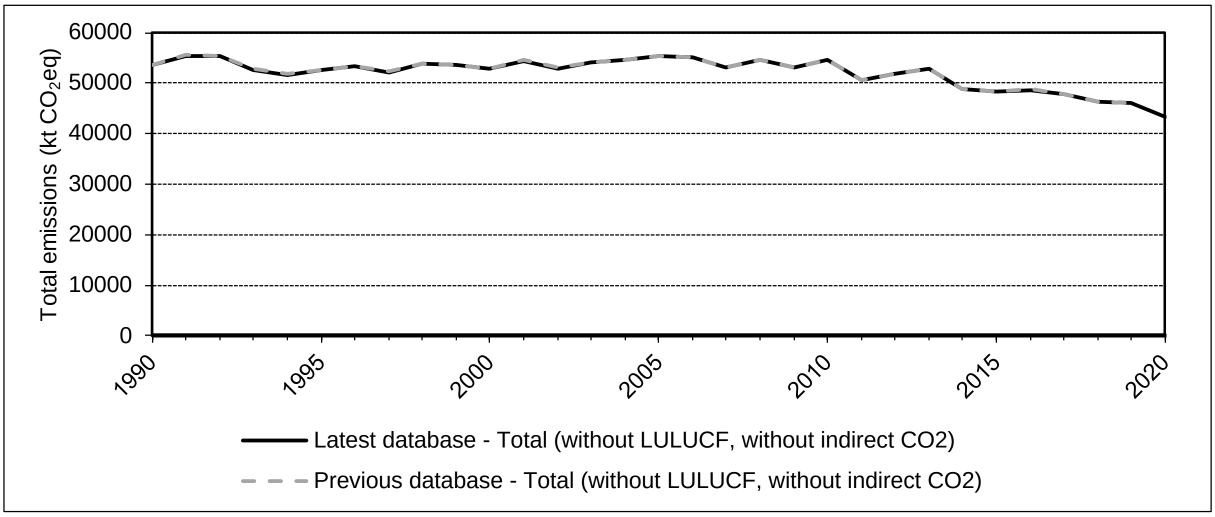



Figure 10-19 Comparison of total emissions (without LULUCF, without indirect $CO_2$) as reported in the previous and the latest submissions.

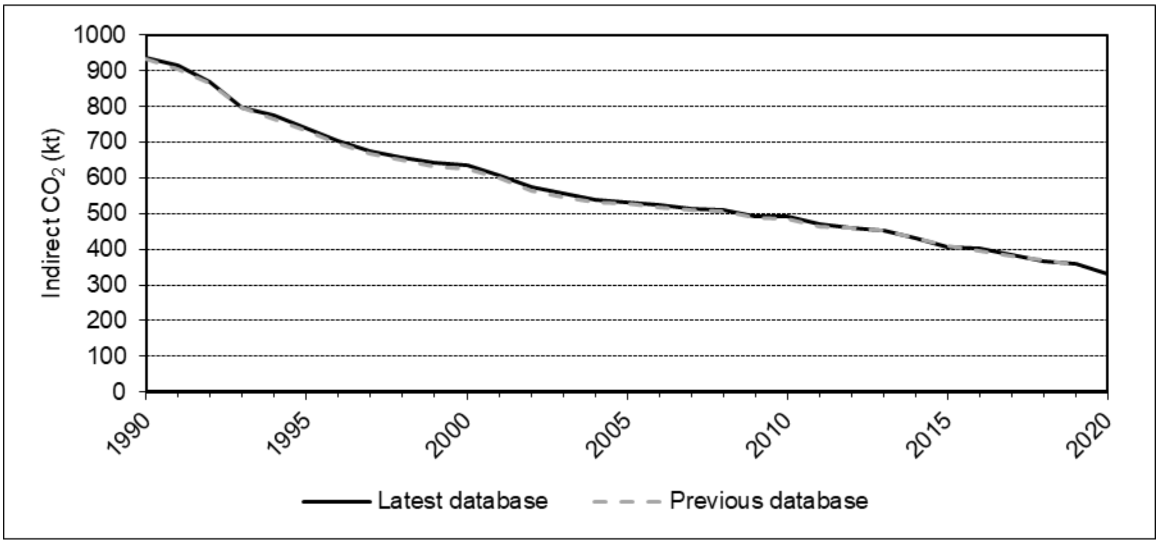



Figure 10-20 Comparison of total indirect $CO_2$ emissions as reported in the previous and the latest submissions.

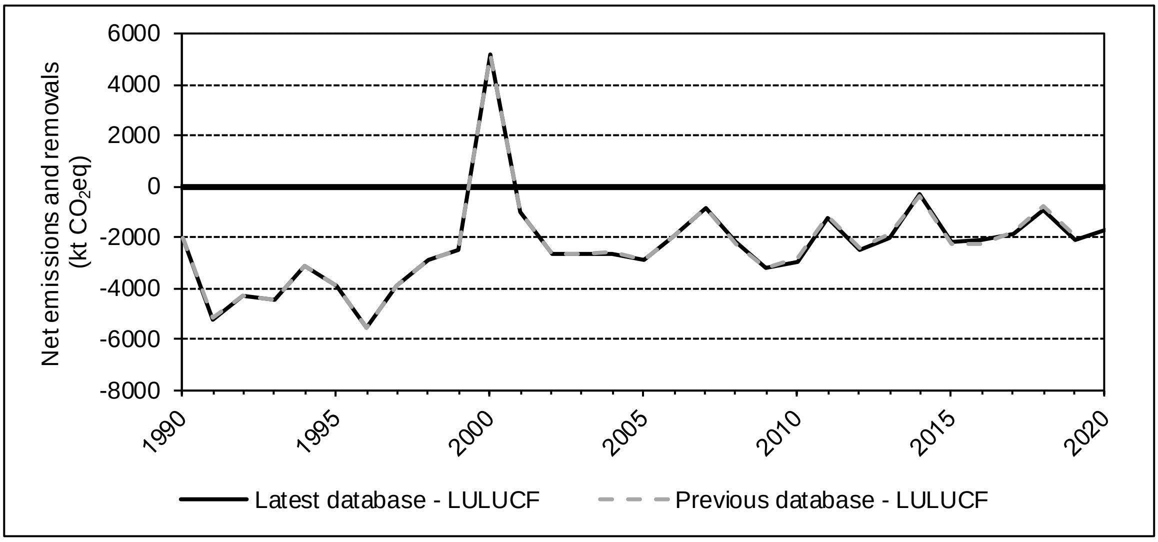



Figure 10-21 Comparison of net emissions (positive values) and net removals (negative values) from LULUCF as reported in the previous and the latest submissions.

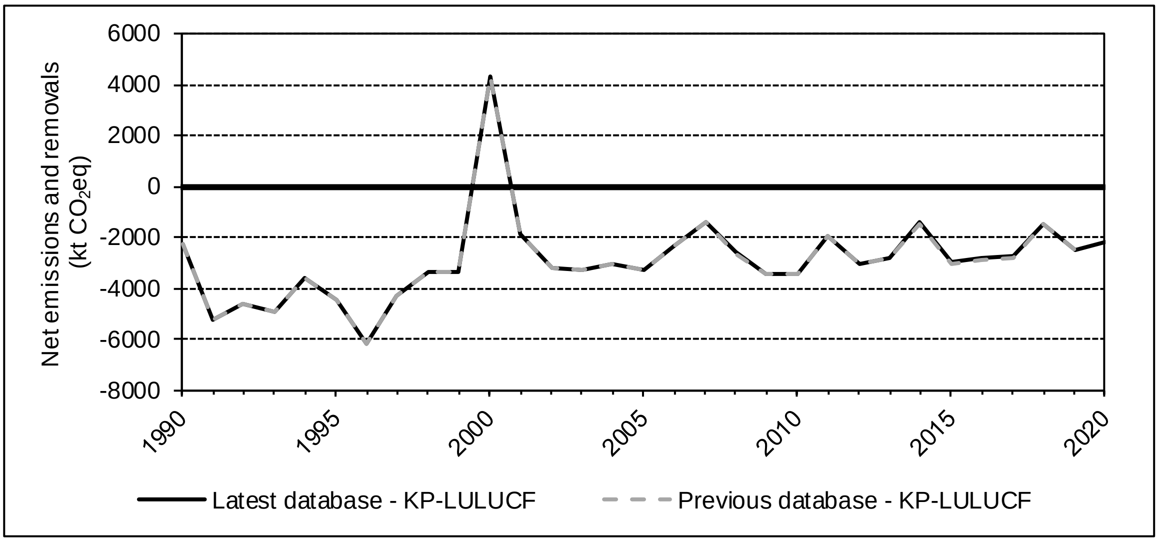



Figure 10-22 Comparison of net emissions (positive values) and net removals (negative values) from KP-LULUCF as reported in the previous and the latest submissions.

## 10.3. Implications for emissions trends, including time series consistency

As recalculations are applied to the entire time series (as appropriate), time series consistency is maintained. The emission trend for the Total excluding LULUCF from 1990–2019 has only slightly changed (see Table 10-5). Changes of the trend were slightly larger for the Total including LULUCF, mainly due to a recalculation in category 4C Grassland that had a major impact in the years after 2007 (chp. 10.1.2.4).

Table 10-5 Estimated emission trends 1990–2019, calculated based on national total emissions excluding indirect $CO_2$ as shown in the previous and the latest submission (for additional details see Table 10-3 and Table 10-4).

| Trend | 1990 | | 2019 | | Change 1990/2019 | |
|---|---|---|---|---|---|---|
| | Latest | Previous | Latest | Previous | Latest | Previous |
| | $CO_2$ equivalent (kt) | | | | % | |
| Total including LULUCF | 51'522 | 51'616 | 43'858 | 44'175 | -14.9% | -14.4% |
| Total excluding LULUCF | 53'566 | 53'631 | 45'974 | 46'108 | -14.2% | -14.0% |

## 10.4. Planned improvements, including in response to the review process

All categories mentioned hereafter have been identified as key categories according to the key category analysis except category 5B Biological treatment of solid waste (see overview of key categories in Table 1-9).

- 2F1: Improvements of HFC emission calculations from refrigeration and air conditioning equipment.
- 2F1: Changes are expected and will be analysed in this area due to the revision of the Chemical Risk Reduction Ordinance and $CO_2$ compensation programmes (share of products with HFC, recycling of HFC, early replacement of HFC).
- 3D: Started in 2019, FOEN funds the development and evaluation of a process-oriented model for $N_2O$ emissions in agricultural soils subject to common Swiss management practices.
- 4: The new Land Use Statistics (AREA5) will reduce the interval between successive surveys in the future to six years.
- 4: The suitability of newly available satellite data for land area representation in Switzerland is being evaluated.
- 4A: An update of the average carbon stock and carbon stock changes in living biomass of afforestations and young stands is planned for the submission in 2024.
- 4A: Planned progress on Yasso modelling for the submission in 2023 includes a review of the litter production estimates (including turnover rates) and improved uncertainty estimates for litter production (using a Monte Carlo approach).
- 4A: The Nussbaum and Burgos (2021) soil carbon stock data will be further processed and used for unproductive forest (CC13) in the next submission.
- 4B, 4C, 4D, 4E: Price et al. (2017) created a nationwide model for tree biomass in Switzerland (both inside and outside of forest), using structural information available from airborne laser scanning. The suitability of the obtained data for reporting in

categories 4B, 4C, 4D, and 4E, respectively, is subject to ongoing evaluation (Mathys et al. 2019; Price 2020; Kükenbrink et al. 2021). To account for the detected differences in tree geometry and associated biomass pattern a nationwide non-Forest land field survey of above ground tree biomass at the plot level was initiated by FOEN (2018–2024). The methodological approach is pursued with the overall objective to calculate a sound wall-to-wall above ground tree biomass database and map for Switzerland.

- 4B, 4C, 4D, 4E: A digital soil modelling (DSM) project at the Competence Center for Soils (CCSoils) addressed the shortcomings of missing spatially inclusive and comprehensive soil information in Switzerland. For the submission in 2023 initial SOC stocks for RothC modelling in categories 4B and 4C will be recalculated based on newly available DSM soil carbon and clay contents. An ongoing LULUCF module at CCSoils aims at improving the estimates of soil carbon stocks in Swiss non-forest soils. Results should be available for the GHG submission in 2024.
- 4C: A study on GHG ($CO_2$, $CH_4$, $N_2O$) emissions from an intensively used fen under grassland management in the Rhine valley (Agroscope, 2017–2022, financed by FOEN) will improve the robustness of country-specific carbon stock change and emission factor estimates for Grassland soils rich in organic matter in the medium term (Paul et al. 2020; Wang et al. 2021, 2022).
- 4G: Increased implementation of data from domestic industry is being explored.
- 5B: A research project in the framework of a joint research programme is investigating the $CH_4$ emissions from agricultural biogas facilities. Results will be implemented in the greenhouse gas inventory after completion of the project as appropriate.
- 5D: A research project aiming at deriving country-specific emission factors for $N_2O$ from wastewater treatment plants was completed recently (Gruber et al. 2021). Results will be implemented in the next greenhouse gas inventory.
- 5D1: In order to address the recommendations from the UNFCCC review process (UNFCCC 2022, issues W.5, W.6, W.7) concerning $CH_4$ emissions from domestic wastewater treatment outside the public sewer system, a study has been commissioned by FOEN. Results will be implemented in the greenhouse gas inventory after completion of the study as appropriate.

# PART 2

# 11. KP-LULUCF

| Responsibilities for chapter KP-LULUCF (Kyoto Protocol - Land use, and land-use change and forestry) | |
|---|---|
| Overall responsibility | Nele Rogiers (FOEN) |
| Authors & sector experts | Markus Didion (WSL), Nele Rogiers (FOEN), Esther Thürig (WSL) |
| Annual updates (NIR text, tables, figures) | Dominik Eggli (Meteotest), Pascal Graf (Meteotest), Nele Rogiers (FOEN) |
| Quality control NIR (annual updates) | Markus Didion (WSL), Marjo Kunnala (FOEN), Andreas Schellenberger (FOEN) |
| Internal review | Markus Didion (WSL), Andreas Schellenberger (FOEN) |

Switzerland has chosen to account over the entire second commitment period for GHG emissions and removals from activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol (FOEN 2016c, FOEN 2016d). In addition to the mandatory submission of the inventory years of the second commitment period, data for the years 1990–2012 are available. Switzerland accounts for the mandatory activity Forest management under Article 3, paragraph 4, of the Kyoto Protocol (FOEN 2016c). Switzerland applies the condition of direct human-induced in relation to Afforestation and Deforestation very strictly for both activities (see chp.11.1.3, FOEN 2010d, FOEN 2010h). CRF NIR-1 shows the activity coverage, the carbon pools and the GHG sources reported for the mandatory activities under Article 3, paragraph 3 and for Forest management under Article 3, paragraph 4, of the Kyoto Protocol. Detailed information on completeness of the activity coverage and reported pools is given in chp. 11.3.1.2. The areas and change in areas between the previous and the latest inventory year are shown in CRF NIR-2. CRF NIR-3 summarizes the results of the KCA for LULUCF activities under the Kyoto Protocol.

An overview of net annual $CO_2$ eq emissions and removals of activities under Article 3, paragraph 3 and Forest management under Article 3, paragraph 4, of the Kyoto Protocol is shown in

Figure 11-1 and Table 11-1. Fluctuations in annual GHG emissions and removals from Afforestation and Deforestation (Figure 11-2) can mainly be attributed to the changes in their respective areas (see Table 11-2 for activity data). The relative changes in the area of managed forest are comparatively small and fluctuations of the annual net carbon changes in Forest management can primarily be explained by changes in the carbon losses from the (1) living biomass pool, (2) dead wood pool and (3) litter pool (Table 11-1). The exceptionally high net emissions of Forest management in 2000 and the small net removals in the following year 2001 originate from winter storm “Lothar” at the end of 1999, which caused large-scale damages in forest stands and increased losses of living biomass due to salvage logging. Harvesting rates in Swiss forests gradually increased between 1991 and 2007. Peak values in 2006 and 2007 resulted in small removals from Forest management. In 2008 harvesting rates dropped (Table 6-14) due to the international and domestic economic framework conditions and remained relatively constant thereafter with interannual fluctuation of ca. 2 to 8%. These fluctuations are reflected in the year-to-year variability of the removals from Forest management. The small net removals in 2011, 2014 and 2018 are due to relative high harvesting rates in conjunction with above-average losses in the litter pool (related to climatic circumstances). Fluctuations in the Harvested wood products (HWP) pool are mainly caused by changes in the production of sawnwood and panels (see Table 6-33 and Figure

6-14). The contribution of paper and paperboard to changes in HWP fluctuates over the years, but is rather small compared to the contribution of sawnwood and panels.

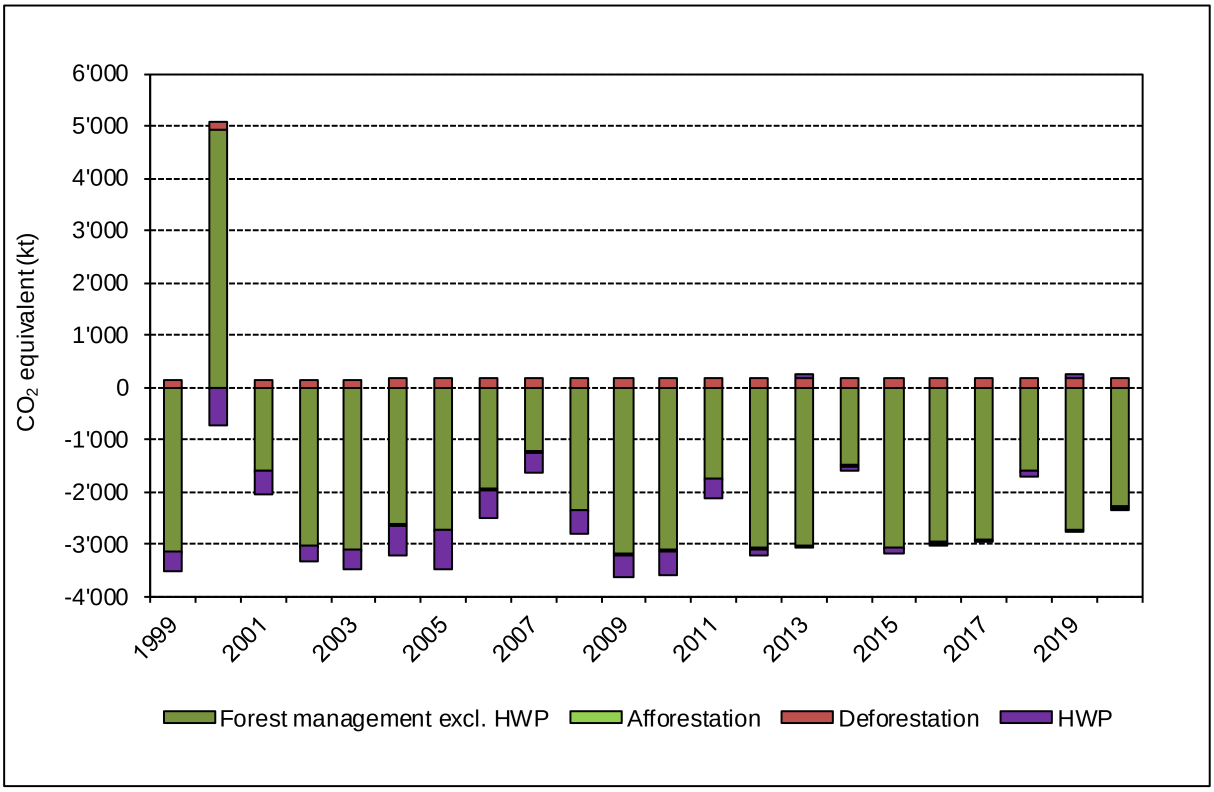



Figure 11-1 GHG emissions (positive sign) and removals (negative sign) from Afforestation (too small to be distinguishable) and Deforestation under Article 3, paragraph 3, Forest management excluding HWP, and HWP under Article 3, paragraph 4.

Table 11-1 Net $CO_2$ eq emissions (positive sign) and removals (negative sign) for activities accounted for under Article 3, paragraph 3 and Forest management under Article 3, paragraph 4, of the Kyoto Protocol, selected years. Abbreviations are explained in chp. 6.1.3.2 except for $loss_{drainage\ and\ LUC}$ ($N_2O$), $loss_{LUC}$ ($N_2O$), $loss_{drainage}$ ($N_2O$): $N_2O$ emissions associated with drainage and/or land-use change (LUC); $C_{l\_ag}$: carbon in above ground living biomass; $C_{l\_bg}$: carbon in below ground living biomass; $C_{s\_m}$: carbon in mineral soil; $C_{s\_o}$: carbon in organic soil; $C_{HWP}$: carbon in HWP pool; $loss_{biomburn}$: $CH_4$ and $N_2O$ emissions from biomass burning. Values correspond to data in CRF 4(KP) and CRF 4(KP-I)B.1.

| Greenhouse gas source and sink activities | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | kt $CO_2$ equivalent | | | | |
| **A. Article 3.3 activities** | **83.64** | **106.76** | **129.77** | **142.35** | **160.69** |
| A.1. Afforestation and Reforestation incl. $N_2O$; 4(KP) | -2.99 | -14.72 | -19.28 | -23.00 | -23.74 |
| Afforestation <= 20 yr | -2.99 | -14.75 | -19.31 | -23.03 | -22.97 |
| Afforestation > 20 yr | NO | NO | NO | NO | -0.80 |
| $loss_{drainage\ and\ LUC}$ ($N_2O$) | 0.006 | 0.03 | 0.03 | 0.03 | 0.03 |
| A.2. Deforestation incl. $N_2O$; 4(KP) | 86.62 | 121.48 | 149.05 | 165.35 | 184.43 |
| Deforestation excl. $N_2O$ | 86.50 | 120.72 | 147.54 | 163.03 | 181.27 |
| $loss_{LUC}$ ($N_2O$) | 0.12 | 0.76 | 1.52 | 2.32 | 3.16 |
| **B. Article 3.4 activities** | **-2'327.34** | **-4'587.76** | **4'222.81** | **-3'435.69** | **-3'564.51** |
| B.1. Forest management; 4(KP) | -2'327.34 | -4'587.76 | 4'222.81 | -3'435.69 | -3'564.51 |
| gain$C_{l_ag}$ | -9'759.89 | -9'698.18 | -9'730.50 | -9'766.63 | -9'987.11 |
| gain$C_{l_bg}$ | -2'749.42 | -2'751.13 | -2'763.85 | -2'777.29 | -2'866.87 |
| loss$C_{l_ag}$ | 8'870.59 | 6'792.34 | 13'984.67 | 8'468.23 | 8'600.22 |
| loss$C_{l_bg}$ | 2'682.92 | 2'006.48 | 3'904.90 | 2'465.81 | 2'612.47 |
| change$C_h$ | 25.55 | -236.12 | -77.06 | -704.26 | -990.05 |
| change$C_d$ | -253.57 | -223.73 | -371.53 | -390.14 | -472.41 |
| change$C_{s_m}$ | -3.97 | -4.50 | -7.99 | -9.91 | -9.80 |
| change$C_{s_o}$ | 1.08 | 1.09 | 1.09 | 1.10 | 1.12 |
| change$C_{HWP}$ | -1'168.76 | -486.96 | -722.55 | -727.12 | -455.33 |
| Forest management excl. $CH_4$ and $N_2O$; 4(KP-I)B.1 | -2'355.49 | -4'600.72 | 4'217.19 | -3'440.21 | -3'567.77 |
| $loss_{biomburn}$ ($CH_4$ and $N_2O$) | 28.00 | 12.81 | 5.47 | 4.38 | 3.11 |
| $loss_{drainage}$ ($N_2O$) | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| B.2. Cropland management | NA | NA | NA | NA | NA |
| B.3. Grazing land management | NA | NA | NA | NA | NA |
| B.4. Revegetation | NA | NA | NA | NA | NA |

| Greenhouse gas source and sink activities | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| | kt $CO_2$ equivalent | | | | | | | | | |
| **A. Article 3.3 activities** | **163.73** | **165.70** | **167.99** | **169.77** | **167.75** | **168.08** | **175.67** | **179.14** | **177.89** | **180.25** |
| A.1. Afforestation and Reforestation incl. $N_2O$; 4(KP) | -21.56 | -20.71 | -19.38 | -16.83 | -18.11 | -17.56 | -17.24 | -15.11 | -16.94 | -15.89 |
| Afforestation <= 20 yr | -20.63 | -18.31 | -16.31 | -14.83 | -13.93 | -13.14 | -12.67 | -12.43 | -12.18 | -11.93 |
| Afforestation > 20 yr | -0.95 | -2.42 | -3.09 | -2.02 | -4.19 | -4.43 | -4.59 | -2.70 | -4.77 | -3.96 |
| $loss_{drainage\ and\ LUC}$ ($N_2O$) | 0.03 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| A.2. Deforestation incl. $N_2O$; 4(KP) | 185.29 | 186.41 | 187.37 | 186.60 | 185.86 | 185.64 | 192.92 | 194.25 | 194.83 | 196.14 |
| Deforestation excl. $N_2O$ | 182.05 | 183.09 | 183.98 | 183.14 | 182.34 | 182.08 | 189.30 | 190.59 | 191.13 | 192.40 |
| $loss_{LUC}$ ($N_2O$) | 3.24 | 3.32 | 3.40 | 3.46 | 3.51 | 3.56 | 3.62 | 3.66 | 3.70 | 3.74 |
| **B. Article 3.4 activities** | **-2'083.10** | **-3'209.25** | **-2'964.66** | **-1'592.72** | **-3'147.28** | **-3'017.74** | **-2'916.12** | **-1'678.94** | **-2'658.92** | **-2'330.00** |
| B.1. Forest management; 4(KP) | -2'083.10 | -3'209.25 | -2'964.66 | -1'592.72 | -3'147.28 | -3'017.74 | -2'916.12 | -1'678.94 | -2'658.92 | -2'330.00 |
| gain$C_{l_ag}$ | -10'000.42 | -10'013.73 | -10'026.47 | -10'038.97 | -10'037.10 | -10'064.23 | -10'076.48 | -10'088.54 | -10'100.75 | -10'113.67 |
| gain$C_{l_bg}$ | -2'871.53 | -2'876.20 | -2'880.83 | -2'885.23 | -2'885.30 | -2'894.06 | -2'898.46 | -2'902.86 | -2'907.29 | -2'911.94 |
| loss$C_{l_ag}$ | 8'548.17 | 7'867.12 | 8'135.41 | 8'372.36 | 7'781.47 | 7'655.44 | 7'999.27 | 8'728.00 | 7'827.69 | 8'001.87 |
| loss$C_{l_bg}$ | 2'603.52 | 2'411.01 | 2'505.79 | 2'585.19 | 2'408.14 | 2'382.80 | 2'485.19 | 2'695.96 | 2'450.58 | 2'484.72 |
| change$C_h$ | 240.13 | -165.23 | -419.74 | 593.76 | -77.21 | 113.61 | -180.13 | 151.14 | 154.80 | 336.05 |
| change$C_d$ | -245.65 | -293.13 | -330.31 | -100.61 | -235.45 | -157.05 | -225.63 | -160.15 | -133.69 | -68.50 |
| change$C_{s_m}$ | -11.06 | -10.84 | -11.08 | -11.68 | -11.09 | -11.21 | -11.16 | -11.48 | -11.37 | -11.22 |
| change$C_{s_o}$ | 1.12 | 1.12 | 1.13 | 1.13 | 1.13 | 1.14 | 1.14 | 1.14 | 1.15 | 1.15 |
| change$C_{HWP}$ | -353.54 | -132.57 | 58.29 | -112.18 | -95.33 | -51.93 | -14.54 | -95.81 | 57.14 | -51.14 |
| Forest management excl. $CH_4$ and $N_2O$; 4(KP-I)B.1 | -2'089.26 | -3'212.45 | -2'967.81 | -1'596.22 | -3'150.75 | -3'025.49 | -2'920.80 | -1'682.59 | -2'661.74 | -2'332.69 |
| $loss_{biomburn}$ ($CH_4$ and $N_2O$) | 6.00 | 3.05 | 2.99 | 3.35 | 3.31 | 7.59 | 4.53 | 3.49 | 2.67 | 2.53 |
| $loss_{drainage}$ ($N_2O$) | 0.15 | 0.15 | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 |
| B.2. Cropland management | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| B.3. Grazing land management | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| B.4. Revegetation | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |

The CRF table “accounting” (Information table on accounting for activities under Articles 3.3 and 3.4 of the Kyoto Protocol) gives an overview of the net $CO_2$ eq emissions and removals from Afforestation and Deforestation under Article 3, paragraph 3 and Forest management under Article 3, paragraph 4.

In 2020, Forest management in Switzerland caused removals of -2’330.00 kt $CO_2$ eq. The debit incurred from activities under Article 3.3 is 180.25 kt $CO_2$ eq (Table 11-1).

Further information on the extend removals from Forest management offset the debit incurred under Article 3, Paragraph 3 is provided in chp. 11.5.5.

## 11.1. General information

The data sets on which the calculations are based are described in chp. 6.2, chp. 6.3 (Swiss Land Use Statistics AREA) and chp. 6.4.2.1 (National Forest Inventory NFI).

Methodological issues and assumptions concerning the calculation of activity data and implied carbon stock change factors used for the reporting under Article 3, paragraphs 3 and 4, of the Kyoto Protocol follow the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) as described in chp. 6.4.2 and in the KP Supplement (IPCC 2014).

### 11.1.1. Definition of forest and any other criteria

The forest definition used under the Kyoto Protocol is defined in Switzerland's first Initial Report (FOEN 2006h, Sect. E) and it is still valid for the second commitment period (FOEN 2016c; see also chp. 6.4.1). Forest is defined as a minimum area of land of 0.0625 ha with crown cover of at least 20% and a minimum width of 25 m. The minimum height of the dominant trees must be 3 m or have the potential to reach 3 m at maturity in situ. The selected parameters are listed in CRF NIR-1.

Some land categories were explicitly excluded from the land-use category Forest land, although they may partly fulfil the requirements of the Swiss forest definition used under the Kyoto Protocol (see chp. 6.2.1, Table 6-6, chp. 6.4.1, and FOEN 2006h, Sect. E):

- Vineyards, Low-Stem Orchards, Tree nurseries, Copses and Orchards in the land-use category Grassland;
- Cemeteries and public parks in the land-use category Settlements.

### 11.1.2. Elected activities under article 3, paragraph 4, of the Kyoto Protocol

Switzerland only accounts for the mandatory activity Forest management under Article 3, paragraph 4, of the Kyoto Protocol (FOEN 2016c). In accordance with Annex I to Decision 2/CMP.7 (Annex I, Para 13), additions to the assigned amount resulting from Forest management under Article 3, paragraph 4, are capped. This cap for the second commitment period amounts to 15’037’884 t $CO_2$ eq for the entire commitment period 2013–2020 (FOEN 2016d).

### 11.1.3. Description of how the definitions of each activity under article 3.3 and each elected activity under article 3.4 have been implemented and applied consistently over time

The definitions of Afforestation, Deforestation and Forest management are published in Switzerland's Initial Report (see FOEN 2006h, Sect. E and F). They are still valid for the second commitment period (FOEN 2016c). Switzerland applies the condition of direct human-induced in relation to Afforestation and Deforestation very strictly for both activities (see FOEN 2010d; FOEN 2010h).

For the notation of activities under article 3.3 and article 3.4 of the Kyoto Protocol, the first character is capitalised (see chp. 6.1.3.1): Afforestation, Deforestation and Forest management.

**Afforestation**

Afforestation is the conversion to forest of an area not fulfilling the definition of forest for a period of at least 50 years if the definition of forest in terms of minimum area (625 $m^2$) is fulfilled, and the conversion is a direct human-induced activity (FOEN 2006h).

Forest land is expanding in Switzerland (see “Forest management area” in Table 11-2). The land-use change matrix (Table 6-9) shows that these conversions are mainly occurring on former grasslands (CC3X to CC12 or to CC13; cf. Table 6-2). In response to UNFCCC (2022, ID#KL.2), the main reason for this expansion is natural forest regeneration in the alpine area: In Switzerland, land-use change from non-forest land to forest land is usually not caused by plantation but by abandonment of agricultural land-use (Gehrig-Fasel et al. 2007; Rutherford et al. 2008; SWI 2009; Brändli 2014; Rigling and Schaffer 2015; Brändli et al. 2020; see chp. 6.4.2.8). Such newly forested areas typically exhibit a large diversity in diameter at breast height (DBH) and tree age.

Natural forest regeneration following the abandonment of subalpine pastures is not considered to be a direct human-induced activity. Only conversions to forest land which can clearly be attributed as direct human-induced from aerial photographs (SFSO 2021; see also chp. 6.1.3.1) are considered as Afforestation under the Kyoto Protocol. Examples of direct human-induced conversions to forest land (Afforestations) are shown in FOEN (2010h).

**Deforestation**

Deforestation is the permanent conversion of areas fulfilling the definition of forest in terms of minimum forest area (625 $m^2$) to areas not fulfilling the definition of forest as a consequence of direct human influence (FOEN 2006h).

Temporary removals of trees (e.g. of strips or clusters for the construction of high-voltage power lines, cable car lines, maintenance roads along railway lines and highways) are not reported as Deforestation under the Kyoto Protocol because in those cases the forest stand has to be re-established (FOEN 2014q). In the NFI, small areas <25m wide (e.g. unsurfaced storage yards located next to a forest road) or strips that are clear of trees (e.g. unpaved forest roads <6 m wide) or areas where trees are maintained at a certain lower height (e.g. under power lines) are considered as forest if they are not clearly separable from the surrounding forested land (Lanz et al. 2019). In the course of the next survey of land use statistics (inter-survey period 9 to 12 years; see chp. 6.3.1) it is possible to check if deforestations or other land-use changes have been correctly classified. The classification of all land-use changes classified as Deforestation under the Kyoto Protocol were screened (Sigmaplan 2012a). Based on Table CRF 4(KP-I)A.2, in the reporting year 21% (2.7 kha) of the 12.6 kha Kyoto Deforestations were in fact temporary removals of tree cover, which should be classified as "management interventions" rather than as real land-use changes. 79% of the area of the Deforestations were still deforested after 30 years. As no reclassification was done, the area of Deforestations reported under the Kyoto Protocol Art. 3.3 is in fact an overestimation. Accordingly, emissions are overestimated since implied carbon stock change factors for carbon losses in living biomass for Deforestations are higher than for Forest management (see CRF 4(KP-I)A.2 for Deforestations and CRF 4(KP-I)B.1 for Forest management). The area of the current land-use after Deforestation is given as information item in CRF 4(KP-I)A.2. Since no additional activities besides Forest management are elected under Art. 3.4, only the activity data are given and no information on changes in carbon stocks is provided.

In response to UNFCCC (2022, ID#KL.3), an additional check of the areas displayed in CRF 4(KP-I)A.2 has been performed and added to the checklist described in chp. 1.2.3, to ensure that the total areas reported under the information item ("land areas under deforestation by land-use category in the reporting year") are consistent with the total areas reported for deforestation and with the deforested areas reported in CRF table NIR-2.

**Reforestation**

Reforestation does not occur in Switzerland (FOEN 2006h, Sect. E; see also chp. 11.4.1).

**Forest management**

Forest management includes all activities serving the purpose of fulfilling the Federal Law on Forests (Swiss Confederation 1991: Art. 1c), i.e. the obligation to conserve forests and to ensure forest functions – such as wood production, protection against natural hazards, preservation of biodiversity, purification of drinking water, and maintenance of recreational value – in a sustainable manner.

### 11.1.4. Description of precedence conditions and/or hierarchy among 3.4. activities and how they have been consistently applied in determining how land was classified.

Since Switzerland only accounts for Forest management from the activities of Article 3, paragraph 4, of the Kyoto Protocol, the hierarchy among 3.4 activities does not affect Swiss reporting.

## 11.2. Land-related information

### 11.2.1. Spatial assessment unit used for determining the area of the units of land

The spatial assessment unit for the submission of the KP reporting tables covers the entire territory of Switzerland, i.e. 4'129.073 kha (see chp. 6.3.1; Table 6-8).

All activity data for reporting the activities under the Kyoto Protocol are retrieved from the Swiss Land Use Statistics AREA (https://www.bfs.admin.ch/bfs/en/home.gnpdetail.2021-0316.html; SFSO 2006a; SFSO 2021; see chp. 6.3.1). AREA uses a georeferenced sample grid with a grid size of 100 m by 100 m. To each grid point a specific combination category is assigned (see Table 6-2).

## 11.2.2. Methodology used to develop the land transition matrix

The methodology used to develop the land transition matrices is described in detail in chp. 6.2.3.

## 11.2.3. Maps and/or database to identify the geographical locations and the system of identification codes for the geographical locations

All Afforestations and Deforestations are accounted for under Article 3, paragraph 3 and are not reported under Forest management under Article 3, paragraph 4. Afforestations older than the conversion period of 20 years are still reported under Afforestation: The value of “Total for Activity A.1” in CRF 4(KP-I)A.1 equals the cumulated afforestated areas since 1990 as shown in Table 11-2 and CRF NIR-2. The area of Deforestations displayed under “Total for activity A.2” in CRF 4(KP-I)A.2 encompasses the cumulated area of Deforestations since 1990 (see also Table 11-2 and CRF NIR-2). However, only the cumulated area of Deforestations of the last 20 years are relevant to calculate changes in carbon stocks (Table 6-3).

The calculation of changes in carbon stocks is described in chp. 11.3.1.1. The changes in areas between the activities under Article 3, paragraph 3 and Article 3, paragraph 4 are listed in CRF NIR-2.

The area under Forest management is subdivided into productive forests (CC12) and unproductive forests (CC13; for a description see chp. 6.4.2.7). Productive forests in Switzerland reveal a high heterogeneity in terms of elevation, growth conditions and tree species composition (see chp. 6.2.2 and Figure 6-4). Therefore, Switzerland has been stratified into five National Forestry Inventory production regions (L1: Jura, L2: Central Plateau, L3: Pre-Alps, L4: Alps, L5: Southern Alps), three elevation zones (Z1: <601 m, Z2: 601-1200 m, Z3: >1200 m) and two soil types (mineral soils and organic soils). In the reporting tables, the stratification of the activity data into production region (L) and elevation level (Z) is indicated in the column “Subdivision”.

**Area reported under Afforestation, Deforestation and Forest management**

Land Use Statistics (AREA) data allow to clearly separate between the land areas subject to a specific activity. Absolute and cumulated activity data since 1990 of Afforestations, Deforestations and Forest management are listed in Table 11-2. The total country area amounts to 4'129'073 ha (Table 6-8).

Table 11-2 Activity data for activities under Article 3, paragraphs 3 and 4, selected years. Data for Afforestation, Deforestation and areas under Forest management were derived from the Swiss Land Use Statistics (AREA) (SFSO 2006a, 2021). See also CRF NIR-2.

| | Unit | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Afforestation area | kha | 0.26 | 0.12 | 0.06 | 0.05 | 0.04 |
| Cumulated area of Afforestation since 1990 | kha | 0.26 | 1.28 | 1.67 | 1.96 | 2.19 |
| Deforestation area | kha | 0.30 | 0.36 | 0.40 | 0.41 | 0.46 |
| Cumulated area of Deforestation since 1990 | kha | 0.30 | 1.93 | 3.85 | 5.89 | 8.13 |
| Forest management area | kha | 1'210.65 | 1'221.63 | 1'229.18 | 1'236.06 | 1'245.14 |

| | Unit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Afforestation area | kha | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.03 | 0.04 | 0.04 | 0.04 | 0.04 |
| Cumulated area of Afforestation since 1990 | kha | 2.23 | 2.27 | 2.31 | 2.35 | 2.39 | 2.42 | 2.46 | 2.49 | 2.53 | 2.57 |
| Deforestation area | kha | 0.46 | 0.45 | 0.45 | 0.44 | 0.44 | 0.43 | 0.45 | 0.45 | 0.44 | 0.45 |
| Cumulated area of Deforestation since 1990 | kha | 8.59 | 9.04 | 9.49 | 9.93 | 10.37 | 10.80 | 11.25 | 11.70 | 12.15 | 12.60 |
| Forest management area | kha | 1'247.04 | 1'248.95 | 1'250.84 | 1'252.68 | 1'254.54 | 1'256.44 | 1'258.39 | 1'260.35 | 1'262.31 | 1'264.30 |

## Afforestation

Activity data for Afforestations are derived from the Swiss Land Use Statistics (AREA; SFSO 2006a, 2021; see also chp. 6.3.1). A detailed description of the identification of Afforestations fulfilling the Kyoto definition is provided in FOEN (2010h).)

In Switzerland, land-use change from non-forest to forest is usually not caused by plantation but by abandonment of agricultural land-use (see 11.1.3 for references in response to UNFCCC (2022, ID#KL.2)).

## Deforestation

Data for Deforestations are derived from the Swiss Land Use Statistics (AREA; SFSO 2006a, 2020; see also chp. 6.3.1). A detailed description of the identification of Deforestations under the Kyoto Protocol from the AREA data set is given in FOEN (2010d) and Sigmaplan (2010a).

Not all changes from a forest combination category (afforestation CC11, productive forest CC12 and unproductive forest CC13) to a non-forest combination category correspond to the definition of Deforestation according to the Kyoto Protocol Art. 3.3. The following criteria are used to identify conversions from a forest combination category to a non-forest combination category, which are not classified as Deforestations under the Kyoto Protocol Art. 3.3 (FOEN 2010d):

1. Non-permanent conversions are due to common forest management practices, natural dynamics or hazards:

- Tree loss is temporally limited, i.e., areas with loss of tree biomass, but where a change in land use cannot be identified: Natural regeneration, which is a common practice in Swiss forest management, is expected, but could not yet be recognized on the aerial photograph at the time the last AREA survey (see chp. 6.3.1) was conducted. Also, in the NFI methodology (Lanz et al. 2019) “forest aisles” under power lines are explicitly classified as forests (see also chp. 11.1.3). Further, data in the information item of CRF 4(KP-I)A.2 show that although the aspect of "temporal limitiation" was considered when classifying Deforestations, at the end approximately 21% of these Kyoto Deforestations were in fact "short-term reduction of crown coverage" and should have been classified as "management interventions" rather than as real land-use changes (see chp. 11.1.3; Sigmaplan 2012a).

- Tree loss is spatially limited, i.e., conversion is caused by an alteration of the surrounding stand, but the change does not affect the tree cover at the sample point: this criterion applies also to the case of a Swiss-specific silvo-pastoral system of grasslands with tree cover. It is very difficult for interpreters of aerial photographs to determine this land use/land cover correctly. In fact, these points could be attributed to two coequal land-use types: agricultural area (NOLU04 2XX) and forest area (NOLU04 3XX; cf. Table 6-6). Land cover on these points is in general open forest (NOLC04 44), linear woods (NOLC04 46) or cluster of trees (NOLC04 47; cf. Table 6-6). When tree vegetation on these grasslands becomes denser over time, land owners remove single trees every now and then. This management practice can lead to the fact that an interpreter of aerial photographs reclassifies the sample point into a different land-use type during a later survey (i.e. change from forest area NOLU04 3XX to agricultural area NOLU04 2XX), although in reality no LUC took place on these sites; and, moreover, all elements of the Kyoto forest definition are still fulfilled (see Table 2 in FOEN 2010d).

2. Conversions of combination categories (see Table 6-2 and Table 6-6) which do not meet the definition of Deforestation as defined under the Kyoto Protocol and in Switzerland's Initial Report (FOEN 2006h):

- Areas smaller than the minimum area of 625 $m^2$.
- Areas with a reduction in forest cover on the grid point but still fulfilling the Kyoto definition of forest, i.e. having the potential to reach 3 m at maturity in situ.

3. No change in land use took place: reduction of tree cover without land-use change; former land use was mainly pasture.

4. Tree loss is not directly human-induced: Conversion due to natural hazards and dynamics.

The four criteria were applied to the land-use change data of the AREA survey for calculating annual values of the respective area (e.g. the cumulative area of non-Kyoto loss of forest cover was 1.229 kha in 2020, see Table 11-6).

It was ensured that the criteria and the application to identify conversions which do not correspond to Deforestations under the Kyoto Protocol do not result in inconsistencies in the estimates of changes in carbon stocks on the converted areas. If a sample point in the AREA data set is not classified as Kyoto Deforestation, it remains classified as Forest management. The classification under Forest management implies that carbon stocks on these areas are based on NFI data (see chp. 6.4.2.1). Thus, carbon stock changes are reflected in the implied carbon stock change factors in the reporting tables and are completely accounted for.

**Forest management**

Since all forests in Switzerland are subject to certain forest management practices, the area under the activity Forest management corresponds to the forest area (see FOEN 2006h, Sect. E; FOEN 2016c) as derived from the Swiss Land Use Statistics (AREA; SFSO 2006a, 2020; see also chp. 6.3). Changes in pools for the following geographical locations are reported:

- productive forest remaining productive forests (CC12 remaining)
- productive forest converted to unproductive forests (CC12 to CC13)
- unproductive forest remaining unproductive forests (CC13 remaining)
- unproductive forest converted to productive forests (CC13 to CC12).

# 11.3. Activity-specific information

## 11.3.1. Methods for carbon stock change and GHG emission and removal estimates

### 11.3.1.1. Description of the methodologies and the underlying assumptions used

Implied carbon stock change factors for Afforestations, Deforestations and Forest management were accounted for following the methodology described in chp. 6.1.3.2. The methodological approach is based on the details provided in Table 6-3 and on equations 6.1-6.8, and it is displayed in detail for each carbon pool in Table 11-4. Annual values for carbon stocks and carbon stock changes in the pools of living biomass, dead wood, litter and mineral soil of Afforestations (CC11), productive forests (CC12) and unproductive forests (CC13) are displayed in Table 6-4, Table 6-15, Table 6-16 and Table 6-17. All working steps and data required to reproduce the calculation of emission factors in the reporting tables are summarized in FOEN (2022d).

**Separation of above- and below ground living biomass**

Carbon stock of total living biomass can be separated into above- and below ground components. Under the UNFCCC aggregated pools were reported, under the Kyoto Protocol the pools were reported separately. For Forest management the stratified ratios shown in Table 11-3 were used. For Afforestation and Deforestation the domestic mean value (0.30) was used.

Table 11-3 Root-to-shoot ratios to separate total living biomass into above- and below ground living biomass. The ratios are retrieved from the NFI (Brändli 2010: Table 95).

| NFI region | Elevation [m] | Root-to-shoot ratios for living trees |
|---|---|---|
| 1 | <601 | 0.22 |
| | 601-1200 | 0.27 |
| | >1200 | 0.35 |
| 2 | <601 | 0.22 |
| | 601-1200 | 0.24 |
| | >1200 | 0.40 |
| 3 | <601 | 0.23 |
| | 601-1200 | 0.28 |
| | >1200 | 0.37 |
| 4 | <601 | 0.25 |
| | 601-1200 | 0.30 |
| | >1200 | 0.40 |
| 5 | <601 | 0.28 |
| | 601-1200 | 0.32 |
| | >1200 | 0.40 |
| Switzerland | <601 | 0.23 |
| | 601-1200 | 0.27 |
| | >1200 | 0.39 |
| | average | 0.30 |

Table 11-4 Application of the methodolgy described in equations 6.1-6.8 in chp. 6.1.3.2 and in Table 6-3 for calculating carbon stock changes for the Kyoto activities Afforestations (CC11) younger than 20 years (≤ 20 yr) and older than 20 years (>20 yr), Deforestations, and Forest management appearing in four types as defined by land use and land-use change, respectively (CC12 remaining, CC13 remaining, CC12 to CC13, i.e. conversions from CC12 to CC13, and CC13 to CC12, i.e. conversions from CC13 to CC12). In the case of Deforestation to buildings and constructions (i.e. a land-use change from C1X to CC51), carbon stock changes in mineral soils and in organic soils are accounted for by reducing the carbon stock by 20% (see chp. 6.8.2.2.3). A conversion time (CT) of 20 years was applied for all pools except for the losses in living biomass, in litter and in dead wood after Deforestation (CT=1 year). Subscripts used: l = living biomass, h = litter, d = dead wood, s_m = mineral soil, s_o = organic soil, i = spatial stratum, a = land-use-type after the conversion, b = land-use-type before the conversion. CC11 (Afforestation), CC12 (productive forests) and CC13 (unproductive forests) refer to the respective combination category, CC1X = CC11, CC12, and CC13 (see Table 6-2).

| | Living Biomass | Litter | Dead Wood | Mineral Soil | Organic Soil |
|---|---|---|---|---|---|
| **Afforestation CC11 ≤ 20 yr** | gain-loss<br>gainC$_{l,i,CC11}$ - lossC$_{l,i,CC11}$ | stock-difference, CT=20<br>(stockC$_{h,i,CC11}$ -<br>stockC$_{h,i,b}$)/CT = 0 | stock-difference, CT=20<br>(stockC$_{d, i,CC11}$ -<br>stockC$_{d,i,b}$)/CT = 0 | stock-difference, CT=20<br>(stockC$_{s_m,i,CC11}$ - stockC$_{s_m,i,b}$)/CT | gain-loss<br>changeC$_{s_o,i,CC11}$ |
| **Afforestation CC11 > 20 yr** | gain-loss<br>gainC$_{l,i,CC12}$ - lossC$_{l,i,CC12}$ | gain-loss<br>changeC$_{h,i,CC12}$ | gain-loss<br>changeC$_{d,i,CC12}$ | gain-loss<br>changeC$_{s_m,i,CC12}$ | gain-loss<br>changeC$_{s_o,i,CC12}$ |
| **Deforestation** | stock-difference, CT=1<br>(stockC$_{l,i,a}$-<br>stockC$_{l,i,CC1X}$)/CT | stock-difference, CT=1<br>(stockC$_{h,i,a}$ -<br>stockC$_{h,i,CC1X}$)/CT | stock-difference, CT=1<br>(stockC$_{d,i,a}$ -<br>stockC$_{d,i,CC1X}$)/CT | stock-difference, CT=20<br>C1X to CC51:<br>0.2 * (stockC$_{s_m,i,CC51}$ -<br>stockC$_{s_m,i,CC1X}$)/CT =<br>0.2 * ( 0 - stockC$_{s_m,i,CC1X}$)/CT<br>C1X to other:<br>(stockC$_{s_m,i,a}$ - stockC$_{s_m,i,CC1X}$)/CT | stock-difference, CT=20<br>C1X to CC51:<br>0.2*(stockC$_{s_o,i,CC51}$ -<br>stockC$_{s_o,i,CC1X}$)/CT =<br>0.2 * (0 - stockC$_{s_o,i,CC1X}$)/CT<br>C1X to other:<br>gain-loss; changeC$_{s_o,i,a}$ |
| **Forest management CC12 remaining** | gain-loss<br>gainC$_{l,i,CC12}$ - lossC$_{l,i,CC12}$ | gain-loss<br>changeC$_{h,i,CC12}$ | gain-loss<br>changeC$_{d,i,CC12}$ | gain-loss<br>changeC$_{s_m,i,CC12}$ | gain-loss<br>changeC$_{s_o,i,CC12}$ |
| **Forest management CC13 remaining** | gain-loss<br>gainC$_{l,i,CC13}$ - lossC$_{l,i,CC13}$<br>= 0 | gain-loss<br>changeC$_{h,i,CC13}$ = 0 | gain-loss<br>changeC$_{d,i,CC13}$ = 0 | gain-loss<br>changeC$_{s_m,i,CC13}$ = 0 | gain-loss<br>changeC$_{s_o,i,CC13}$ |
| **Forest management CC12 to CC13** | stock-difference, CT=20<br>(stockC$_{l,i,CC13}$ -<br>stockC$_{l,i,CC12}$)/CT | stock-difference, CT=20<br>(stockC$_{h,i,CC13}$ -<br>stockC$_{h,i,CC12}$)/CT | stock-difference, CT=20<br>(stockC$_{d,i,CC13}$ -<br>stockC$_{d,i,CC12}$)/CT<br>= (0 - stockC$_{d,i,CC12}$)/CT | stock-difference, CT=20<br>(stockC$_{s_m,i,CC13}$ -<br>stockC$_{s_m,i,CC12}$)/CT<br>= 0 | gain-loss<br>changeC$_{s_o,i,CC13}$ |
| **Forest management CC13 to CC12** | gain-loss<br>gainC$_{l,i,CC12}$ - lossC$_{l,i,CC12}$ | stock-difference, CT=20<br>(stockC$_{h,i,CC12}$ -<br>stockC$_{h,i,CC13}$)/CT | stock-difference, CT=20<br>(stockC$_{d,i,CC12}$ -<br>stockC$_{d,i,CC13}$)/CT<br>= stockC$_{d,i,CC12}$/CT | stock-difference, CT=20<br>(stockC$_{s_m,i,CC12}$ -<br>stockC$_{s_m,i,CC13}$)/CT<br>= 0 | gain-loss<br>changeC$_{s_o,i,CC12}$ |

## Reforestation

Reforestation does not occur in Switzerland (FOEN 2006h, Sect. E).

## Afforestation ≤ 20 years: units of land not harvested since the beginning of the commitment period

Living biomass

- Gains and losses in living biomass of Afforestations (gross growth and cut and mortality) were taken from the study by Thürig and Traub (2015). Values are available for two elevation levels (Table 6-4).

Litter and dead wood

- On Afforestations, carbon stocks in litter and in dead wood were assumed to be zero (IPCC 2006, Volume 4, chp. 4.3.2; see chp. 11.3.1.2 for details). Applying the stock-difference calculation approach (conversion time = 20 years; Table 11-4), calculated changes in the litter and dead wood pool on Afforestations are zero since there is no litter and no dead wood neither on Afforestations (land-use after conversion) nor on any other land-use types outside of forests (land-use before conversion; Table 6-4).

Soil carbon

- Mineral soils: In the case of a land-use change to Afforestations, the difference in soil carbon stocks between land use before and after the conversion was calculated. A conversion time of 20 years was applied.
- Organic soils: Emissions due to drainage were calculated as described in chp. 6.4.2.9 and chp. 11.3.1.2.

**Afforestation >20 years: units of land harvested since the beginning of the commitment period**

After 20 years, afforestated areas are subject to common forest management practices and the first thinnings and treatments are conducted. These afforestated areas are, however, not reclassified to the activity Forest management: all afforestations after 1990 are consistently reported under Afforestation under Article 3.3 (CRF 4(KP-I)A.1; see chp. 11.2.3). Emissions and removals for the carbon pools of Afforestations older than 20 years were calculated using the carbon stock change factors of productive forests (CC12; see methodological description under Forest management) since nearly all of the afforestations (99.9% of CC11 changed into CC12; see Table 6-9) develop into productive forests.

**Deforestation**

The differences in carbon stock in living biomass, litter and dead wood between Forest land and the land-use type after the conversion were immediately accounted for after Deforestation (conversion time = 1 year). Losses in soil carbon stocks due to disturbance caused by Deforestation were calculated using a stock-change approach over a conversion time of 20 years for mineral soil and a gain-loss approach, respectively, for organic soil. In the prevailing case of a Deforestations with a conversion to CC51 (buildings and constructions), losses in mineral and organic soil carbon stocks were accounted for by reducing the carbon stock by 20% of the orginial carbon stock following the proposal of IPCC (2006, Volume 4, chp. 8.3.3.2) over a conversion period of 20 years (see Table 11-4 and chp. 6.8.2.2.3).

**Forest management**

Living biomass

- Gains in living biomass (gross growth) of productive forests were used for “CC12 remaining” (Table 6-15). Gains in living biomass of unproductive forests were used for “CC13 remaining” and were assumed to be zero (see chp. 6.4.2.7; Table 6-4).
- Losses in living biomass reflect yearly cut and mortality in productive forests “CC12 remaining” (CC12 in Table 6-15). Unproductive forests are not systematically harvested (see description in chp. 6.4.2.7). Thus losses in living biomass of unproductive forests “CC13 remaining” were assumed to be zero (Table 6-4). Moreover, since yearly harvesting amounts from forest statistics (see Table 6-14) are distributed over the productive forests, total harvesting in forests was accounted for under “CC12 remaining”.
- For the conversions between different forest combination categories (“CC13 to CC12” and “CC12 to CC13”) the method is chosen in such a way that no potential carbon losses could be underestimated: For areas which changed from “CC12 to CC13” the

difference in carbon stocks of living biomass was considered and a net loss in carbon stock in living biomass was reported. In the case of a conversion from “CC13 to CC12” a gain-loss approach was applied, since applying a stock-difference approach would lead to a considerable removal of $CO_2$ for this type of Forest management.

Litter, dead wood and soil

- For productive forests “CC12 remaining”, yearly values for changes in carbon stocks in litter, dead wood and mineral soil were used (Table 6-17). The estimates were obtained from simulations with Yasso07 (see chp. 6.4.2.6). For unproductive forests “CC13 remaining”, yearly carbon stock changes in litter, dead wood and mineral soil stock were assumed to be zero (chp. 6.4.2.7).
- For the conversions between different forest combination categories (“CC13 to CC12” and “CC12 to CC13”) the differences in carbon stocks in dead wood, litter and mineral soil were taken into account. Carbon stocks in litter, dead wood and mineral soils on CC13 are described in chp. 6.4.2.7 and are shown in Table 6-4. Following the assumption that on CC13 no dead wood occurs, for dead wood, the conversion “CC12 to CC13” results in a net carbon loss, in the case of a conversion “CC13 to CC12”, in a net carbon gain. For litter, carbon stocks on CC13 are assigned to the mean value of the modelled CC12 litter stocks with Yasso07 over the inventory period. Thus, the effect of conversions from “CC12 to CC13”and the reverse depends on the litter carbon stocks on CC12 in a particular inventory year. Calculated carbon stock changes in mineral soils were zero since carbon stocks in mineral soils of CC12 and CC13 are the same.
- For organic soils, emissions due to drainage were calculated as described in chp. 6.4.2.9.

**Differences in accounting for “Forest categories 4A1 and 4A2” under the UNFCCC and Forest management under the Kyoto Protocol Art. 3.4**

Under the Kyoto Protocol Art. 3.4, natural forest regeneration is reported under Forest management as productive forest (CC12) or unproductive forest (CC13) as soon as the KP definition of forest is fulfilled (CRF NIR-1 and chp. 11.1.1). Changes within the activity Forest management are reported under the Kyoto Protocol in the activities “CC12 to CC13” and “CC13 to CC12”.

Under the UNFCCC, all changes in land use from non-Forest land to Forest land are reported in category 4A2 for a conversion time of 20 years. For further details and a quantitative comparison (area budget) see chp. 11.1.3 and chp. 11.3.2.2.

#### 11.3.1.2. Justification when omitting any carbon pool or GHG emissions/removals from activities under article 3.3 and elected activities under article 3.4

CRF NIR-1 summarizes the activity coverage and the carbon pools reported. When using the Tier 1 approach (IPCC 2006, Volume 4, chp. 1.3; IPCC 2014, chp. 2.3.1) assuming a specific carbon pool to be in balance, the carbon pool is indicated as not reported (NR). In CRF 4(KP-I)A.1 and 4(KP-I)B.1 they are indicated as not estimated (NE), since notation key NR is not available in these tables.

This is the case for litter and dead wood under Afforestation ≤ 20 years. Also for all carbon pools of unproductive forests, no changes are reported.

**Changes in carbon pools not reported – Afforestation ≤ 20 years: litter and dead wood**

Applying the stock-difference calculation approach (cf. Table 11-4), calculated changes in the litter and dead wood pools after Afforestation under 20 years are zero (see chp. 6.4.2.8), since carbon stock in litter and dead wood is assumed to be zero on Afforestations (land-use after conversion; IPCC 2006, Volume 4, chp. 4.3.2) and also on all other land-use types outside the forests (land-use before conversion; Table 6-4).

A Tier 1 approach for these pools for Afforestations under 20 years was applied because a) Afforestation is not a key category (see chp. 11.6.1) and b) because the relatively small carbon stock changes in these pools do not justify the (financial) effort to collect higher quality data without jeopardizing the resources for key categories (see Figure 4.1 in Volume 1 of IPCC 2006). Verifiable information to justify this approach is provided here:

- Changes in litter carbon stocks after afforestation: In an experiment by Zimmermann and Hiltbrunner (2012) litter accumulation of an afforestation with Norway Spruce was determined 40 years after afforestation. The authors found accumulation rates of 0.17-0.20 t C $ha^{-1}$ $yr^{-1}$. Other studies show even higher accumulation rates, e.g., 0.24-0.34 t C $ha^{-1}$ $yr^{-1}$ for afforestations with Norway spruce in the Southern Alps (Thuille and Schulze 2006), 0.24 t C $ha^{-1}$ $yr^{-1}$ for afforestation with ash and maple (Alberti et al. 2008) and 0.36 t C $ha^{-1}$ $yr^{-1}$ for Scotch pine (Vesterdal et al. 2002). In Finnish forests, Karhu et al. (2011) found that over 18 years the mean annual rate of carbon accumulation in the litter was 0.28 Mg $ha^{-1}$ for Scots pine and 0.15 Mg $ha^{-1}$ for birch.
- Based on a literature overview, Jandl et al. (2007) argued that the accumulation of a forest floor layer in, e.g., a conifer forest, results in a carbon sink. The authors concluded that after afforestation, forest floors accumulate carbon quickly. A long-term consequence of afforestation is the gradual incorporation of carbon in the carbon pool of the mineral soil. Guidi et al. (2014) found that the carbon stocks in the organic layers were affected by land-use change, with more carbon stored under early-stage forest compared with grassland abandoned 10 years ago, and highest carbon stocks were found under the old forest dominated by *Fagus sylvatica* and *Picea abies*.
- Changes in dead wood carbon stocks after afforestation: Zimmermann and Hiltbrunner (2012) showed that 40 years after afforestation with Norway Spruce, dead wood volume amounted to 10.4 t C $ha^{-1}$. This corresponds to an annual increase of carbon stored in the dead wood of 0.26 t C $ha^{-1}$ $yr^{-1}$ for afforestations with Norway Spruce.
- Besides the results of the case studies listed above, a reasoning based on sound knowledge of likely system responses (Grassi and Blujdea 2011) was provided: At stand level, the pools dead wood and litter of afforestation on cropland and grassland cannot be a source, especially if the previous land use did not have perennial woody biomass. On afforestations, tree growth is assumed to follow an exponential pattern, which can also be assumed for the accumulation of litter and dead wood.

Note that for Afforestations older than 20 years, estimates of carbon stock changes in dead wood, in litter and in mineral soil were reported. Therefore, in CRF NIR-1 for “Afforestation and reforestations”, encompassing both Afforestations under and over 20 years, the pools litter and dead wood were reported as “NR, R” (in response to UNFCCC 2022, ID#KL.1). The insertion of both notation keys reflect that both pools are not reported for Afforestations under 20 years and are reported for Afforestations over 20 years.

**Changes in carbon pools not reported – Unproductive forests**

A description of unproductive forests and the reasoning why the living biomass, litter, dead wood and mineral soil pools were reported to be in equilibrium and thus not a source is given in detail in chp. 6.4.2.7.

Based on the fact that unproductive forest land only covers ca. 8% of the area under Forest management (CRF 4(KP.I)B.1) and based on the description of these stands in chp. 6.4.2.7, emissions or removals of any of the pools of unproductive forests do not account for more than 25-30% of the activity Forest management. Based on the decision tree in Fig. 4.1 in IPCC (2006, Volume 1, chp. 4.1.2) and Figure 1.2 note 4 in IPCC (2006, Volume 1) that "a subcategory is significant if it accounts for 25-30% of emissions/removals for the overall category", Switzerland decided to not jeopardize the resources for key categories and hence used a Tier 1 approach. Thus no changes in the carbon pools of living biomass, litter, dead wood and mineral soil of unproductive forest areas were reported

**GHG sources reported**

Drainage of forests is not a permitted practice in Switzerland (Swiss Confederation 1991). However, it is possible that parts of the Swiss forest were drained before 1990 or had been established on drained areas. Abegg (2017) estimated that 3% of organic soils in forest land is or has been subject to drainage. $CO_2$ emissions due to drainage are calculated as described in chp. 6.4.2.9. $N_2O$ emissions from drainage of organic soils were calculated as described in chp. 6.4.2.10.

**GHG sources reported as “included elsewhere (IE)”**

Emissions from biomass burning on Afforestations and unproductive forests were reported under Forest management, sub-division productive forests (CC12). In this way, emissions were not underestimated, since the carbon stock (available fuel) in productive forests is higher than the carbon stocks of Afforestations and unproductive forests. Moreover, this approach reflects reality quite well since fires on Afforestations or in unproductive forests are rather unlikely to occur (see chp. 6.4.2.11).

Biomass burning on areas under Forest management: $CO_2$ emissions were reported as “IE”. The reported losses of living biomass and dead wood are covered by NFI data and thus the values reported in the reporting tables Table4.A and 4(KP-I)B.1 include these losses. Emissions of $CH_4$ and $N_2O$ were reported. The calculation of these emissions is described in chp. 6.4.2.11.

**GHG sources reported as “not occurring (NO)”**

Fertilisation of forests is prohibited by the Swiss forest law and adherent ordinances (Swiss Confederation 1991, 1992). Additionally, the “Chemical Risk Reduction Ordinance“ (Swiss Confederation 2005) prohibits the application of fertilisers, including liming, in forests. Thus, emissions from fertilisation on Afforestations and Forest management were reported as “not occurring”.

HWP from Afforestation: Since land under Afforestation in Switzerland typically serves purposes other than timber production, biomass is not removed for products entering the

HWP pool. In case there is some wood of first thinnings in Afforestations since 1990, it is mostly left on the site or sometimes collected for energy purposes (i.e. it could be assessed as instantaneous oxidation). Therefore, the amount of HWP from Afforestation was reported as not occurring ("NO") and all carbon stock changes in HWP were reported under Forest management (see chp. 6.11.2). HWP from Deforestation was accounted for on the basis of instantaneous oxidation "IO".

#### 11.3.1.3. Information on whether or not indirect and natural GHG emissions and removals were factored out

No anthropogenic GHG emissions and removals from elevated $CO_2$ concentrations, indirect nitrogen deposition or the dynamic effects of the age structure resulting from LULUCF activities under Article 3, paragraphs 3 and 4 prior to 01 January 1990 were factored out.

The IPCC does not give specific methods for factoring out these effects. Besides this, there are no reliable country-specific data available. Investigations on elevated $CO_2$ concentrations on growth showed complex relationships in the mid-term. Some species showed an increase others a decrease and some no change in growth (Bader et al. 2013). Opposing patterns are also reported regarding the effect of nitrogen deposition: A positive effect of N deposition on growth was found by e.g. Spiecker (1999) and Jarvis and Linder (2000). Other studies (e.g., Hyvönen et al. 2008; Högberg et al. 2006; Braun et al. 2010; Gschwantner 2006; Meining et al. 2008) indicate that N deposition, while leading to soil acidification, can cause a reduction in growth. Such acidification processes are widely detected in Swiss forest soils (Braun and Flückiger 2012).

#### 11.3.1.4. Changes in data and methods since the previous submission (recalculations)

There were no recalculations directly related to recommendations from the latest UNFCCC review (UNFCCC 2022) of the GHG inventory submission in 2021 (FOEN 2021). Methodological improvements and further recalculations for Forest land in the LULUCF and the KP-LULUCF sectors are listed in chp. 6.4.5 and in chp. 6.11.5 and the most significant among them are quantitatively assessed in chp. 10.1.2.4 and in chp. 10.1.2.8. Beside the technical correction of the FMRL (cf. chp. 11.5.2.4), no Kyoto-specific methodological modification was made.

#### 11.3.1.5. Uncertainty estimates

Uncertainty estimates of activity data are discussed in detail in chp. 6.1.5 and chp. 6.3.3 and are shown in Table 6-10.

A detailed description of the determination of the carbon stock change factor uncertainty for Forest land, which is also assigned to the activity Forest management, can be found in chp. 6.4.3. Uncertainty estimates of LULUCF carbon stock change factors are shown in Table 6-5, and deduced overall uncertainties for the reported activities under the Kyoto Protocol are composed in Table 11-5: 46.7% for Afforestations (associated UNFCCC category: 4A2), 50.2% for Deforestations (associated UNFCCC category: mainly 4E2) and 46.7% for Forest management (associated UNFCCC category: 4A1).

Lands fulfilling the definition of forest (see chp. 11.1.1) were accounted for under Forest management. Accordingly, the area under Forest management resulting from natural regeneration is attributed the uncertainty of Forest management.

Table 11-5 Uncertainty estimates of activity data (see Table 6-10) and carbon stock change factors (see Table 6-5) and the overall uncertainty of activities reported under the Kyoto Protocol Article 3.3 and Article 3.4.

| Activity under KP | Associated category in UNFCCC inventory (chp. 6.3) | Activity data uncertainty | Emission factor uncertainty [%] | Combined uncertainty |
|---|---|---|---|---|
| | | % | % | % |
| Afforestation | 4A2 Land converted to forest land | 1.5 | 46.7 | 46.7 |
| Deforestation | mainly 4E2 Land converted to settlements | 4.6 | 50.0 | 50.2 |
| Forest management | 4A1 Forest land remaining forest land | 1.1 | 46.7 | 46.7 |

#### 11.3.1.6. Information on other methodological issues

$N_2O$ emissions as a result of the disturbance associated with land-use conversion (Deforestation) were reported in CRF 4(KP-II)3. The emissions were calculated according to the methodology described in chp. 6.10.

#### 11.3.1.7. The year of the onset of an activity, if after 2013

The starting year of the activities reported can directly be derived from the land-use change matrix (Table 6-9), from which a consistent time series was derived (Table 11-2).

### 11.3.2. Category-specific QA/QC and verification

In chp. 6.4.4 category-specific QA/QC and verification items for Forest land are described. The general QA/QC measures are described in chp. 1.2.3.

In response to UNFCCC (2022, ID#KL.3), an additional check of the areas displayed in CRF 4(KP-I)A.2 has been performed and added to the checklist described in chp. 1.2.3, to ensure that the total area of Deforestation (activity A.2) equals the total area as reported under the information item (land areas under Deforestation by land-use category in the reporting year).

#### 11.3.2.1. Changes in soil carbon stock under Afforestation

The assumption that soils are acting as small sinks under Afforestation is supported by Jandl et al. (2007) who reviewed several studies on the effect of different forest management systems (including afforestations) on soil carbon sequestration and concluded that a long-term consequence of afforestation is the gradual incorporation of carbon in the mineral associated soil carbon pool. This is supported by a recent synthesis of current evidence on the influences of forest management activities on soil organic carbon stocks by Mayer et al. (2020). The authors concluded that afforestation on former grassland (which is the main land-use change to Forest land, cf. CRF Table4.1) are primarily associated with no change. Any possible negative effects, if any, can be expected to be, at least, partially compensated by the positive effects of afforestations on former crop land, which also occur in Switzerland (CRF Table4.1).

#### 11.3.2.2. Comparison of the forest areas reported in the reporting tables

A direct comparison of the areas reported under the UNFCCC Forest land remaining forest land (CRF Table4.A) and under the Kyoto Protocol Forest management (CRF 4(KP-I)B.1) is not possible due to the different structure of the reporting tables and due to different reporting requirements:

- Conversions to Forest land which are not human-induced (natural regeneration) were not accounted for as Afforestations under the Kyoto Protocol. These areas were reported under KP Art. 3.4 Forest management in CRF 4(KP-I)B.1 as soon as the definition of Forest was fulfilled. Under the Convention, these afforestations were reported under land-use category 4A2 with a conversion time of 20 years.
- Afforestations under the Kyoto Protocol which are older than 20 years were consistently reported under Art. 3.3 (sub-division >20 years in CRF 4(KP-I)A.1: units of land harvested since the beginning of the commitment period). Thus, there is no reclassification of the units of lands reported under Art. 3.3. In contrast, under the UNFCCC, afforestations older than 20 years were reallocated to the land-use category 4A1 Forest land remaining forest land.
- Not all changes from a forest combination category (CC11, CC12, CC13) to a non-forest combination category correspond to the definition of Deforestation according to the Kyoto Protocol Art. 3.3. (see chp. 11.2.3). These areas remained under the Kyoto Protocol Art. 3.4 activity Forest management and were included in the areas as reported in CRF 4(KP-I)B.1.
- Reporting of land-use changes: Since only the KP activity Forest management is accounted for under KP Art. 3.4, changes from other KP activities to Forest land were not reported separately, but were reported under Forest management (CC12 or CC13) as soon as the KP definition of forest was fulfilled. Only conversions within the activity Forest management were reported under the Kyoto Protocol, i.e. CC12 to CC13 and CC13 to CC12. Under the UNFCCC, land-use change to forest land were reported in category 4A2.

In Meteotest (2022) reported activity data for the inventory year 2020 were examined and compared (Table 11-6). The differences in the reporting tables Table4.A, 4(KP-I)A.1 and 4(KP-I)B.1 can be explained and the resulting budget of areas reported under the UNFCCC and under the Kyoto Protocol is identical.

Table 11-6 Area budget (in kha) of KP-LULUCF and LULUCF under the UNFCCC in the year 2020 for Forest land (Meteotest 2022).

| Activity | Table, Cells | area UNFCCC kha | area KP kha | Check Difference kha | remarks |
|---|---|---|---|---|---|
| **All Forest Land** | | | | | |
| Forest Management | 4(KP-I)B.1, D11 | | 1'264.296 | | a) |
| Afforestations <= 20 years | 4(KP-I)A.1, C29 | | 0.903 | | b) |
| Afforestations > 20 years | 4(KP-I)A.1, C13 | | 1.667 | | c) |
| Total area KP | | | 1'266.866 | | |
| Non-Kyoto loss of forest cover | | | -1.229 | | d) |
| Forest Land UNFCCC | 4.A, C10 | 1'265.637 | | | e) |
| Total | | 1'265.637 | 1'265.636 | 0.000 | |
| **Afforestation, CC11** | | | | | |
| UNFCCC | 4.A, C32+C36+C40 +C44+C48 | 0.903 | | | f) |
| KP (<= 20 years) | 4(KP-I)A.1, C29 | | 0.903 | 0.000 | g) |

Remarks:

a) Forest management consists of CC12 and CC13 areas fulfilling the criteria of the KP.

b) Afforestations are afforested areas since 1990 cumulated over 20 years at most.

c) Afforestations "older than 20 years" (>20 years) comprise the area that has been afforested since more than 20 years. In the UNFCCC tables these areas belong to 4A1 (both CC12 and CC13).

d) The non-Kyoto loss of forest cover is the part of the total area of forest loss (reported under UNFCCC) not fulfilling the definition of Deforestations according to the Kyoto Protocol (see NIR Chapter 11.2.3). For the comparison this area must be subtracted from the KP forest area. It is an annual value (not cumulated) calculated for each year in the period under consideration on the basis of the AREA survey data (chp. 6.2).

e) The Total forest land in CRF Table4.A covers productive forests (CC12), unproductive forests (CC13) and afforestations (CC11). It is congruent with the forest area derived from the aerial photos of the AREA survey (chp. 6.2).

f) The CC11 area under the UNFCCC can be derived from CRF Table4.A.2 by summing up the afforestation categories.

g) The cumulated (20 years) CC11 area of KP and UNFCCC are identical.

#### 11.3.2.3. Impact of forest management on changes in carbon stocks in litter and mineral soil

**Accounting for forest management impacts on carbon storage in litter and mineral soil in Swiss productive forests with Yasso07**

To estimate carbon stocks and carbon stock changes in the reported litter and mineral soil pools, Switzerland uses the carbon cycling model Yasso07 (Didion et al. 2012, Didion 2020a;

chp. 6.4.2.6). Yasso07 requires information on carbon inputs from dead organic matter (i.e. non-woody inputs, including foliage and fine roots, woody inputs, including standing and lying dead wood and dead roots) and climate (annual monthly temperature and precipitation). The carbon inputs are obtained for each plot in the NFI that is simulated with Yasso07. The NFI plots were repeatedly measured since the first inventory in 1985 and, hence, observed changes in the volume of living and dead biomass reflect, among other, the site-specific impact of forest management practices. Based on harvesting statistics and allometric relationships, the production of dead wood (incl. dead roots, stems, stumps and branches) and litter from living trees (i.e. controlled by forest management) and as harvest residues were estimated.

Thus, the Yasso07 model reflects the impact of forest management practices: effects of common forest management on carbon stocks in litter (including non-woody and woody material) and soil were fully accounted for in the GHG inventory (Didion et al. 2014a).

**Literature Review**

A recent comprehensive synthesis of current evidence regarding the influences of forest management activities on soil organic carbon stocks by Mayer et al. (2020) indicates that for forests in Switzerland no or even positive changes can be expected. Forest management practices that are associated with negative effects on soil carbon stocks such as clearcutting or removal of residues by harvesting whole-trees and stumps do not occur in Switzerland as they are not in line with the principle of sustainable forest management and thus prohibited (Swiss Confederation 1991, 1992).

The production of litter is directly affected by silvicultural practices since the removal of trees results in harvest residues and in a decrease in the amount of remaining foliage (e.g. Van Miegroet and Olsson 2011). Generally, the impact of forest management on litter production is temporary and carbon losses in litter can be rapidly replaced (Nave et al. 2010).

## 11.4. Article 3.3.

Net $CO_2$ eq removals from Afforestation and $CO_2$ eq emissions from Deforestation under Article 3, paragraph 3 differ by one order of magnitude (Figure 11-2, Figure 11-3). Since carbon from living biomass is immediately removed after harvesting, deforestation can be seen as a process where carbon is lost over a very short time. In contrast, afforestation is a slow process where carbon is sequestered and accumulated over decades. $CO_2$ emissions from organic soils under Afforestation are due to the previous installation of drainage systems (see chp. 11.3.1.2). Figure 11-2 shows net $CO_2$ eq removals and emissions from Afforestation and $CO_2$ eq emissions from Deforestation for the period 1999 until the latest inventory year. Associated data for selected years are listed in Table 11-1.

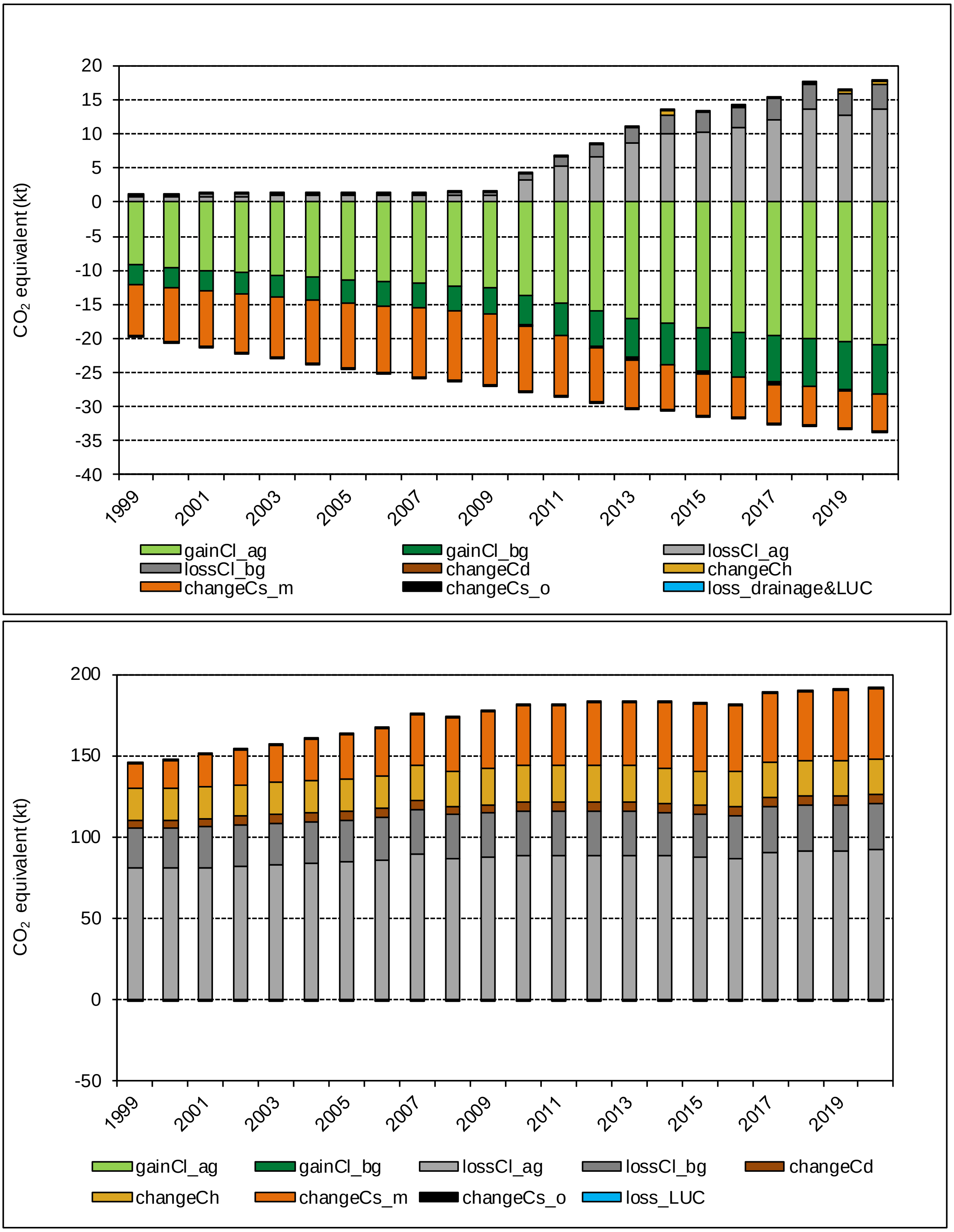



Figure 11-2 Net $CO_2$ eq removals (negative sign) and $CO_2$ eq emissions (positive sign) from Afforestation under Article 3, paragraph 3 (upper panel) and emissions from Deforestation under Article 3, paragraph 3 (lower panel) shown per carbon pool. For abbreviations see Table 11-1 and chp. 6.1.3.2. The individual contributions of gains, losses and net changes are shown in the unit $CO_2$ and with a reversed sign, in contrast to the information given in the reporting tables. Note the different scale of the y-axis in both graphs.

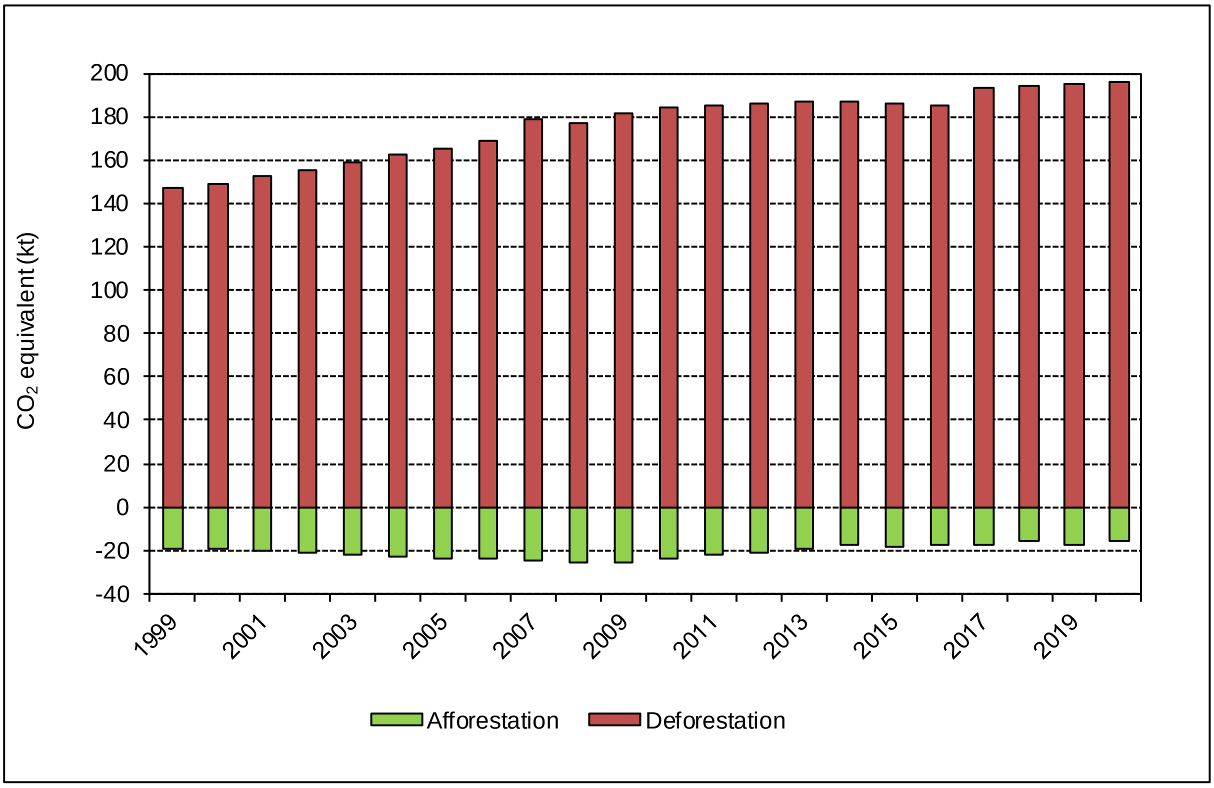



Figure 11-3 Net $CO_2$ eq removals (negative sign) of Afforestations under Article 3, paragraph 3 and $CO_2$ eq emissions (positive sign) of Deforestations under Article 3, paragraph 3.

## 11.4.1. Information that demonstrates that activities under Article 3.3. began on or after 01 January 1990 and before December 2020 and are direct human-induced.

The Swiss definitions of Afforestation and Deforestation only consider direct human-induced activities (see FOEN 2006h, Sect. E and FOEN 2010d).

### Reforestation

For more than 100 years, the area of forest in Switzerland has been increasing (see chp. 11.5.2). A decrease in forest area as a result of deforestation is not possible, since deforestation is strongly regulated by the Federal Law on Forests (Swiss Confederation 1991). Therefore, reforestation of areas not forested for a period of at least 50 years does not occur in Switzerland (FOEN 2006h, Sect. E). Switzerland only considers Afforestation and Deforestation under Article 3, paragraph 3.

### Afforestation

Switzerland is very restrictive in reporting Afforestations under the Kyoto Protocol and only reports planted forests under Afforestation (see chp. 11.1.3; FOEN 2010h).

The annual rate of all afforested areas since 1990 is assessed based on AREA data (chp. 6.3; chp. 11.1.3; FOEN 2010h). For reporting under the Kyoto Protocol, afforested areas since 1990 always remain in the Afforestation category. Therefore, the area in this activity has been increasing since 1990 (see Table 11-2).

Afforestations older than 20 years are subject to common forest management practices including harvesting (see chp. 11.3.1.1). These areas are reported as a subcategory in CRF 4(KP-I)A.1.

**Deforestation**

In Switzerland, direct human-induced Deforestation is subject to authorization (Swiss Confederation 1991: Art. 5). Deforestation is only allowed for projects with public interests and in these cases, the deforestation has to be compensated by an afforestation of equal area (FOEN 2010h).

For details concerning the classification of Deforestations under the Kyoto Protocol see chp. 11.2.3. Only deforestation events carried out after 01 January 1990 are considered. For reporting under the Kyoto Protocol, deforested areas since 1990 remain in the Deforestation category. Therefore, the area in this category has been increasing since 1990 (see Table 11-2). Since Switzerland only accounts for KP Art. 3.4 activity Forest management, these deforested areas are not accounted for under another KP Art. 3.4 activity.

### 11.4.2. Information on how harvesting or forest disturbance that is followed by the re-establishment of forest is distinguished from Deforestation

The Swiss definition of Deforestation only covers permanent conversions from Forest land to non-Forest land. In the process of the interpretation of land conversions based on AREA data (chp. 11.2.3), the definition is implemented by applying the criteria discussed in chp. 11.2.3. This approach was verified by Sigmaplan (2012a).

The criteria distinguish between permanent conversions and transient situations like harvesting or forest disturbance followed by forest re-establishment. Construction of e.g. pipelines and power supply lines within a forest area are transient situations (see chp. 11.1.3 and chp. 11.2.3; Brändli 2010). As described in FOEN (2010d), these non-permanent conversions are not classified as Deforestation under the Kyoto Protocol.

### 11.4.3. Information on the size and geographical location of forest areas that have lost forest cover but which are not yet classified as deforested

The AREA survey provides a detailed overview of land-use changes with regard to land cover and land use (see chp. 6.2 and chp. 6.3). Temporal changes of land cover can lead to a reclassification in AREA from a forest combination category to a non-forest combination category. However, not all changes from Afforestation CC11, productive forest CC12, or unproductive forest CC13 to a non-forest combination category correspond to the definition of Deforestation according to the Kyoto Protocol Art. 3.3. Explicit criteria were developed (cf. FOEN 2010d and chp. 11.2.3) to identify which conversions from a forest combination category to a non-forest combination category do not correspond to Kyoto Deforestation under the Kyoto Protocol.

### 11.4.4. Information related to the natural disturbances provision under Article 3.3

Switzerland does not apply the provision of exclusion of natural disturbances for Afforestation and reforestation under Article 3, paragraph 3, of the Kyoto Protocol (FOEN 2016c).

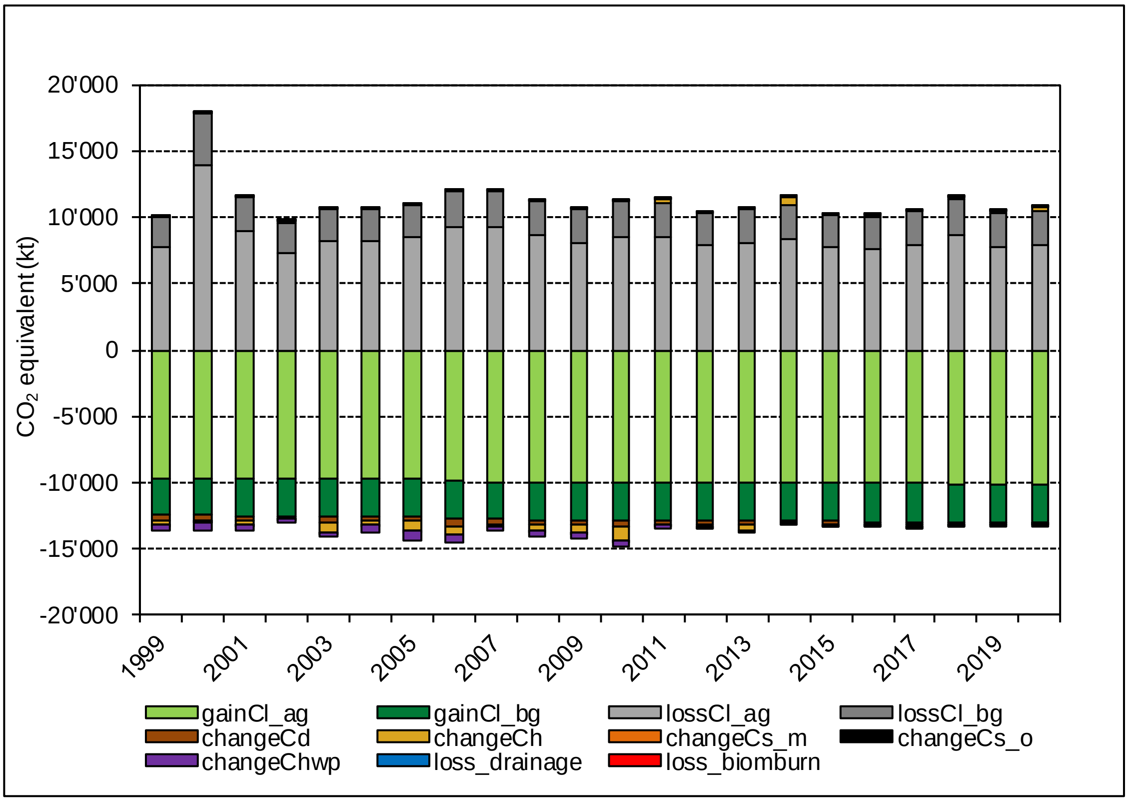
### 11.4.5. Information on Harvested wood products under Article 3.3

The calculation of carbon stock changes in Harvested wood products (HWP) is described in chp. 6.11. The change in carbon stocks was estimated differentiating HWP originating from Deforestation and from Forest management. Based on the available data sets it was not possible to differentiate between HWP from Afforestation (if available, it is a negligible amount) and HWP from Forest management. Thus, HWP from Forest management also covers HWP from Afforestation.

Applying instantaneous oxidation to HWP originating from Deforestations, identical results are obtained for changes in carbon stocks of HWP reported under the UNFCCC (CRF Table4.Gs1) and under the Kyoto Protocol (CRF 4(KP-I)C) as shown in Table 6-33.

## 11.5. Article 3.4

$CO_2$ eq emissions and removals differentiated for the reported carbon pools and the resulting net $CO_2$ eq emissions and removals of KP Article 3, paragraph 4 activity Forest management for the period 1999 until the latest inventory year are shown in Figure 11-4. Associated data for selected years are listed in Table 11-1. The annual fluctuations of net $CO_2$ eq emissions and removals from Forest management are described in chp. 11 in the text accompanying Figure 11-1.



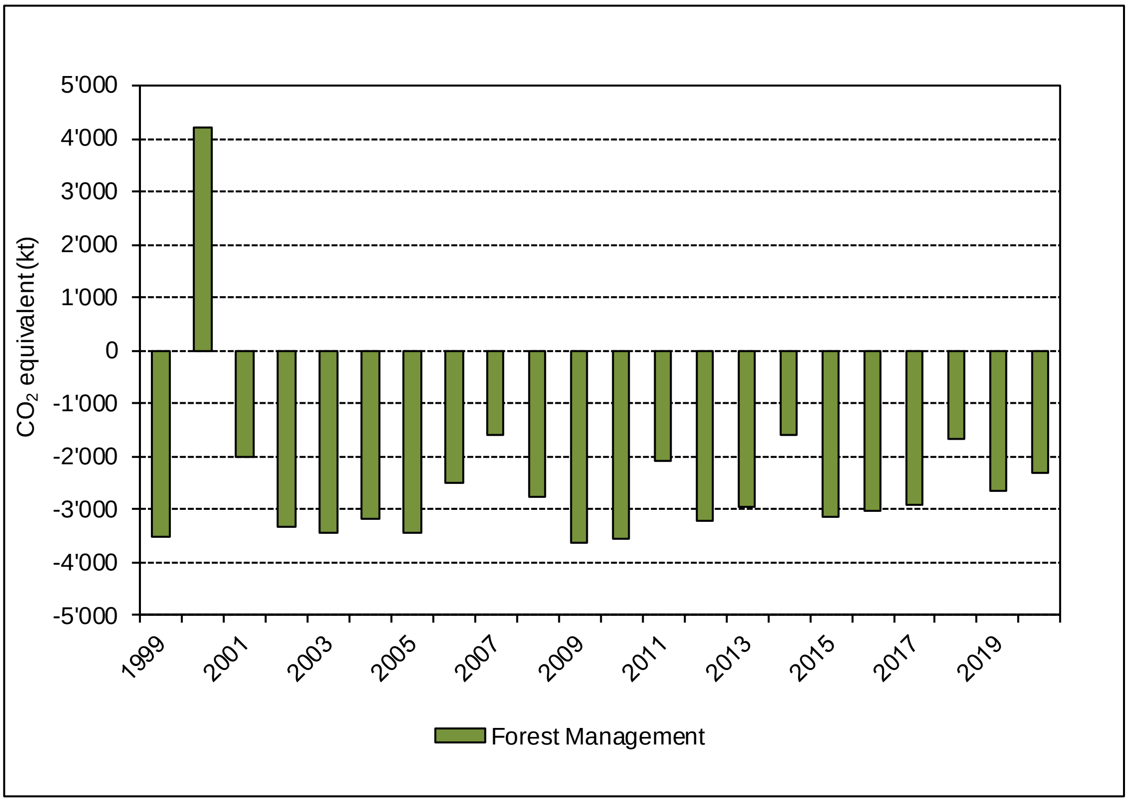




Figure 11-4 $CO_2$ eq emissions (positive sign) and $CO_2$ eq removals (negative sign) broken down by the reported carbon pools under Forest management (upper panel) and net $CO_2$ eq emissions and removals from Forest management (lower panel). For abbreviations see Table 11-1 and chp. 6.1.3.2. The individual contributions of gains, losses and net changes are shown in the unit $CO_2$ and with a reversed sign, in contrast to the information given in the reporting tables. Note the different scale of the y-axis in both graphs.

### 11.5.1. Information that demonstrates that activities under Article 3.4. have occurred since 1 January 1990 and are human-induced

According to the Federal Act on Forest, the extent and the spatial distribution of the total forest area in Switzerland has to be preserved (Swiss Confederation 1991: Art. 1) and thus, any change of the forest area has to be authorized. All Swiss forests are under continuous observation of the Swiss Forest Service and monitored by the NFI. Therefore, all forests in Switzerland are subject to forest management and reported under Forest management under Article 3, paragraph 4 of the Kyoto Protocol (FOEN 2006h, Sect. F).

### 11.5.2. Information relating to Forest management

There is a long tradition of forest protection in Switzerland. The first federal Forest Act came into force in 1876, but it only covered regions located at higher elevations. It aimed to put a halt to the depletion of forests, to manage the remaining forest areas in a sustainable way, and to promote afforestation. The Forest Act of 1902 covered the whole country. The Forest Act as well as an increasing economic development, resulted in an increase of the forest area in Switzerland by nearly 50% compared to the mid-19th century (Figure 11-5). Also the growing stock increased significantly due to changes in forest management practices. The revised Forest Act (Swiss Confederation 1991) that came into force in 1993, reaffirmed the long-standing Swiss tradition of preserving both forest area and forest ecosystem functions and services. It prescribes sustainable forest management, prohibits clearing, and bans deforestation unless it is replaced by an equal area of afforested land or an equivalent measure to improve biodiversity.

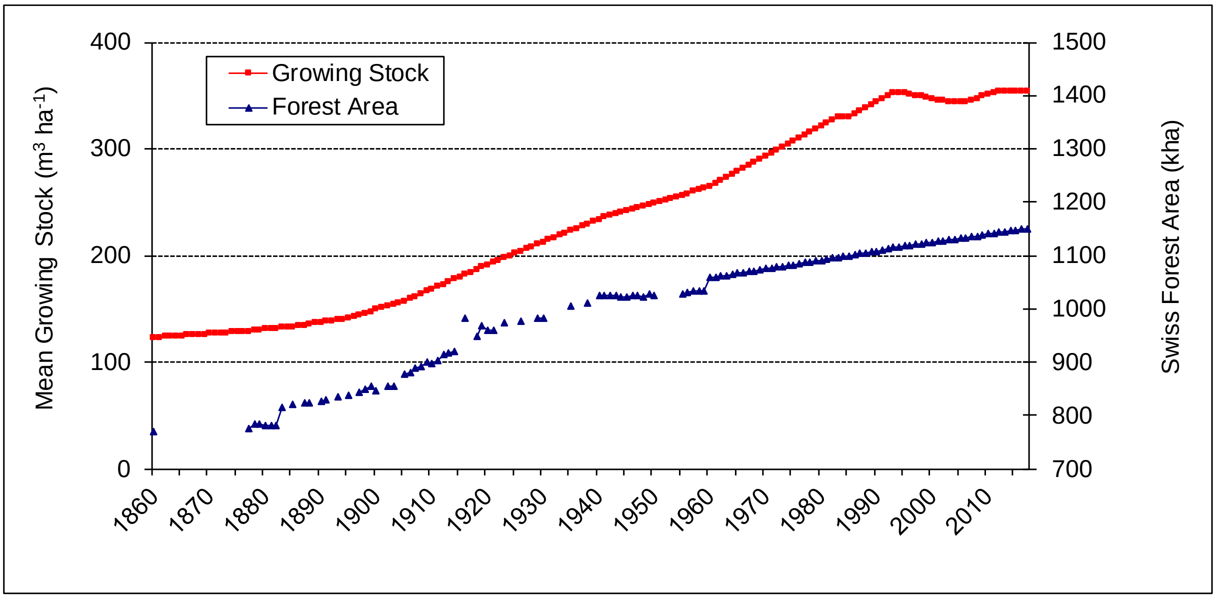



Figure 11-5 Historical mean growing stock ($m^3 ha^{-1}$) and forest area (kha) in Switzerland. Data for the period 1860–1985 were published in Kurz et al. (1998), data on growing stock from 1985 onwards are available from the Swiss National Forest Inventory (see chp. 6.4.2.1), data on the area of productive forests are taken from the Swiss Land Use Statistics (AREA; chp. 6.2).

In 2004, the Swiss National Forest Programme was published, outlining an action plan for the period 2004–2015 (SAEFL 2004b). It specifies five priority objectives: (1) the forests' protective function is guaranteed, (2) the economic viability of the forestry sector is improved,

(3) the value-added chain for wood is strengthened, (4) biodiversity is conserved and (5) forest soils, trees and drinking water are not threatened. These objectives encompass that $CO_2$ removals by sinks and emissions by sources in the forests shall be recognized in terms of compliance with the Kyoto Protocol while making better use of the potential of forests for timber production and fuel wood through economic incentives and implementing new technologies.

In November 2006, the Swiss government communicated in its Initial Report to the UNFCCC that Switzerland will account for Forest management under Article 3.4 of the Kyoto Protocol (FOEN 2006h). In the second commitment period of the Kyoto Protocol, the accounting of Forest management was mandatory for all Parties.

To implement the objectives of the National Forest Programme (SAEFL 2004b), FOEN has formulated its Wood Resource Policy first initiated in 2008 (FOEN 2008h), updated in 2014, in 2017 (FOEN 2017j) and in 2021 (FOEN 2021k)). With this Wood Resource Policy the Swiss Confederation formulated a separate Wood Action Plan, which is coordinated with the Forest Policy 2020 (FOEN 2013l), climate policy, energy policy and regional policy. As the lead agency in this process, the FOEN actively promotes the cooperation between these sectoral policy areas, the Swiss forestry and timber sector, and the cantons. The aim of the Wood Resource Policy is to ensure that wood from Swiss forests is supplied, processed and used in a way that is sustainable and resource-efficient. By this means, it makes a major contribution to forest, climate and energy policy. Upon evaluation of the first (2009–2012), a second phase (2013–2016) and a third phase (2017–2020), the Wood Resource Policy was updated. In 2021, a fourth programme phase of the Wood Action Plan started (2021–2026). With its two priority areas of ”climate-appropriate building” and “Swiss wood added value”, the Wood Action Plan supports the implementation of the Wood Resource Policy.

#### 11.5.2.1. Conversion of natural forest to planted forest

Not applicable. Switzerland did not choose to apply the concept of carbon equivalent forests (see CRF 4(KP-I)B.1.2).

#### 11.5.2.2. Forest management reference level (FMRL)

Switzerland’s Forest management reference level (FMRL) is documented in FOEN (2011l). The Swiss FMRL is inscribed in the appendix to the annex to Decision 2/CMP.7 and amounts to +0.220 Mt $CO_2$ eq. $yr^{-1}$. Since its submission in FOEN (2011l), several technical corrections have been applied to the FMRL (FOEN 2022g):

- FOEN (2015: chp. 11.7), FOEN (2016: chp. 11.5.2.3) and FOEN (2016d): To address recommendations of the technical assessment report (UNFCCC 2011a) and applying guidance of IPCC (2014) as implemented for FOEN (2015, 2016) and updated in FOEN (2016d) after the in-country review;
- FOEN (2019: chp. 11.5.2.4): To address changes in the activity data;
- FOEN (2021: chp. 11.5.2.4): To address model improvements and changes in the activity data;
- Latest submission (chp. 11.5.2.4): To address changes in the activity data.

#### *11.5.2.2.1. Description and implementation of the BAU harvesting scenario*

Switzerland's BAU in FOEN (2011l) is based on Switzerland's Wood Resource Policy (FOEN 2008h), which is reflected in Switzerland's' Forest Policy (FOEN 2013l). This policy states that a harvesting level equal to the "potential sustainable wood supply" of 8.2 mio $m^3$ merchantable timber should be reached in Swiss Forests until 2020. Switzerland's Wood Resource Policy from 2008 has been elaborated based on exploring several scenarios from two scientific studies: (1) Switzerland's Potential Sustainable Wood Supply (FOEN 2008h; it was calculated in Hofer and Altwegg 2008 and refined in Hofer et al. 2011) and (2) Wood Market Model (Pauli and Thees 2009). A linear extrapolation of historical data (1990–2007) supported the increase of harvesting rates to this level.

The implementation of the BAU defined in FOEN (2011l) is described in Thürig et al. (2021) and was elaborated in the first (FOEN 2016d) and second (FOEN 2019) technical correction (describing an exponential pathway to reach the harvesting level of 8.2 Mio $m^3$ in 2020. After 2020, harvesting amount was assumed to remain constant.

**Merchantable wood and assortments into semi-finished products**

In Switzerland's Wood Resource Policy (FOEN 2008h) the targeted annual harvesting amount was formulated as "merchantable wood". However, it was not further specified how "merchantable wood" is assigned to the different assortments. The assignment into the different assortments was therefore based on the mean distribution observed in the harvesting statistics 2005–2009 (Table 6-14; calculated as described in Thürig et al. 2021).

**BAU harvesting volume: regional distribution and harvesting of brances**

The BAU scenario aims at reaching 8.2 million $m^3$ merchantable timber by 2020 following an exponential increase of harvesting being realized in all NFI production regions of Switzerland. While the Central Plateau (Figure 6-4) remains the largest provider of coniferous timber, this amount cannot be further increased, because harvesting already exceeds increment resulting in decreasing growing stock and conifer proportion (see FOEN 2015q: chp. 1.2 and chp. 3.1). NFI data show that between 2007 and 2017 (NFI3-4) growing stock has decreased by 11% in the Central Plateau due to increased harvesting and increased mortality by storms and insect infestation (Brändli et al. 2020). Thürig et al. (2021) showed that the BAU scenario of increasing the harvesting amount to 8.2 million $m^3$ merchantable timber can only be realized by intensifying harvesting in other production regions in Switzerland.

Further, based on recent harvesting statistics (Table 6-14), it was approximated that 35% of all branches of deciduous trees are removed from the forest (Thürig et al. 2021).

**Mortality equals "background level for natural disturbances"**

Mortality was adjusted to amount to 16.34%, this equals the total mean cut and mortality ("losses in living biomass") from 1990–2009 and corresponds to the Swiss "background level for natural disturbances" (FOEN 2016c).

### 11.5.2.3. Information on the main factors generating the accounted quantity

The difference between the mean annual carbon balance of Forest management over the period 2013–2020 (-2.54 Mt $CO_2$ eq $yr^{-1}$ based on Table 11-1; CRF accounting) and the corrected FMRL (-1.80 Mt $CO_2$ eq $yr^{-1}$; Table 11-9; CRF accounting) amounts to 0.74 Mt $CO_2$ eq $yr^{-1}$.

The differences per pool between the FMRLcor and the reported data in the latest submission are summarized in Table 11-9. There are several reasons for differences between the FMRL and the annually reported carbon balance of Forest management:

- The harvesting rates are higher in the BAU scenario than as observed in the NFI. This leads to less $CO_2$ removals by living biomass and consequently higher net $CO_2$ emissions from HWP in the FMRLcor as it is reported in the NIR.
- The higher harvest rates in the BAU scenario result in more trees that are removed from the forest, which thus do not contribute to the production of dead wood and litter and hence not to the related $CO_2$ emissions or removals in the forest. For the total dead wood, litter, and mineral soil pool this thus results in larger removals in the FMRL.
- Further, there are methodological differences in the calculation of the FMRLcor (using the Massimo model) and the reported values (derived from NFI data), including
    - NFI sample plots that are classified as forest in the NFI4 and where non-forest in the NFI3, cannot be considered in the simulations runs for the FMRL.
    - Single harvested trees in the Massimo model do not correspond to harvested trees identified in the terrestrial NFI survey with implications on the tree volume, and particularly biomass and carbon estimate.
    - Estimation of tree volume due to the availability of additional attributes in the terrestrial NFI survey allowing for a higher accuracy in tree specific estimates and in the upscaling to national estimates.

### 11.5.2.4. Technical correction Forest management reference level

Switzerland decided not to provide technical corrections of the FMRL on an annual basis, but to correct the FMRL periodically. The last technical correction was reported and described in detail in FOEN (2021: chp. 11.5.2.4). In order to reflect the most recent scientific knowledge, data availability and model versions and to ensure methodological consistency between the FMRL and reporting for Forest management, a technical correction of the FMRL is reported in the latest submission.

Corrections originating from recalculations are listed in chp. 6.4.5, chp. 6.11.5 of this and former submissions (since FOEN 2015). All calculation steps and a detailed list of all new and former modifications are described in FOEN (2022g). This section provides a detailed overview of the conducted recalculations leading to a technical correction of the FMRL.

#### *11.5.2.4.1. Activity data for FMRL*

The area under Forest management for the period 2013–2020 was calculated by linear extrapolation of the trend from the historical activity data 1990–2009 (FOEN 2011l). The area under Forest management was stratified per land-use type (productive forest CC12, unproductive forest CC13 and for mutual changes between CC12 and CC13) and per soil type (mineral and organic soils; Table 11-7).

The activity data for land under Forest Management for 1990–2009 changed since the previous technical correction of the FMRL (FOEN 2021). Several updates and modifications related to land area data led to recalculations for 1990–2009 (see chp. 6.3.5 in the latest and previous submissions).

The following updates and modifications, described in FOEN (2022g), are directly relevant for the latest technical correction:

- The most recent land-use data from the fourth area survey (AREA4) were included (SFSO 2021). They are based on aerial photographs from 2012 to 2019. The interpolation and projection procedures were adapted accordingly (see chp. 6.3.2 and Sigmaplan 2022).
- Along with the AREA4 survey the SFSO continuously performed consistency checks and, where appropriate, corrections in the data of AREA3 (2004–2009). Due to temporal interpolation (cf. chp. 6.3.2) the years 1990–2003 were affected.
- The total area of the country recorded by the AREA survey increased by 67 ha to 4'129'073 ha (SFSO 2021). This modification is due to the inclusion of the most recent land survey data elaborated at the Federal Office of Topography (changes caused e.g. by glacial melting), defining the country's frontiers.

Previous technical corrections included the following improvements:

- The definition of the land-use category CC13 (unproductive forest) in terms of land-use (LU) and land-cover (LC) codes was updated to improve the compatibility of the forest areas measured in the AREA surveys with the definition of forest for the Kyoto Protocol (FOEN 2016).
- A more complete, consistent and reliable data set defining the geographical distribution of organic soils in Switzerland (Wüst-Galley et al. 2015) was integrated in FOEN (2016).

Table 11-7 FMRL activity data averaged for 2013–2020 derived from linear extrapolation of historical data 1990–2009 stratified per soil type: comparison of the latest technical correction (upper table), the previous technical corrections in FOEN (2021) and in FOEN (2019), and the data used for submission of the FMRL (FOEN 2011l) as shown in FOEN (2014).

**Values TC FMRL, latest submission**

| Mean 2013-2020 (kha) | Productive forest CC12 | CC12 to CC13 | CC13 to CC12 | Unproductive forest CC13 |
|---|---|---|---|---|
| Mineral soils | 1132.09 | 6.33 | 13.91 | 100.64 |
| Organic soils | 3.72 | 0.01 | 0.02 | 0.17 |
| Total soils | 1135.80 | 6.34 | 13.92 | 100.81 |

**Values previous TC FMRL, submission FOEN (2021)**

| Mean 2013-2020 (kha) | Productive forest CC12 | CC12 to CC13 | CC13 to CC12 | Unproductive forest CC13 |
|---|---|---|---|---|
| Mineral soils | 1130.41 | 6.25 | 13.83 | 100.88 |
| Organic soils | 3.72 | 0.01 | 0.02 | 0.17 |
| Total soils | 1134.13 | 6.26 | 13.85 | 101.05 |

**Values previous TC FMRL, submission FOEN (2019)**

| Mean 2013-2020 (kha) | Productive forest | CC12 to CC13 | CC13 to CC12 | Unproductive forest |
|---|---|---|---|---|
| Mineral soils | 1130.46 | 6.02 | 13.09 | 101.95 |
| Organic soils | 3.72 | 0.01 | 0.01 | 0.18 |
| Total soils | 1134.18 | 6.02 | 13.11 | 102.13 |

**Values FMRL submitted in 2011, submission FOEN (2014) as applied in FOEN (2011l)**

| Mean 2013-2020 (kha) | Productive forest | CC12 to CC13 | CC13 to CC12 | Unproductive forest |
|---|---|---|---|---|
| Mineral soils | 1134.45 | 4.15 | 10.61 | 89.33 |
| Organic soils | 3.40 | 0.01 | 0.01 | 0.10 |
| Total soils | 1137.85 | 4.16 | 10.62 | 89.43 |

#### *11.5.2.4.2. Modelling carbon stock changes in living biomass with Massimo*

To project carbon changes in living biomass, the model Massimo is used (Stadelmann et al. 2019). A detailed description of the model implementation for the FMRL can be found in Thürig et al. (2021).

For the latest submission, no technical correction for living biomass in FMRLcor has been implemented.

Previous technical corrections are described in detail in Thürig et al. (2021) and included:

- general model improvements to Massimo;
- more realistic tree regeneration (Zell et al. 2019);
- more plausible data-driven formulation of mortality;
- adjusted error calculation in Massimo correcting the underestimated uncertainties of previous versions;
- general model improvements: improved usability, better implementation of harvest interventions.

The model has been validated based on observed NFI data. The model was initialized with NFI 3 data. For the validation, it was driven by observed harvesting rates in NFI4 (2009–2013; Abegg et al. 2014). As NFI4 (2009–2013) data were not used for model calibration, this is an independent model validation. The validation showed that the model Massimo is assessed as a valuable tool to simulate short-term development of Swiss forests based on predefined management scenarios.

Methodological consistency between the FMRL and reporting for Forest management was achieved to a large extend, but some exceptions occurred as described in chp. 11.5.2.3. The most recent time series of NFI data (chp. 6.4.5) was used.

For the Massimo model, it is planned to further improve the algorithms and assumptions. The major aspects of the revision, which will be implemented over the coming years for the calculation of the Swiss Forest Reference Level to be used under the Paris Agreement, include:

- Long-term improvements of Massimo: Implementation of the "economic restrictions", climate sensitivity of "growth and mortality modules" and further improvements in the "ingrowth module".
- Verification of allometries used to obtain estimates of whole tree volume and biomass, incl. branches, foliage, and roots.
- The amount of branches that are removed from the forest is highly variable. An additional study shall give better estimates about the percentage of the branches removed from the forest.
- The current improvements of Massimo do not yet distinguish forest reserves. However, according to Hofer and Altweg (2008: 18) this affects only 15'509 ha or approximately 1.2% of the forest area.

#### *11.5.2.4.3. Modelling carbon stock changes in dead wood, litter and mineral soil with Yasso07*

For the latest submission, only the inventory year has been remodelled with Yasso considering measured climate data for 2020. Detailied information can be found in the supplement to Thürig et al. (2021). Otherwise, no changes have been applied for the simulations with Yasso07.

Previous technical corrections included the following elements:

In general, improvements and corrections to the modelling of living biomass with Massimo, lead to revised input data for the model Yasso and thus also revisions to the Yasso estimates of dead wood and litter.

Since the first application of the model Yasso07 for the Swiss GHG inventory 2013 (FOEN 2013), the model and its application in the context of the Swiss GHG inventory has been continuously improved (chp. 2.4 in Didion 2020a). The model was first used for the calculation of a previous technical correction of Switzerland's FMRL (FOEN 2015). The revisions to the model application since 2015 relevant for the FMRL estimate (see Thürig et al. 2021 for more details) were the consideration of:

- fine woody litter to annual litter production such as twigs and small branches <7 cm in diameter originating from trees with DBH ≥12cm;
- historic data on forest cover development on NFI sample plots since 1880;
- observed climate data for the years 2014 to 2019 replacing projected data.

It is planned to further improve the application of Yasso07 for Switzerland as described in chp. 6.4.6 in order to further apply Yasso07 for reporting under the Paris Agreement.

#### 11.5.2.4.4. Harvested wood products

For the latest submission, no technical correction for HWP in FMRLcor has been implemented. The calculation and the results based on the activity data and method described in FOEN (2021e) have not changed.

Since the first calculation of HWP estimates in FOEN (2015), the activity data have been updated and the calculation method has been continuously improved, including:

- The most recent time series of the activity data (production, import and export from the FAOSTAT database) was used. These data were updated regularly (chp. 6.11.5 in the latest and previous submissions): the share of domestic to total HWP was revised.
- The HWP paper and paperboard were included in the FMRL according to chp. 6.11.5 in FOEN (2019) and in response to UNFCCC (2018, ID#KL.7).
- For calculating paper production, the share of recovered fibre pulp was included as well as the share of domestic pulp wood contained in recycled products (chp. 6.11.5 in FOEN 2020). Consequently, the feedstock in paper and paper board decreased by more than 80%. This recalculation was performed in response to UNFCCC (2018, ID#KL.7).
- The conversion factors for sawnwood (coniferous and non-coniferous) were updated with country-specific data for wood densities. The new values are based on national measurements of the wood industry (chp. 6.11.5 in FOEN 2020).
- Due to recalculations of AREA data the split between HWP from Afforestation and from Forest management as well as the split between Deforestation and Forest management were recalculated. This procedure is done in each submission (see chp. 6.11.5) and was adopted for the technical corrections in the years concerned.

#### 11.5.2.4.5. Other emissions and removals recalculated for the FMRL

Emissions from drainage from organic soils: based on results of Abegg (2017), the share of drained organic soils under Forest land was reduced from 100% to 3% (see chp. 6.4.2.9). This correction was made in response to UNFCCC (2018, ID#L.6 and ID#KL.3).

#### 11.5.2.4.6. Pools or emissions and removals removed from the FMRL

$CH_4$ and $N_2O$ emissions from wildfires were considered for the calculation of the background level and the margin with respect to the application of excluding natural disturbances from the accounting (see UNFCC 2018, ID#KL.5; FOEN 2016d). By moving these emissions to the background level, $CH_4$ and $N_2O$ emissions from wildfires had to be excluded from the contributing pools of the FMRL accordingly.

#### 11.5.2.4.7. Pools or emissions and removals not included in the FMRL

Emissions from controlled burning cover the emissions from burning of residues in forestry (addressing UNFCCC 2018, ID#KL.4). Since GHG inventory submission in 2017, these emissions were reported in the category Forest land within the LULUCF sector (see chp. 6.4.2.12 in FOEN 2017 and in the latest submission). The emissions from controlled burning were added as a pool to the FMRL (UNFCCC 2018, ID#KL.5)

#### *11.5.2.4.8. Calculation of the technical correction of the FMRL*

Mean yearly carbon stock change factors over the period 2013–2020 for living biomass, dead wood, litter and mineral soil for the BAU scenario are summarized in Thürig et al. (2021). The carbon stock change factor for HWP for 2013–2020 is taken from FOEN (2021e).

These carbon stock change factors were then applied for the area under Forest management stratified by land-use type and soil type (Table 11-7) in order to calculate carbon stock changes in living biomass, dead wood, litter and mineral and organic soils in forests (Table 11-8). Further, emissions from drainage of organic soils and emissions from forest fires were considered to correct the FMRL.

Table 11-8: Contribution to $FMRL_{cor}$ (Mt $CO_2$ eq $yr^{-1}$) of mean carbon stock changes (changeC) over the period 2013–2020 for the total area under Forest management. For the $FMRL_{cor}$ carbon stock changes in living biomass ($changeC_l$), in litter ($changeC_h$), in dead wood ($changeC_d$), in mineral and organic soils ($changeC_s$) and in HWP ($changeC_{HWP}$) were considered, as well as the emissions from controlled burning of forest residues ($loss_{biomburn}$). Positive values indicate emissions by sources, negative values indicate removals by sinks. Stratification of Forest management land-use types: productive forest CC12, unproductive forest CC13 and mutual changes between CC12 and CC13.

| Pool | Land-Use Type under FM | changeC for $FMRL_{cor}$ (Mt $CO_2$ eq $yr^{-1}$) |
|---|---|---|
| $changeC_l$ | CC12 | -0.40 |
| | CC13 | 0.00 |
| | CC12/CC13 | 0.11 |
| | CC13/CC12 | 0.00 |
| | Total Living Biomass | -0.30 |
| $changeC_h$, $changeC_d$, $changeC_s$ | CC12 | -0.74 |
| | CC13 | 0.00 |
| | CC12/CC13 | 0.01 |
| | CC13/CC12 | -0.02 |
| | Total Soil, Litter, Dead Wood | -0.75 |
| $changeC_{HWP}$ | CC12 | -0.76 |
| $loss_{biomburn}$ | CC12 | 0.005 |
| **Total $FMRL_{cor}$** | | **-1.80** |

The impact of all technical corrections of the FMRL made since FOEN (2011l) on carbon stock changes in living biomass, dead wood, litter and mineral and organic soils in forests are summarized in Table 11-9. The technical correction equals the difference between the FMRL submitted in February 2011 (FOEN 2011l) and the corrected values for the FMRL published in the latest submission and amounts to -2.02 Mt $CO_2$ eq $yr^{-1}$ (see CRF Table4(KP-I)B.1.1)

Table 11-9: Comparison of the FMRL technical corrections: FMRL as defined in FOEN (2011l), corrected values as described in FOEN (2015), FOEN (2016) and updated in FOEN (2016d) after the in-country review 2016, in FOEN (2019), in FOEN (2021), and in the latest submission. Mean yearly values over the commitment period 2013-2020 are shown in the column on the right. Data are listed per carbon pool and source, respectively, and expressed in Mt $CO_2$ eq $yr^{-1}$. Positive values indicate emissions by sources, negative values indicate removals by sinks. Abbreviations as used in chp. 6.1.3.2 and in Table 11-8.

| Pool (Mt $CO_2$ eq $yr^{-1}$) | FMRL FOEN 2011l | FMRLcor FOEN 2016d | FMRLcor FOEN 2019 | FMRLcor FOEN 2021 | FMRLcor FOEN 2022 | FOEN 2022 Mean 2013-2020 |
|---|---|---|---|---|---|---|
| $changeC_l$ | 0.48 | -0.33 | -0.73 | -0.30 | -0.30 | -2.40 |
| $changeC_h$, $changeC_d$, $changeC_s$ | -0.05 | -0.59 | -0.88 | -0.86 | -0.75 | -0.10 |
| $changeC_{HWP}$ | -0.21 | -0.78 | -0.89 | -0.76 | -0.76 | -0.04 |
| $loss_{biomburn}$ | IE (in 5C2) | 0.01 | 0.005 | 0.005 | 0.005 | 0.00 |
| **Total FMRL / $FMRL_{cor}$** | **0.22** | **-1.69** | **-2.49** | **-1.92** | **-1.80** | **-2.54** |

### 11.5.2.5. Information related to the natural disturbance provision under Article 3.4

#### *11.5.2.5.1. Application of the provision of natural disturbances*

As indicated in Switzerland’s Second Initial Report (FOEN 2016c, FOEN 2016d), Switzerland intends to apply, in the case of significant magnitude events, the provision of natural disturbances for units of lands under Forest management during the second commitment period in accordance with decision 2/CMP.7. In cases or events in which emissions from natural disturbances are higher than the nationally established threshold value and in which all other requirements defined in 2/CMP.7 and IPCC (2014) are met, Switzerland will evaluate and decide whether the technical effort would be justified to exclude them.

Between 2013 and the reporting year, no natural disturbances causing emissions exceeding the upper confidence interval (background level plus margin) occurred. Thus, no emissions from natural disturbances were excluded for the entire commitment period 2013–2020.

#### *11.5.2.5.2. Technical correction of the background level and margin*

The background level and margin have been reviewed and are reported in the update of Switzerland’s Second Initial Report under the Kyoto Protocol (FOEN 2016d).

There is no technical correction of the background level and margin.

### 11.5.2.6. Information on Harvested wood products under Article 3.4

Methodology, estimates and uncertainties of carbon stock changes in the HWP pool are described in chp. 6.11. The same methodology was applied for reporting HWP from Forest land under the UNFCCC and accounting for HWP from Forest management under the Kyoto Protocol. A time series for changes in the HWP pool is shown in Table 6-33 and Figure 6-14. An overview of emissions and removals resulting from the HWP pool from Forest management is presented in Table 11-1 and Figure 11-1.

## 11.5.3. Information relating to Cropland management, Grazing Land management, Revegetation and Wetland drainage and rewetting if elected, for the Base Year

Not applicable.

### 11.5.4. Information that demonstrates that emissions and removals resulting from elected Article 3, paragraph 4 activities are not accounted for under activities under Article 3, paragraph 3

This information is requested in the Annex to 15/CMP.1 paragraph 9(c). The reporting of Forest management under Article 3, paragraph 4 is clearly separated from the reporting of the activities under Article 3, paragraph 3.

Units of lands with ARD (Afforestation, Reforestation and Deforestation) activities, are reported under Article 3, paragraph 3. These areas always remain under Article 3, paragraph 3. Afforestations older than 20 years are accounted for based on carbon stock change factors of mature forests under Forest management. These units of lands are reported in CRF 4(KP-I)A.1 and not under Forest management. Thus, there is no double counting of units of lands under article 3, paragraph 3 and Article 3, paragraph 4.

### 11.5.5. Information that indicates to what extend removals from Forest management offset the debit incurred under Article 3, Paragraph 3

Over the commitment period 2013–2020, Afforestations amount to net removals of -137.07 kt $CO_2$ eq and Deforestation to net emissions of 1’523.60 kt $CO_2$ eq (CRF accounting). Thus, the debit incurred under Article 3, Paragraph 3 amounts to 1’386.54 kt $CO_2$ eq.

The accounting quantity of Forest Management over the commitment period 2013–2020 amounts to -5’894.86 kt $CO_2$ eq (CRF accounting).

Thus, over the commitment period 2013–2020, forest-related activities under Article 3, Paragraph 3 (Afforestations and Deforestation) and Forest Management under Article 3, Paragraph 4 act as a net accountable sink of -4’508.32 kt $CO_2$ eq.

## 11.6. Other information

### 11.6.1. Key category analysis for Article 3.3 and 3.4 activities

The results of the Approach 1 key category analysis including LULUCF for the reporting year are shown in Table 1-4 (by emissions) and summarized in Table 1-9. The method is explained in chp. 1.5. The smallest UNFCCC category, considered key based on an Approach 1 level assessment within the given threshold of 95% is “4F2 Land Converted to Other Land, $CO_2$” with a contribution of 129.55 kt $CO_2$ eq.

The following LULUCF activities under the Kyoto Protocol are listed in CRF NIR-3 because their associated LULUCF categories in the UNFCCC inventory are key categories under the level or trend assessment:

- Forest management (-2’281.55 kt $CO_2$; subtotal without HWP in CRF 4(KP-I)B.1) encompasses net $CO_2$ removals from Forest management excluding HWP, biomass burning and drainage (see Table 11-1) and is a key category under the Kyoto Protocol because its absolute contribution is higher than the smallest category considered key in the UNFCCC inventory. This activity is associated with the UNFCCC category Forest land remaining forest land. Since the total Swiss forest is considered as managed, there is a good agreement between the activity under the Kyoto Protocol and the UNFCCC category (Table 11-6). According to Table 1-9 the UNFCCC category ”Forest land remaining forest land“ is both level and trend key category under Approaches 1 and 2 assessments in the reporting year.

- Afforestation and Reforestation (-15.90 kt $CO_2$; CRF 4(KP-I)A.1) encompasses net $CO_2$ removals and is not a key category under the Kyoto Protocol because its absolute contribution is substantially lower than the smallest category considered key in the UNFCCC inventory. The associated UNFCCC category Land converted to Forest Land includes converted areas after natural regenerations due to abandonment of land, which are not reported as Afforestation under the Kyoto Protocol. The UNFCCC category Land converted to forest Land is level key category under Approaches 1 and 2 assessments in the reporting year (Table 1-9).
- Deforestation (192.40 kt $CO_2$; CRF 4(KP-I)A.2) encompasses net $CO_2$ emissions and is a key category under the Kyoto Protocol because its contribution is higher than the smallest UNFCCC category considered key. The associated UNFCCC category is Land converted to settlements, but only a part of this UNFCCC category represents the activity Deforestation under the Kyoto Protocol (see chp. 11.2.3). The UNFCCC category Land converted to settlements is level key category under Approach 1 and 2 assessment in the reporting year (Table 1-9).
- Harvested wood products (-51.14 kt $CO_2$; CRF 4(KP-I)C) is not a key category under the Kyoto Protocol because its absolute contribution is lower than the smallest UNFCCC category considered key. The same method is used for the calculation of HWP under the UNFCCC and the KP. According to Table 1-9 the UNFCCC category ”HWP“ is trend key category category under Approaches 1 and 2 assessments in the reporting year.

## 11.7. Information relating to Article 6

Switzerland does not host Joint Implementation projects.

# 12. Information on accounting of Kyoto units

| Responsibilities for chapter Information on accounting of Kyoto units | |
|---|---|
| Overall responsibility | Stefan Meier (FOEN), Regine Röthlisberger (FOEN) |
| Authors | Stefan Meier (FOEN), Regine Röthlisberger (FOEN) |
| Sector expert | Susanne Riedener (FOEN) |
| Internal review | Michael Bock (FOEN), Susanne Riedener (FOEN) |

## 12.1. Background information

The Swiss Emissions Trading Registry completed the go-live process and got fully operational with the International Transaction Log (ITL) on 4 December 2007.

The user interface is located on the Swiss Emissions Trading Registry website (https://www.emissionsregistry.admin.ch). Switzerland uses the CR registry software, which has been developed by Lippke & Wagner GmbH. On 21 September 2020, the link of the emissions trading registries of Switzerland and the European Union (EU) has become operational.

The following registry systems' reporting includes the Standard Electronic Format (SEF) tables and the standard independent assessment report (SIAR) tables in accordance with sections E and G of the annex to decision 15/CMP.1.

## 12.2. Summary of information reported in the SEF tables

The Standard Electronic Format reports for units with applicable commitment period 1 (CP1), and with applicable commitment period 2 (CP2) for 2021, have been submitted to the UNFCCC Secretariat electronically.

### Overview of CP1 units

By the end of 2021, 241'826'246 Assigned Amount Units (AAUs) were held in the Swiss Emissions Trading Registry (Table 12-1). In addition, 4'210'465 Emission Reduction Units (ERUs), 9'280'880 Removal Units (RMUs), 23'935'525 Certified Emission Reductions (CERs), and 114'793 temporary Certified Emission Reductions (tCERs) were held in the Swiss Emissions Trading Registry.

Table 12-1 Total quantities of CP1 Kyoto Protocol units by account type at the end of 2021 (SEF table 4)

| Account type | Unit type | | | | | |
|---|---|---|---|---|---|---|
| | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
| Party holding accounts | NO | NO | NO | NO | NO | NO |
| Entity holding accounts | NO | NO | NO | NO | NO | NO |
| Article 3.3/3.4 net source cancellation accounts | 172'587 | NO | 1'013'340 | NO | | |
| Non-compliance cancellation account | NO | NO | NO | NO | | |
| Other cancellation accounts | 4'796'312 | 3'651'820 | NO | 7'897'328 | 114'793 | NO |
| Retirement account | 236'857'347 | 558'645 | 8'267'540 | 16'038'197 | NO | NO |
| tCER replacement account for expiry | NO | NO | NO | NO | NO | |
| lCER replacement account for expiry | NO | NO | NO | NO | | |
| lCER replacement account for reversal of storage | NO | NO | NO | NO | | NO |
| lCER replacement account for non-submission of certification report | NO | NO | NO | NO | | NO |
| Total | 241'826'246 | 4'210'465 | 9'280'880 | 23'935'525 | 114'793 | NO |

### Overview of CP2 units

By the end of the reporting year 2021, a total balance of 367'563'047 AAUs, 79'866'271 ERUs, and 75'460'443 CERs were held in the Swiss Emissions Trading Registry, of which 2'388'698 ERUs and 30'016'668 CERs have been voluntarily cancelled (Table 12-2).

Table 12-2 Total quantities of CP2 Kyoto Protocol units by account type at the end of 2021 (SEF table 4)

| Account type | Unit type | | | | | |
|---|---|---|---|---|---|---|
| | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
| Party holding accounts | 361'768'524 | NO | NO | 1'961'642 | NO | NO |
| Entity holding accounts | NO | 77'477'573 | NO | 43'482'133 | NO | NO |
| Retirement account | NO | NO | NO | NO | NO | NO |
| Previous period surplus reserve account | 5'794'523 | | | | | |
| Article 3.3/3.4 net source cancellation accounts | NO | NO | NO | NO | | |
| Non-compliance cancellation account | NO | NO | NO | NO | | |
| Voluntary cancellation account | NO | 2'388'698 | NO | 30'016'668 | NO | NO |
| Cancellation account for remaining units after carry-over | NO | NO | NO | NO | NO | NO |
| Article 3.1 ter and quater ambition increase cancellation account | NO | | | | | |
| Article 3.7 ter cancellation account | NO | | | | | |
| tCER cancellation account for expiry | | | | | NO | |
| lCER cancellation account for expiry | | | | | | NO |
| lCER cancellation account for reversal of storage | | | | | | NO |
| lCER cancellation account for non-submission of certification report | | | | | | NO |
| tCER replacement account for expiry | NO | NO | NO | NO | NO | |
| lCER replacement account for expiry | NO | NO | NO | NO | | |
| lCER replacement account for reversal of storage | NO | NO | NO | NO | | NO |
| lCER replacement account for non-submission of certification report | NO | NO | NO | NO | | NO |
| **Total** | 367'563'047 | 79'866'271 | NO | 75'460'443 | NO | NO |

## 12.3. Discrepancies and notifications

Switzerland's reports on discrepancies (R-2), Clean development mechanism (CDM) notifications (R-3), non-replacements (R-4) including reversal of storage and failure of certification and invalid units (R-5) have been uploaded on the UNFCCC Submission Portal.

During the reported year 2021, the Swiss Emissions Trading Registry had had two discrepant transactions with the DES response code 5104, no CDM notifications, no non-replacements including reversal of storage and failure of certification and no invalid units. The discrepant transactions have been reported in the SIAR table R-2.

## 12.4. Publicly accessible information

In accordance to section E of the annex to decision 13/CMP.1 the Swiss Emissions Trading Registry makes non-confidential information available to the public via webpage or user-interface.

Non-confidential information is publicly available on the Swiss Emissions Trading Registry website https://www.emissionsregistry.admin.ch. The report 'Accounts' in the Public Information menu provides a list of open accounts in the national registry. The report 'Transaction list' in the Public Information menu provides a list of all transactions in the Swiss Emissions Trading Registry up to 30 April each three years prior to the reporting year, i.e. all transactions details of the last three years remain confidential. The report 'Issued Attestations" lists all the issued attestations originating from domestic emission-reduction projects. The national allocation plans of installation and aviation operators are accessible under 'Allocation' in the respective ETS reports menu. The 'Surrendering Obligation', and 'Surrendered units' per operator are also publicly accessible.

Data of transfers and holdings of individual accounts are considered as business secrets and the disclosure may prejudice their competitiveness. Information on acquiring and transferring units of companies (as legal persons) is therefore regarded as personal data. Article 19 of the Federal Act on Data Protection (FADP, SR 235.1 Bundesgesetz vom 19. Juni 1992 über den Datenschutz (DSG)) enacts that federal bodies may disclose personal data if there is a legal basis for doing so or if there is an overriding public interest. Article 65 letter $c^{bis}$ of the $CO_2$ Ordinance (SR 641.711 Ordinance of 30 November 2012 for the Reduction of $CO_2$ Emissions) enacts the possibility, subject to preservation of manufacturing and trade secrecy, to electronically publish transaction data. Therefore, information on acquiring and transferring accounts in the Swiss Emissions Trading Registry are published except for the last three years prior to the reporting year. The Representative identifier (13/CMP.1 Annex paragraph 45 (d)), as well as all information according to 13/CMP.1 Annex paragraph 45 (e) are also considered as confidential. A statement on which information is considered as confidential can be found on the website https://www.emissionsregistry.admin.ch under the Public Information menu.

All other information referred to in paragraphs 44 to 48 to the annex to decision 13/CMP.1 are made publicly available by the Swiss Emissions Trading Registry, if they are not covered by the above mentioned articles.

Switzerland does not host Joint Implementation (JI)-projects and therefore no issuance of ERUs has taken place. A corresponding statement can be found on the registry website.

## 12.5. Calculation of the Commitment Period Reserve (CPR)

The commitment period reserve and the assigned amount for the second commitment period is defined based on the *Report to facilitate the calculation of the assigned amount pursuant to Article 3, paragraphs 7bis, 8 and 8bis, of the Kyoto Protocol for the second commitment period 2013–2020 (Switzerland's Initial Report under the Kyoto Protocol, 2nd CP)* (FOEN 2016c), and the update to the report following the review (FOEN 2016d). According to the final review report (UNFCCC 2017a), Switzerland's assigned amount for the second commitment period is 361'768.524 kt $CO_2$ equivalent. The commitment period reserve is 325'591.672 kt $CO_2$ equivalent.

## 12.6. KP-LULUCF accounting

Switzerland chose to account over the entire commitment period for emissions and removals from activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol.

# 13. Information on changes in National Registry

| Responsibilities for chapter Information on changes in National Registry | |
|---|---|
| Overall responsibility | Stefan Meier (FOEN) |
| Internal review | Susanne Riedener (FOEN) |

Table 13-1 Changes in the national registry in accordance with §32 decision 15/CMP.1

| Annual Submission Item | Reporting |
|---|---|
| 15/CMP.1 annex II.E paragraph 32.(a):<br>Change of name or contact | No change in the name or contact information of the registry administrator occurred during the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(b):<br>Change of cooperation arrangement | No change of cooperation arrangement occurred during the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(c):<br>Change of the database or the capacity of National Registry | No change to the database or to the capacity of the national registry occurred during the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(d):<br>Change of conformance to technical standards | No change in the registry's conformance to technical standards occurred for the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(e):<br>Change of discrepancies procedures | No change of discrepancies procedures occurred during the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(f):<br>Change of Security | No change of security measures occurred during the reporting period. |
| 15/CMP.1 annex II.E paragraph 32.(g):<br>Change of list of publicly available information | No change to the list of publicly available information occurred during the reporting period. |
| 15/CMP.1 annex II.E paragraph 32.(h):<br>Change of Internet address | No change of the registry Internet address occurred during the reporting period. |
| 15/CMP.1 annex II.E paragraph 32.(i):<br>Change of data integrity measures | No change of data integrity measures occurred during the reporting period. |
| 15/CMP.1 annex II.E paragraph 32.(j):<br>Change of test results | No change of test results occurred during the reporting period. |

# 14. Information on minimization of adverse impacts in accordance with Article 3, Paragraph 14

| Responsibilities for chapter Information on minimization of adverse impacts in accordance with Article 3, Paragraph 14 | |
|---|---|
| Overall responsibility | Adrian Schilt (FOEN) |
| Authors | Matthias Bachmann (FDFA-SDC), Gabriela Blatter (FOEN), Phillip Brunet (FDFA-SDC), Annetta Holl (SECO), Yvan Keckeis (FDFA-PSD), Lydie-Line Paroz (FOEN), Françoise Salamé (SECO), Julien Volery (SECO), Laura Wyss (FDFA-PSD) |
| Internal review | Regine Röthlisberger (FOEN) |

The Convention (Art. 4 §8 and §10) and its Kyoto Protocol (Art. 2 §3 and Art. 3 §14) commit Parties to strive to implement climate policies and measures in such a way as to minimize adverse economic, social and environmental impacts on developing countries when responding to climate change.

**Context**

Switzerland strives to design climate change policies and measures in a way as to ensure a balanced distribution of mitigation efforts by implementing climate change response measures in all sectors and for different gases. Indirectly, this approach is deemed to minimise also potential adverse impacts on concerned actors (including developing countries). Given Switzerland's size and share in international trade (mainly with the European Union), it is assumed that Swiss climate change policies do not have any significant adverse economic, social or environmental impacts in developing countries. Additionally, the policies and measures are very much compatible and consistent with those of the European Union in order to avoid trade distortion, non-tariff barriers to trade and to set similar incentives. All major legal reform projects in Switzerland are to be accompanied by impact assessments, inter alia including evaluation of trade-related issues. This approach strives for climate change response measures which are least trade distortive and do not create unnecessary barriers to trade. Consistently, Switzerland notifies all proposed non-tariff measures having a potential impact on trade to the World Trade Organisation.

Impact assessments of legal reform projects are accompanied by a broad internal and external consultation process, inter alia inviting competent and potentially affected actors to provide advice on economic, social and environmental aspects of proposed policies and measures. The open public consultation process, together with regular policy dialogues with other countries, guarantee that domestic and foreign stakeholders can raise concerns and issues related to new policy initiatives, including their coherence with other policies and measures and those concerns about possible adverse impacts on other countries.

In the framework of the Comprehensive Economic Partnership Agreement (CEPA) between member states of the European Free Trade Association and Indonesia, Switzerland is piloting a new regulatory mechanism to link the granting of certain trade preferences with sustainable production and processing methods.

**Progressive reduction or phasing out of market imperfections, fiscal incentives, tax and duty exemptions and subsidies in all greenhouse-gas-emitting sectors, taking into account the need for energy price reforms to reflect market prices and externalities**

Environmental policy in Switzerland, including climate change policies, is guided by the polluter pays principle, as enshrined in the Swiss Federal Act on the Protection of the Environment (Swiss Confederation, 1983). Accordingly, the internalisation of external costs and adequate price signals are key aspects of Switzerland's climate change policy. Regarding greenhouse gas emissions, market-based instruments – such as the Swiss emissions trading scheme, the supplemental use of international carbon credits from the Clean Development Mechanism or the $CO_2$ levy on heating and process fuels – are important measures to put a price on emissions of greenhouse gases that are then reflected in market prices and thus internalizing externalities.

Regarding fiscal incentives, tax and duty exemptions and subsidies, price-based measures are recognised as essential instruments for promoting the efficient use of resources and to reduce market imperfections. In 2001, Switzerland introduced a heavy vehicle charge. It is applied to passenger and freight transport vehicles of more than 3.5 tonnes gross weight. The impact of the heavy vehicle charge was most clearly demonstrated by changes in traffic volume (truck-kilometres), but also by reduced air pollution, a renewal of the heavy vehicle fleet and an increase of load per vehicle, i.e. fewer trucks transported more goods. Two thirds of the revenues are used to finance major railway infrastructure projects (such as the base tunnels through the Alps), and one third is transferred to the cantons. The Swiss Federal Office for Spatial Development annually publishes a report analysing all external effects of transport (including costs and benefits). The most recent estimates for 2017 correspond to total external costs of transport of about 13.4 billion Swiss francs with external costs related to climate contributing about 2.7 billion Swiss francs (ARE 2020).

In 2008, Switzerland introduced the $CO_2$ levy on heating and process fuels to set an incentive for a more efficient use of fossil fuels, promote investment in energy-efficient technologies and the use of low-carbon or carbon-free energy sources. Companies, especially those with substantial $CO_2$ emissions from use of heating and process fuels, may apply for exemption from the $CO_2$ levy on heating and process fuels, provided the company commits to emission reductions. The company has to elaborate an emission reduction target based on the technological potential and economic viability of various measures within the company. While the proceeds from the $CO_2$ levy on heating and process fuels were initially to be fully refunded to the Swiss population (on a per capita basis) and to the Swiss economy (in proportion to wages paid), a parliamentary decision of June 2009 earmarked a third of the revenues from the $CO_2$ levy on heating and process fuels for $CO_2$ relevant measures in the buildings sector. As of 1 January 2018, the funds for the national buildings refurbishment programme are limited to a maximum of 450 million Swiss francs per year (previously 300 million Swiss francs per year).

In general, Switzerland does not subsidise fossil fuels. However, depending on the definition, there are some policies in place that may be regarded as fossil fuel subsidies, but these policies are only applicable to small amounts of fossil fuels consumed in Switzerland. At the federal level, a few tax exemptions and reductions provide limited support to users of fossil fuels. Farmers, foresters, fishermen and the fuel use of snow cats are exempt from the mineral oil tax that is normally levied on sales of mineral oils, while public transport companies benefit from a reduced rate. These mineral oil tax exemptions in the specific sectors are listed in appendix 3 of the Swiss Federal Council's subsidy report (Swiss Federal Council 2008). Moreover, the mineral oil tax refunds in the agriculture sector was subject to an examination by the Swiss Federal Audit Office. In the respective report published in August 2018, the Swiss Federal Audit Office recommends the preparation of a legislative revision to abolish the mineral oil tax refunds in the agriculture sector (economic support for agriculture should be provided entirely in the form of direct payments) (EFK 2018). Some vehicles are also exempt from the performance-related heavy vehicle charge, e.g. agricultural vehicles, vehicles used for the concessionary transport of persons or vehicles for police, fire brigades, oil and chemical emergency units, civil protection and ambulances.

Worldwide subsidies for fossil fuels are estimated at 300 billion to 500 billion US dollars per year, depending on what is measured (consumption/production subsidies) and the level of energy prices. This huge market distortion does not only produce severe fiscal problems and opportunity costs for the countries concerned, it also poses a major obstacle for enhanced investments in energy efficiency measures and renewable energies. Switzerland as a founding member of the Friends of Fossil Fuels Subsidy Reform supports the gradual and sustained phasing out of fossil fuel subsidies and the reduction of unnecessary market distortions. Furthermore, Switzerland contributes to the Energy Sector Management Assistance Program administered by the World Bank. This programme manages the Energy Subsidy Reform Facility that offers technical assistance for states that want to reform their fossil fuel subsidies, and provides the analytical basis for the implementation of such reforms.

**Removing subsidies associated with the use of environmentally unsound and unsafe technologies**

Switzerland does not subsidise the use of environmentally unsound and unsafe technologies with a direct negative climate impact.

**Cooperating in the technological development of non-energy uses of fossil fuels, and supporting developing country Parties to this end**

Switzerland does not support any activities linked to the technological development of non-energy uses of fossil fuels in developing countries.

**Cooperating in the development, diffusion, and transfer of less-greenhouse-gas-emitting advanced fossil fuel technologies, and/or technologies, relating to fossil fuels, that capture and store greenhouse gases, and encouraging their wider use; and facilitating the participation of the least developed countries and other non-Annex I Parties in this effort**

Switzerland is an active participant in the negotiations for a plurilateral initiative with five other members of the World Trade Organisation (Costa Rica, Fiji, Iceland, New Zealand, Norway) on the Agreement on Climate Change, Trade and Sustainability (ACCTS) that seeks to liberalise trade in environmental goods and services, eliminate harmful fossil fuel subsidies, and promote voluntary eco-labelling programmes.

Furthermore, Switzerland advocates the use of the most efficient technologies available for gas mid-stream and down-stream projects in developing countries. The Swiss policy on fossil fuel investments by multilateral development banks (MDBs) rejects investments in coal financing and up-stream fossil fuel activities but allows support to gas power plants as well as gas mid-stream and down-stream projects in limited circumstances when four cumulative criteria (need, efficiency, additionality and transition) are met. This ensures that the project is in line with the goals of the Paris Agreement.

Several Swiss universities conduct research in the field of carbon capture and storage and cooperate with other research institutions, companies and universities primarily in Europe and northern America to further develop the technology. Currently, Switzerland is not supporting any least developed countries and other developing countries in the development of fossil fuel-fired power plants with carbon capture and storage technology, because Switzerland is of the view that the technology is not sufficiently mature and cost effective yet.

**Strengthening the capacity of developing country Parties for improving efficiency in upstream and downstream activities relating to fossil fuels, taking into consideration the need to improve the environmental efficiency of these activities**

Switzerland supports through different projects the enhancement of efficiency in industrial production, i.e. 'cleaner production'. These cleaner production projects promote eco-efficient means of production and better working conditions attained through technological improvements and behavioural changes in both management and staff in industrial companies and services. The resulting rise of economic and environmental efficiency and improved competitiveness is gained through the systematic optimisation of energy use, processing of raw material, more efficient use of resources and thus better protection of the environment. Switzerland also supports efforts aiming at the adoption of cleaner fuel standards (i.e. with lower sulphur content) as well as higher vehicle emission standards, which can reduce air pollution.

Switzerland also supports through different projects the energy efficiency and decarbonisation of end-use sectors such as construction and transportation. These projects support the use of low greenhouse gas construction materials and processes, the efficiency of heating of building and facilities, meeting the growing need for cooling while avoiding soaring energy demand and greenhouse gas emissions, and improve efficiency of energy use for transport.

Furthermore, there is a rising awareness and demand by consumers for environmentally sound products. In order to alleviate potential adverse economic impacts of corresponding national measures Switzerland promotes and supports the development of international standards, especially with regard to the sustainable use of natural resources (including agricultural commodities), e.g. through the creation of sustainability standards, financial incentives and favourable framework conditions in developing countries.

**Assisting developing country Parties which are highly dependent on the export and consumption of fossil fuels in diversifying their economies**

Most developing and transition countries have, in recent years, taken important steps towards trade liberalisation, in order to align their trade policies with international trade agreements. The Swiss State Secretariat for Economic Affairs supports these efforts, because a multilaterally acknowledged and respected set of regulations for international transactions not only strengthens trade as such, but also creates more potent and legally secure markets to the benefit of all players.

The measures taken by the Swiss State Secretariat for Economic Affairs aim at creating the necessary conditions for earning additional income in the beneficiary countries and thereby contribute directly to the alleviation of poverty. The Swiss State Secretariat for Economic Affairs is focusing on three areas of intervention along the value chain: (1) enabling framework conditions for trade, (2) international competitiveness, and (3) improving market access.

Conversely, measures taken to help countries highly dependent on fossil fuel consumption to reduce this consumption through energy efficiency measures and the transition to renewable energies allows them to free up resources that were dedicated to this consumption, to accordingly invest in the diversifying of their economies – notably their energy sector, and to limit their exposure to the risk of a concomitant increase in fossil fuel prices.

Regarding market access, trade between developing and industrial countries is often insufficiently developed respectively not diversified enough. On the one hand, in some developing countries there is still a lack of necessary production capacities, quality standards, transport infrastructure and know-how; on the other hand, tariff and non-tariff barriers to trade make economic diversification and direct access to markets more difficult.

Switzerland promotes access to Swiss markets by granting preferential tariffs on products from developing and emerging countries. In addition, the Swiss State Secretariat for Economic Affairs runs programmes for promoting imports to Switzerland and the rest of Europe. Easing market entry for products from disadvantaged countries is an important contribution to the promotion and diversification of trade, the increase of export revenues and thus to the economic development of the partner countries. Switzerland supports developing and transition countries in the following areas:

- Generalised system of preferences;
- Swiss Import Promotion Program (www.sippo.ch);
- Promotion and strengthening of private voluntary social and environmental standards based on international multi-stakeholder approaches, such as Better Cotton, 4C (Common Code for the Coffee Community), Roundtable for Sustainable Biofuels, etc.

Finally, Switzerland is a strong supporter of the Extractive Industries Transparency Initiative. Switzerland acts based on the conviction that an efficient, inclusive and sustainable use of natural resources is an important driving force for sustainable economic growth, contributing to sustainable development and poverty reduction. The sustainable management of natural resources – as supported by the Extractive Industries Transparency Initiative principle and criteria including regular publication and audit of revenues – is key to mobilise the funds for diversification strategies.

**Changes compared to the previous submission**

There are no fundamental changes compared to the previous submission.

# Annexes

# Annex 1 Key category analysis (KCA)

Table A – 1 Overview of Switzerland's key category analysis, including LULUCF categories and indirect $CO_2$ emissions. L: level assessment (2020); T: trend assessment (1990–2020); 1: KCA approach 1; 2: KCA approach 2. $SF_6$ and $NF_3$ are not emitted from any key category. Note that categories which are key for the level assessment for the base year only are not reported in this table. Columns A to D are labelled according to Table 4-4 in the IPCC guidelines, vol.1, chp. 4 (IPCC, 2006).

| SUMMARIES TO IDENTIFY KEY CATEGORIES | | | | | | |
|---|---|---|---|---|---|---|
| A | B | C & D | | | | |
| Code | IPCC category | CO2 | CH4 | N2O | HFC | PFC |
| 1A1 | Energy Industries; Biomass | | | | | |
| 1A1 | Energy Industries; Gaseous Fuels | L1, T1 | | | | |
| 1A1 | Energy Industries; Liquid Fuels | L1, T1 | | | | |
| 1A1 | Energy Industries; Other Fuels | L1, T1, L2, T2 | | | | |
| 1A1 | Energy Industries; Solid Fuels | | | | | |
| 1A2 | Manufacturing Industries and Construction; Biomass | | | | | |
| 1A2 | Manufacturing Industries and Construction; Gaseous Fuels | L1, T1, L2 | | | | |
| 1A2 | Manufacturing Industries and Construction; Liquid Fuels | L1, T1 | | | | |
| 1A2 | Manufacturing Industries and Construction; Other Fuels | L1, T1 | | | | |
| 1A2 | Manufacturing Industries and Construction; Solid Fuels | L1, T1 | | | | |
| 1A3a | Civil Aviation; Kerosene | T1 | | | | |
| 1A3b | Road Transportation; Biomass | | | | | |
| 1A3b | Road Transportation; Diesel oil | L1, T1 | | T1 | | |
| 1A3b | Road Transportation; Gaseous Fuels | | | | | |
| 1A3b | Road Transportation; Gasoline | L1, T1 | T1 | T1 | | |
| 1A3b | Road Transportation; Liquefied Petroleum Gas | | | | | |
| 1A3c | Railways; Biomass | | | | | |
| 1A3c | Railways; Liquid Fuels | | | | | |
| 1A3d | Water-borne Navigation; Biomass | | | | | |
| 1A3d | Water-borne Navigation; Liquid Fuels | | | | | |
| 1A3e | Other Transportation; Gaseous Fuels | | | | | |
| 1A4a | Commercial; Biomass | | | | | |
| 1A4a | Commercial; Gaseous Fuels | L1, T1 | | | | |
| 1A4a | Commercial; Liquid Fuels | L1, T1 | | | | |
| 1A4b | Residential; Biomass | | | | | |
| 1A4b | Residential; Gaseous Fuels | L1, T1, L2 | | | | |
| 1A4b | Residential; Liquid Fuels | L1, T1 | | | | |
| 1A4b | Residential; Solid Fuels | | | | | |
| 1A4c | Agriculture and Forestry; Biomass | | | | | |
| 1A4c | Agriculture and Forestry; Gaseous Fuels | | | | | |
| 1A4c | Agriculture and Forestry; Liquid Fuels | L1, T1 | | | | |
| 1A5 | Non-Specified; Biomass | | | | | |
| 1A5 | Non-Specified; Liquid Fuels | | | | | |
| 1B | Fugitive Emissions from Fuels; CH4 (indirect) | | | | | |
| 1B | Fugitive Emissions from Fuels; NMVOC (indirect) | | | | | |
| 1B2 | Oil and Natural Gas Energy Production; All Fuels | | L1, T1 | | | |
| 2A | Mineral Industry; CO (indirect) | | | | | |
| 2A | Mineral Industry; NMVOC (indirect) | | | | | |
| 2A1 | Cement Production | L1, T1, L2 | | | | |
| 2A2 | Lime production | | | | | |
| 2A3 | Glass Production | | | | | |
| 2A4 | Other Process Uses of Carbonates | | | | | |
| 2B | Chemical Industry; CH4 (indirect) | | | | | |
| 2B | Chemical Industry; CO (indirect) | | | | | |
| 2B | Chemical Industry; NMVOC (indirect) | | | | | |
| 2B2 | Nitric Acid Production | | | | | |
| 2B5 | Carbide Production | | | | | |
| 2B8 | Petrochemical and Carbon Black Production | | | | | |
| 2B10 | Chemical Industry, Other | | | L1, T1, L2 | | |
| 2C | Metal Industry; CO (indirect) | | | | | |
| 2C | Metal Industry; NMVOC (indirect) | | | | | |
| 2C1 | Iron and Steel Production | | | | | |
| 2C3 | Aluminium Production | T1 | | | | T1 |
| 2C4 | Magnesium Production | | | | | |
| 2C7 | Rare Earths | | | | | |
| 2D | Non-Energy Products from Fuels and Solvent Use | | | | | |
| 2D | Non-Energy Products from Fuels and Solvent Use; CO (indirect) | | | | | |
| 2D | Non-Energy Products from Fuels and Solvent Use; NMVOC (indirect) | T1, L2, T2 | | | | |
| 2E1 | Integrated Circuit or Semiconductor | | | | | |
| 2E3 | Photovoltaics | | | | | |
| 2E5 | Electronics Industry, Other | | | | | |
| 2F1 | Refrigeration and Air Conditioning | | | | L1, T1, L2, T2 | |
| 2F2 | Foam Blowing Agents | | | | | |
| 2F4 | Aerosols | | | | | |
| 2F5 | Solvents | | | | | |
| 2G | Other Product Manufacture and Use | | | | | |
| 2G | Other Product Manufacture and Use; CO (indirect) | | | | | |
| 2G | Other Product Manufacture and Use; NMVOC (indirect) | L2 | | | | |
| 2H | Other | | | | | |
| 2H | Other; CO (indirect) | | | | | |
| 2H | Other; NMVOC (indirect) | | | | | |

Table A – 1 (continued)

| SUMMARIES TO IDENTIFY KEY CATEGORIES | | | | | | |
|---|---|---|---|---|---|---|
| A | B | C & D | | | | |
| Code | IPCC category | CO2 | CH4 | N2O | HFC | PFC |
| 3A | Enteric Fermentation | | L1, T1, L2 | | | |
| 3B1-4 | Manure Management, all Livestock, direct | | L1, L2 | L2 | | |
| 3B5 | Manure Management, indirect | | | L1, L2 | | |
| 3Da | Direct Emissions from Managed Soils | | | L1, T1, L2 | | |
| 3Db | Indirect Emissions from Managed Soils | | | L1, L2 | | |
| 3G | Liming | | | | | |
| 3H | Urea Application | | | | | |
| 4A1 | Forest Land Remaining Forest Land | L1, T1, L2, T2 | | | | |
| 4A2 | Land Converted to Forest Land | L1, L2 | | | | |
| 4B1 | Cropland Remaining Cropland | T1, L2, T2 | | | | |
| 4B2 | Land Converted to Cropland | | | | | |
| 4C1 | Grassland Remaining Grassland | L1, T1, L2, T2 | | | | |
| 4C2 | Land Converted to Grassland | L1, T1, L2 | | | | |
| 4D1 | Wetland Remaining Wetland | L2 | | | | |
| 4D2 | Land Converted to Wetland | | | | | |
| 4E1 | Settlements Remaining Settlements | | | | | |
| 4E2 | Land Converted to Settlements | L1, L2 | | | | |
| 4F2 | Land Converted to Other Land | L1, L2 | | | | |
| 4G | HWP Harwested Wood Products | T1, T2 | | | | |
| 4II | Drainage and Rewetting | | | | | |
| 4III | Direct N2O from Disturbance | | | L2 | | |
| 4II | Drainage and Rewetting | | | | | |
| 4IV | Indirect N2O | | | | | |
| 4V | Biomass Burning | | | | | |
| 5A | Solid Waste Disposal | | L1, T1, L2 | | | |
| 5B | Biological Treatment of Solid Waste | | | | | |
| 5C | Incineration and Open Burning of Waste | | | L2 | | |
| 5C | Incineration and Open Burning of Waste; CH4 (indirect) | | | | | |
| 5C | Incineration and Open Burning of Waste; CO (indirect) | | | | | |
| 5C | Incineration and Open Burning of Waste; NMVOC (indirect) | | | | | |
| 5D | Wastewater Treatment and Discharge | | L1, T1, L2 | L2 | | |
| 5E | Waste, Other; CO (indirect) | | | | | |
| 5E | Waste, Other; NMVOC (indirect) | | | | | |
| 6 | Other | | | | | |
| 6A | Other; CH4 (indirect) | | | | | |
| 6A | Other; CO (indirect) | | | | | |
| 6A | Other; NMVOC (indirect) | | | | | |

# Annex 2 Assessment of uncertainty

## A2.1 Input uncertainty values

Table A – 2 Input uncertainties for the year 2020, including LULUCF categories and indirect $CO_2$ emissions. Input uncertainties are assigned to activity data (col. E) and emissions factors (col. F) or, if unknown, to emissions only (col. G). The uncertainties are given considering a 95% confidence interval (from 2.5% to 97.5%) and expressed as the distance from edge to mean, in percentage of the mean, except for triangular distributions where uncertainties are the edges of the distribution. Columns A to G are labelled according to Table 3-2 in the IPCC guidelines, vol.1, chp. 3 (IPCC, 2006).

| A | B | E | | | | | F | | | | | G | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code | Gas | Activity data uncertainty year 2020 | | | | | Emission factor uncertainty year 2020 | | | | | Emission uncertainty year 2020 | | | | |
| | | Distribution type | 2*std. dev. % | (-)% | (+)% | Corr. | Distribution type | 2*std. dev. % | (-)% | (+)% | Corr. | Distribution type | 2*std. dev. % | (-)% | (+)% | Corr. |
| 1A1; Biomass | CH4 | normal | 10.0 | 10.0 | 10.0 | no | normal | 28.3 | 28.3 | 28.3 | yes | | | | | |
| 1A1; Biomass | N2O | normal | 10.0 | 10.0 | 10.0 | no | normal | 79.4 | 79.4 | 79.4 | yes | | | | | |
| 1A1; Gaseous Fuels | CO2 | normal | 5.0 | 5.0 | 5.0 | no | normal | 0.4 | 0.4 | 0.4 | no | | | | | |
| 1A1; Gaseous Fuels | CH4 | normal | 5.0 | 5.0 | 5.0 | no | normal | 29.6 | 29.6 | 29.6 | yes | | | | | |
| 1A1; Gaseous Fuels | N2O | normal | 5.0 | 5.0 | 5.0 | no | normal | 79.8 | 79.8 | 79.8 | yes | | | | | |
| 1A1; Liquid Fuels | CO2 | normal | 0.7 | 0.7 | 0.7 | no | normal | 0.1 | 0.1 | 0.1 | yes | | | | | |
| 1A1; Liquid Fuels | CH4 | normal | 0.7 | 0.7 | 0.7 | no | normal | 30.0 | 30.0 | 30.0 | yes | | | | | |
| 1A1; Liquid Fuels | N2O | normal | 0.7 | 0.7 | 0.7 | no | normal | 80.0 | 80.0 | 80.0 | yes | | | | | |
| 1A1; Other Fuels | CO2 | normal | 5.0 | 5.0 | 5.0 | no | normal | 16.9 | 16.9 | 16.9 | yes | | | | | |
| 1A1; Other Fuels | N2O | normal | 5.0 | 5.0 | 5.0 | no | normal | 79.8 | 79.8 | 79.8 | no | | | | | |
| 1A1; Solid Fuels | CO2 | normal | 5.0 | 0.0 | 0.0 | no | normal | 5.1 | 0.0 | 0.0 | yes | | | | | |
| 1A1; Solid Fuels | CH4 | normal | 5.0 | 0.0 | 0.0 | no | normal | 29.6 | 0.0 | 0.0 | yes | | | | | |
| 1A1; Solid Fuels | N2O | normal | 5.0 | 0.0 | 0.0 | no | normal | 79.8 | 0.0 | 0.0 | yes | | | | | |
| 1A2; Biomass | CH4 | normal | 10.0 | 10.0 | 10.0 | no | normal | 28.3 | 28.3 | 28.3 | yes | | | | | |
| 1A2; Biomass | N2O | normal | 10.0 | 10.0 | 10.0 | no | normal | 79.4 | 79.4 | 79.4 | yes | | | | | |
| 1A2; Gaseous Fuels | CO2 | normal | 5.0 | 5.0 | 5.0 | no | normal | 0.4 | 0.4 | 0.4 | no | | | | | |
| 1A2; Gaseous Fuels | CH4 | normal | 5.0 | 5.0 | 5.0 | no | normal | 29.6 | 29.6 | 29.6 | yes | | | | | |
| 1A2; Gaseous Fuels | N2O | normal | 5.0 | 5.0 | 5.0 | no | normal | 79.8 | 79.8 | 79.8 | yes | | | | | |
| 1A2; Liquid Fuels | CO2 | normal | 0.7 | 0.7 | 0.7 | no | normal | 0.1 | 0.1 | 0.1 | yes | | | | | |
| 1A2; Liquid Fuels | CH4 | normal | 0.7 | 0.7 | 0.7 | no | normal | 30.0 | 30.0 | 30.0 | yes | | | | | |
| 1A2; Liquid Fuels | N2O | normal | 0.7 | 0.7 | 0.7 | no | normal | 80.0 | 80.0 | 80.0 | yes | | | | | |
| 1A2; Other Fuels | CO2 | normal | 5.0 | 5.0 | 5.0 | no | normal | 9.2 | 9.2 | 9.2 | yes | | | | | |
| 1A2; Other Fuels | CH4 | normal | 5.0 | 5.0 | 5.0 | no | normal | 29.6 | 29.6 | 29.6 | yes | | | | | |
| 1A2; Other Fuels | N2O | normal | 5.0 | 5.0 | 5.0 | no | normal | 79.8 | 79.8 | 79.8 | no | | | | | |
| 1A2; Solid Fuels | CO2 | normal | 5.0 | 5.0 | 5.0 | no | normal | 5.1 | 5.1 | 5.1 | yes | | | | | |
| 1A2; Solid Fuels | CH4 | normal | 5.0 | 5.0 | 5.0 | no | normal | 29.6 | 29.6 | 29.6 | yes | | | | | |
| 1A2; Solid Fuels | N2O | normal | 5.0 | 5.0 | 5.0 | no | normal | 79.8 | 79.8 | 79.8 | yes | | | | | |
| 1A3a; Kerosene | CO2 | normal | 1.0 | 1.0 | 1.0 | no | normal | 0.2 | 0.2 | 0.2 | no | | | | | |
| 1A3a; Kerosene | CH4 | normal | 1.0 | 1.0 | 1.0 | no | normal | 60.0 | 60.0 | 60.0 | yes | | | | | |
| 1A3a; Kerosene | N2O | normal | 1.0 | 1.0 | 1.0 | no | gamma | 150.0 | 90.0 | 191.4 | yes | | | | | |
| 1A3b; Biomass | CH4 | normal | 10.0 | 10.0 | 10.0 | no | normal | 59.2 | 59.2 | 59.2 | yes | | | | | |
| 1A3b; Biomass | N2O | normal | 10.0 | 10.0 | 10.0 | no | gamma | 149.7 | 90.0 | 190.9 | yes | | | | | |
| 1A3b; Diesel oil | CO2 | normal | 0.9 | 0.9 | 0.9 | no | normal | 0.1 | 0.1 | 0.1 | no | | | | | |
| 1A3b; Diesel oil | CH4 | normal | 0.9 | 0.9 | 0.9 | no | normal | 20.0 | 20.0 | 20.0 | yes | | | | | |
| 1A3b; Diesel oil | N2O | normal | 0.9 | 0.9 | 0.9 | no | normal | 22.0 | 22.0 | 22.0 | yes | | | | | |
| 1A3b; Gaseous Fuels | CO2 | normal | 5.0 | 5.0 | 5.0 | no | normal | 0.4 | 0.4 | 0.4 | no | | | | | |
| 1A3b; Gaseous Fuels | CH4 | normal | 5.0 | 5.0 | 5.0 | no | normal | 29.6 | 29.6 | 29.6 | yes | | | | | |
| 1A3b; Gaseous Fuels | N2O | normal | 5.0 | 5.0 | 5.0 | no | normal | 79.8 | 79.8 | 79.8 | yes | | | | | |
| 1A3b; Gasoline | CO2 | normal | 0.7 | 0.7 | 0.7 | no | normal | 0.1 | 0.1 | 0.1 | no | | | | | |
| 1A3b; Gasoline | CH4 | normal | 0.7 | 0.7 | 0.7 | no | normal | 37.0 | 37.0 | 37.0 | yes | | | | | |
| 1A3b; Gasoline | N2O | normal | 0.7 | 0.7 | 0.7 | no | normal | 50.0 | 50.0 | 50.0 | yes | | | | | |
| 1A3b; Liquefied Petroleum Gas | CO2 | normal | 0.7 | 0.7 | 0.7 | no | normal | 10.0 | 10.0 | 10.0 | yes | | | | | |
| 1A3b; Liquefied Petroleum Gas | CH4 | normal | 0.7 | 0.7 | 0.7 | no | normal | 30.0 | 30.0 | 30.0 | yes | | | | | |
| 1A3b; Liquefied Petroleum Gas | N2O | normal | 0.7 | 0.7 | 0.7 | no | normal | 80.0 | 80.0 | 80.0 | yes | | | | | |
| 1A3c; Biomass | CH4 | normal | 10.0 | 10.0 | 10.0 | no | normal | 59.2 | 59.2 | 59.2 | yes | | | | | |
| 1A3c; Biomass | N2O | normal | 10.0 | 10.0 | 10.0 | no | gamma | 149.7 | 90.0 | 190.9 | yes | | | | | |
| 1A3c; Liquid Fuels | CO2 | normal | 0.9 | 0.9 | 0.9 | no | normal | 0.1 | 0.1 | 0.1 | no | | | | | |
| 1A3c; Liquid Fuels | CH4 | normal | 0.9 | 0.9 | 0.9 | no | normal | 30.0 | 30.0 | 30.0 | yes | | | | | |
| 1A3c; Liquid Fuels | N2O | normal | 0.7 | 0.7 | 0.7 | no | normal | 80.0 | 80.0 | 80.0 | yes | | | | | |
| 1A3d; Biomass | CH4 | normal | 10.0 | 10.0 | 10.0 | no | normal | 59.2 | 59.2 | 59.2 | yes | | | | | |
| 1A3d; Biomass | N2O | normal | 10.0 | 10.0 | 10.0 | no | gamma | 149.7 | 90.0 | 190.9 | yes | | | | | |
| 1A3d; Liquid Fuels | CO2 | normal | 0.7 | 0.7 | 0.7 | no | normal | 0.1 | 0.1 | 0.1 | no | | | | | |
| 1A3d; Liquid Fuels | CH4 | normal | 0.7 | 0.7 | 0.7 | no | normal | 30.0 | 30.0 | 30.0 | yes | | | | | |
| 1A3d; Liquid Fuels | N2O | normal | 0.7 | 0.7 | 0.7 | no | gamma | 150.0 | 90.0 | 191.4 | yes | | | | | |
| 1A3e; Gaseous Fuels | CO2 | normal | 5.0 | 5.0 | 5.0 | no | normal | 0.4 | 0.4 | 0.4 | no | | | | | |
| 1A3e; Gaseous Fuels | CH4 | normal | 5.0 | 5.0 | 5.0 | no | normal | 29.6 | 29.6 | 29.6 | yes | | | | | |
| 1A3e; Gaseous Fuels | N2O | normal | 5.0 | 5.0 | 5.0 | no | normal | 79.8 | 79.8 | 79.8 | yes | | | | | |

Table A – 2 (continued)

| A | B | E | | | | | F | | | | | G | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code | Gas | Activity data uncertainty year 2020 | | | | | Emission factor uncertainty year 2020 | | | | | Emission uncertainty year 2020 | | | | |
| | | Distribution type | 2*std. dev. % | (-)% | (+)% | Corr. | Distribution type | 2*std. dev. % | (-)% | (+)% | Corr. | Distribution type | 2*std. dev. % | (-)% | (+)% | Corr. |
| 1A4a; Biomass | CH4 | normal | 10.0 | 10.0 | 10.0 | no | normal | 28.3 | 28.3 | 28.3 | yes | | | | | |
| 1A4a; Biomass | N2O | normal | 10.0 | 10.0 | 10.0 | no | normal | 79.4 | 79.4 | 79.4 | yes | | | | | |
| 1A4a; Gaseous Fuels | CO2 | normal | 5.0 | 5.0 | 5.0 | no | normal | 0.4 | 0.4 | 0.4 | no | | | | | |
| 1A4a; Gaseous Fuels | CH4 | normal | 5.0 | 5.0 | 5.0 | no | normal | 29.6 | 29.6 | 29.6 | yes | | | | | |
| 1A4a; Gaseous Fuels | N2O | normal | 5.0 | 5.0 | 5.0 | no | normal | 79.8 | 79.8 | 79.8 | yes | | | | | |
| 1A4a; Liquid Fuels | CO2 | normal | 0.7 | 0.7 | 0.7 | no | normal | 0.1 | 0.1 | 0.1 | yes | | | | | |
| 1A4a; Liquid Fuels | CH4 | normal | 0.7 | 0.7 | 0.7 | no | normal | 30.0 | 30.0 | 30.0 | yes | | | | | |
| 1A4a; Liquid Fuels | N2O | normal | 0.7 | 0.7 | 0.7 | no | normal | 80.0 | 80.0 | 80.0 | yes | | | | | |
| 1A4b; Biomass | CH4 | normal | 10.0 | 10.0 | 10.0 | no | normal | 28.3 | 28.3 | 28.3 | yes | | | | | |
| 1A4b; Biomass | N2O | normal | 10.0 | 10.0 | 10.0 | no | normal | 79.4 | 79.4 | 79.4 | yes | | | | | |
| 1A4b; Gaseous Fuels | CO2 | normal | 5.0 | 5.0 | 5.0 | no | normal | 0.4 | 0.4 | 0.4 | no | | | | | |
| 1A4b; Gaseous Fuels | CH4 | normal | 5.0 | 5.0 | 5.0 | no | normal | 29.6 | 29.6 | 29.6 | yes | | | | | |
| 1A4b; Gaseous Fuels | N2O | normal | 5.0 | 5.0 | 5.0 | no | normal | 79.8 | 79.8 | 79.8 | yes | | | | | |
| 1A4b; Liquid Fuels | CO2 | normal | 0.7 | 0.7 | 0.7 | no | normal | 0.1 | 0.1 | 0.1 | yes | | | | | |
| 1A4b; Liquid Fuels | CH4 | normal | 0.7 | 0.7 | 0.7 | no | normal | 30.0 | 30.0 | 30.0 | yes | | | | | |
| 1A4b; Liquid Fuels | N2O | normal | 0.7 | 0.7 | 0.7 | no | normal | 80.0 | 80.0 | 80.0 | yes | | | | | |
| 1A4b; Solid Fuels | CO2 | normal | 5.0 | 5.0 | 5.0 | no | normal | 5.1 | 5.1 | 5.1 | yes | | | | | |
| 1A4b; Solid Fuels | CH4 | normal | 5.0 | 5.0 | 5.0 | no | normal | 29.6 | 29.6 | 29.6 | yes | | | | | |
| 1A4b; Solid Fuels | N2O | normal | 5.0 | 5.0 | 5.0 | no | normal | 79.8 | 79.8 | 79.8 | yes | | | | | |
| 1A4c; Biomass | CH4 | normal | 10.0 | 10.0 | 10.0 | no | normal | 28.3 | 28.3 | 28.3 | yes | | | | | |
| 1A4c; Biomass | N2O | normal | 10.0 | 10.0 | 10.0 | no | normal | 79.4 | 79.4 | 79.4 | yes | | | | | |
| 1A4c; Gaseous Fuels | CO2 | normal | 5.0 | 5.0 | 5.0 | no | normal | 0.4 | 0.4 | 0.4 | no | | | | | |
| 1A4c; Gaseous Fuels | CH4 | normal | 5.0 | 5.0 | 5.0 | no | normal | 29.6 | 29.6 | 29.6 | yes | | | | | |
| 1A4c; Gaseous Fuels | N2O | normal | 5.0 | 5.0 | 5.0 | no | normal | 79.8 | 79.8 | 79.8 | yes | | | | | |
| 1A4c; Liquid Fuels | CO2 | normal | 0.7 | 0.7 | 0.7 | no | normal | 0.1 | 0.1 | 0.1 | yes | | | | | |
| 1A4c; Liquid Fuels | CH4 | normal | 0.7 | 0.7 | 0.7 | no | normal | 30.0 | 30.0 | 30.0 | yes | | | | | |
| 1A4c; Liquid Fuels | N2O | normal | 0.7 | 0.7 | 0.7 | no | normal | 80.0 | 80.0 | 80.0 | yes | | | | | |
| 1A5; Biomass | CH4 | normal | 10.0 | 10.0 | 10.0 | no | normal | 59.2 | 59.2 | 59.2 | yes | | | | | |
| 1A5; Biomass | N2O | normal | 10.0 | 10.0 | 10.0 | no | gamma | 149.7 | 90.0 | 190.9 | yes | | | | | |
| 1A5; Liquid Fuels | CO2 | normal | 0.7 | 0.7 | 0.7 | no | normal | 0.1 | 0.1 | 0.1 | no | | | | | |
| 1A5; Liquid Fuels | CH4 | normal | 0.7 | 0.7 | 0.7 | no | normal | 30.0 | 30.0 | 30.0 | yes | | | | | |
| 1A5; Liquid Fuels | N2O | normal | 0.7 | 0.7 | 0.7 | no | gamma | 150.0 | 90.0 | 191.4 | yes | | | | | |
| 1B; CH4 (indirect) | CO2 | | | | | | | | | | | normal | 27.4 | 27.4 | 27.4 | no |
| 1B; NMVOC (indirect) | CO2 | | | | | | | | | | | normal | 22.4 | 22.4 | 22.4 | no |
| 1B2; All Fuels | CO2 | normal | 5.0 | 5.0 | 5.0 | no | normal | 5.1 | 5.1 | 5.1 | yes | | | | | |
| 1B2; All Fuels | CH4 | normal | 5.0 | 5.0 | 5.0 | no | normal | 29.6 | 29.6 | 29.6 | yes | | | | | |
| 1B2; All Fuels | N2O | normal | 5.0 | 5.0 | 5.0 | no | normal | 79.8 | 79.8 | 79.8 | yes | | | | | |
| 2A; CO (indirect) | CO2 | | | | | | | | | | | normal | 200.0 | 200.0 | 200.0 | no |
| 2A; NMVOC (indirect) | CO2 | | | | | | | | | | | normal | 200.0 | 200.0 | 200.0 | no |
| 2A1 | CO2 | normal | 2.0 | 2.0 | 2.0 | no | normal | 4.0 | 4.0 | 4.0 | yes | | | | | |
| 2A2 | CO2 | normal | 2.0 | 2.0 | 2.0 | no | normal | 2.0 | 2.0 | 2.0 | no | | | | | |
| 2A3 | CO2 | normal | 2.0 | 2.0 | 2.0 | no | normal | 3.0 | 3.0 | 3.0 | no | | | | | |
| 2A4 | CO2 | normal | 2.0 | 2.0 | 2.0 | no | normal | 2.0 | 2.0 | 2.0 | no | | | | | |
| 2B; CH4 (indirect) | CO2 | | | | | | | | | | | normal | 20.1 | 20.1 | 20.1 | no |
| 2B; CO (indirect) | CO2 | | | | | | | | | | | normal | 50.0 | 50.0 | 50.0 | no |
| 2B; NMVOC (indirect) | CO2 | | | | | | | | | | | normal | 40.0 | 40.0 | 40.0 | no |
| 2B2 | N2O | normal | 2.0 | 0.0 | 0.0 | no | normal | 7.2 | 0.0 | 0.0 | no | | | | | |
| 2B5 | CO2 | normal | 2.0 | 2.0 | 2.0 | no | normal | 10.0 | 10.0 | 10.0 | yes | | | | | |
| 2B5 | CH4 | normal | 2.0 | 2.0 | 2.0 | no | normal | 20.0 | 20.0 | 20.0 | yes | | | | | |
| 2B8 | CO2 | normal | 2.0 | 2.0 | 2.0 | no | normal | 10.0 | 10.0 | 10.0 | no | | | | | |
| 2B10 | CO2 | normal | 2.0 | 2.0 | 2.0 | no | normal | 60.0 | 60.0 | 60.0 | yes | | | | | |
| 2B10 | CH4 | normal | 0.0 | 0.0 | 0.0 | no | normal | 0.0 | 0.0 | 0.0 | no | | | | | |
| 2B10 | N2O | normal | 2.0 | 2.0 | 2.0 | no | normal | 60.0 | 60.0 | 60.0 | no | | | | | |
| 2C; CO (indirect) | CO2 | | | | | | | | | | | normal | 40.0 | 40.0 | 40.0 | no |
| 2C; NMVOC (indirect) | CO2 | | | | | | | | | | | normal | 100.0 | 100.0 | 100.0 | no |
| 2C1 | CO2 | normal | 2.0 | 2.0 | 2.0 | no | normal | 5.0 | 5.0 | 5.0 | no | | | | | |
| 2C3 | CO2 | normal | 5.0 | 0.0 | 0.0 | no | normal | 20.0 | 0.0 | 0.0 | yes | | | | | |
| 2C3 | PFC | | | | | | | | | | | normal | 9.0 | 0.0 | 0.0 | no |
| 2C4 | SF6 | | | | | | | | | | | normal | 0.0 | 0.0 | 0.0 | no |
| 2C7 | CO2 | normal | 2.0 | 2.0 | 2.0 | no | normal | 20.0 | 20.0 | 20.0 | yes | | | | | |
| 2D | CO2 | normal | 10.0 | 10.0 | 10.0 | no | normal | 10.0 | 10.0 | 10.0 | yes | | | | | |
| 2D; CO (indirect) | CO2 | | | | | | | | | | | normal | 200.0 | 200.0 | 200.0 | no |
| 2D; NMVOC (indirect) | CO2 | | | | | | | | | | | normal | 200.0 | 200.0 | 200.0 | no |
| 2E1 | HFC | | | | | | | | | | | gamma | 44.4 | 38.6 | 47.9 | no |
| 2E1 | PFC | | | | | | | | | | | gamma | 69.4 | 56.0 | 78.6 | no |
| 2E1 | SF6 | | | | | | | | | | | gamma | 65.1 | 53.3 | 73.2 | no |
| 2E3 | NF3 | | | | | | | | | | | gamma | 109.7 | 77.0 | 132.7 | no |
| 2E5 | PFC | | | | | | | | | | | gamma | 53.6 | 45.4 | 58.9 | no |
| 2F1 | HFC | | | | | | | | | | | gamma | 18.3 | 17.1 | 18.7 | no |
| 2F1 | PFC | | | | | | | | | | | gamma | 77.8 | 61.1 | 89.4 | no |
| 2F2 | HFC | | | | | | | | | | | gamma | 107.9 | 76.3 | 130.1 | no |
| 2F4 | HFC | | | | | | | | | | | normal | 41.4 | 41.4 | 41.4 | no |
| 2F5 | HFC | | | | | | | | | | | normal | 52.6 | 52.6 | 52.6 | no |
| 2G | CO2 | normal | 10.0 | 10.0 | 10.0 | no | normal | 10.0 | 10.0 | 10.0 | yes | | | | | |
| 2G | N2O | normal | 1.0 | 1.0 | 1.0 | no | normal | 80.0 | 80.0 | 80.0 | yes | | | | | |
| 2G | HFC | | | | | | | | | | | normal | 7.9 | 7.9 | 7.9 | no |
| 2G | PFC | | | | | | | | | | | gamma | 11.8 | 11.2 | 11.9 | no |
| 2G | SF6 | | | | | | | | | | | gamma | 44.7 | 38.9 | 48.4 | yes |
| 2G; CO (indirect) | CO2 | | | | | | | | | | | normal | 201.6 | 201.6 | 201.6 | no |
| 2G; NMVOC (indirect) | CO2 | | | | | | | | | | | normal | 149.8 | 149.8 | 149.8 | no |
| 2H | CO2 | normal | 3.0 | 3.0 | 3.0 | no | normal | 7.1 | 7.1 | 7.1 | yes | | | | | |
| 2H; CO (indirect) | CO2 | | | | | | | | | | | normal | 200.2 | 200.2 | 200.2 | no |
| 2H; NMVOC (indirect) | CO2 | | | | | | | | | | | normal | 100.5 | 100.5 | 100.5 | no |

Table A – 2 (continued)

| A | B | E | | | | | F | | | | | G | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code | Gas | Activity data uncertainty year 2020 | | | | | Emission factor uncertainty year 2020 | | | | | Emission uncertainty year 2020 | | | | |
| | | Distribu-tion type | 2*std. dev. % | (-)% | (+)% | Corr. | Distribu-tion type | 2*std. dev. % | (-)% | (+)% | Corr. | Distribu-tion type | 2*std. dev. % | (-)% | (+)% | Corr. |
| 3A | CH4 | normal | 6.5 | 6.5 | 6.5 | no | gamma | 18.9 | 17.7 | 19.4 | no | | | | | |
| 3B1-4 | CH4 | normal | 6.5 | 6.5 | 6.5 | no | normal | 53.9 | 53.9 | 53.9 | no | | | | | |
| 3B1-4 | N2O | normal | 22.8 | 22.8 | 22.8 | no | gamma | 63.5 | 52.2 | 71.2 | no | | | | | |
| 3B5 | N2O | gamma | 50.1 | 42.9 | 54.7 | no | gamma | 281.5 | 99.9 | 400.2 | yes | | | | | |
| 3Da | N2O | gamma | 17.5 | 16.4 | 17.9 | no | gamma | 126.2 | 83.3 | 156.2 | no | | | | | |
| 3Db | N2O | gamma | 32.1 | 29.0 | 33.8 | no | gamma | 208.0 | 98.0 | 281.6 | no | | | | | |
| 3G | CO2 | normal | 40.0 | 40.0 | 40.0 | no | normal | 5.0 | 5.0 | 5.0 | yes | | | | | |
| 3H | CO2 | normal | 5.0 | 5.0 | 5.0 | no | normal | 5.0 | 5.0 | 5.0 | yes | | | | | |
| 4A1 | CO2 | normal | 1.1 | 1.1 | 1.1 | yes | normal | 46.7 | 46.7 | 46.7 | yes | | | | | |
| 4A2 | CO2 | normal | 1.5 | 1.5 | 1.5 | yes | normal | 46.7 | 46.7 | 46.7 | yes | | | | | |
| 4B1 | CO2 | normal | 4.9 | 4.9 | 4.9 | yes | normal | 5'615.2 | 5'615.2 | 5'615.2 | no | | | | | |
| 4B2 | CO2 | normal | 5.1 | 5.1 | 5.1 | yes | normal | 148.9 | 148.9 | 148.9 | no | | | | | |
| 4C1 | CO2 | normal | 5.2 | 5.2 | 5.2 | yes | normal | 292.7 | 292.7 | 292.7 | no | | | | | |
| 4C2 | CO2 | normal | 5.3 | 5.3 | 5.3 | yes | normal | 43.1 | 43.1 | 43.1 | no | | | | | |
| 4D1 | CO2 | normal | 90.8 | 90.8 | 90.8 | yes | normal | 72.2 | 72.2 | 72.2 | yes | | | | | |
| 4D2 | CO2 | normal | 3.8 | 3.8 | 3.8 | yes | normal | 20.4 | 20.4 | 20.4 | no | | | | | |
| 4E1 | CO2 | normal | 4.4 | 4.4 | 4.4 | yes | normal | 50.0 | 50.0 | 50.0 | yes | | | | | |
| 4E2 | CO2 | normal | 4.6 | 4.6 | 4.6 | yes | normal | 50.0 | 50.0 | 50.0 | yes | | | | | |
| 4F2 | CO2 | normal | 3.2 | 3.2 | 3.2 | yes | normal | 50.0 | 50.0 | 50.0 | yes | | | | | |
| 4G | CO2 | normal | 11.2 | 11.2 | 11.2 | yes | normal | 54.8 | 54.8 | 54.8 | yes | | | | | |
| 4II | CH4 | normal | 10.0 | 10.0 | 10.0 | yes | normal | 70.0 | 70.0 | 70.0 | yes | | | | | |
| 4II | N2O | normal | 48.9 | 48.9 | 48.9 | yes | normal | 66.9 | 66.9 | 66.9 | yes | | | | | |
| 4III | N2O | normal | 83.5 | 83.5 | 83.5 | yes | gamma | 156.2 | 91.4 | 200.8 | yes | | | | | |
| 4IV | N2O | normal | 85.8 | 85.8 | 85.8 | yes | gamma | 177.6 | 95.1 | 233.7 | yes | | | | | |
| 4V | CH4 | normal | 30.0 | 30.0 | 30.0 | yes | normal | 70.0 | 70.0 | 70.0 | yes | | | | | |
| 4V | N2O | normal | 30.0 | 30.0 | 30.0 | yes | normal | 70.0 | 70.0 | 70.0 | yes | | | | | |
| 5A | CO2 | | | | | | | | | | | normal | 10.0 | 0.0 | 0.0 | yes |
| 5A | CH4 | | | | | | | | | | | normal | 30.0 | 30.0 | 30.0 | yes |
| 5B | CH4 | normal | 30.0 | 30.0 | 30.0 | no | normal | 30.0 | 30.0 | 30.0 | yes | | | | | |
| 5B | N2O | normal | 30.0 | 30.0 | 30.0 | no | normal | 30.0 | 30.0 | 30.0 | yes | | | | | |
| 5C | CO2 | normal | 30.0 | 30.0 | 30.0 | no | normal | 26.5 | 26.5 | 26.5 | yes | | | | | |
| 5C | CH4 | normal | 50.0 | 50.0 | 50.0 | no | normal | 33.2 | 33.2 | 33.2 | yes | | | | | |
| 5C | N2O | normal | 30.0 | 30.0 | 30.0 | no | gamma | 147.0 | 89.3 | 186.9 | yes | | | | | |
| 5C; CH4 (indirect) | CO2 | | | | | | | | | | | normal | 60.5 | 60.5 | 60.5 | no |
| 5C; CO (indirect) | CO2 | | | | | | | | | | | normal | 71.1 | 71.1 | 71.1 | no |
| 5C; NMVOC (indirect) | CO2 | | | | | | | | | | | normal | 71.1 | 71.1 | 71.1 | no |
| 5D | CH4 | normal | 36.0 | 36.0 | 36.0 | no | normal | 32.0 | 32.0 | 32.0 | yes | | | | | |
| 5D | N2O | normal | 32.0 | 32.0 | 32.0 | no | gamma | 150.0 | 90.0 | 191.4 | yes | | | | | |
| 5E; CO (indirect) | CO2 | normal | 10.0 | 10.0 | 10.0 | no | normal | 20.0 | 20.0 | 20.0 | yes | | | | | |
| 5E; NMVOC (indirect) | CO2 | normal | 10.0 | 10.0 | 10.0 | no | normal | 20.0 | 20.0 | 20.0 | yes | | | | | |
| 6 | CO2 | | | | | | | | | | | normal | 40.0 | 40.0 | 40.0 | yes |
| 6 | CH4 | | | | | | | | | | | normal | 60.0 | 60.0 | 60.0 | yes |
| 6 | N2O | | | | | | | | | | | normal | 150.0 | 150.0 | 150.0 | yes |
| 6A; CH4 (indirect) | CO2 | | | | | | | | | | | normal | 72.8 | 72.8 | 72.8 | no |
| 6A; CO (indirect) | CO2 | | | | | | | | | | | normal | 90.5 | 90.5 | 90.5 | no |
| 6A; NMVOC (indirect) | CO2 | | | | | | | | | | | normal | 89.0 | 89.0 | 89.0 | no |

## A2.2 Detailed results of approach 1 uncertainty analysis

Table A – 3 Uncertainty analysis of greenhouse gas emissions and removals, approach 1, for 2020 and for the trend 1990–2020, including LULUCF categories and indirect $CO_2$ emissions. The uncertainties are given considering a 95% confidence interval (from 2.5% to 97.5%), and expressed as the distance from edge to mean, in percentage of the mean. AD: activity data; EF: emission factor; EM: emission. d.EM stands for direct emission and indicates that input uncertainties are given for the emission but neither for activity data nor for emission factor. Columns A to M are labelled according to Table 3-2 in the IPCC guidelines, vol.1, chp. 3 (IPCC, 2006).

| A | B | C | D | G | | H | | I | J | K | | L | | M | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code | Gas | Emissions 1990 | Emissions 2020 | Emission combined uncertainty 2020 | | Category contribution to inventory variance 2020 | | Sensitivity if corr. (type A) | Sensitivity if not corr. (type B) | Contribution to inventory trend uncertainty from AD | | Contribution to inventory trend uncertainty from EF | | Contribution to inventory trend uncertainty from EM | |
| | | | | (-)% | (+)% | (-)% | (+)% | | | (-)% | (+)% | (-)% | (+)% | (-)% | (+)% |
| 1A1; Biomass | CH4 | 0.40 | 0.14 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A1; Biomass | N2O | 22.58 | 13.64 | 80 | 80 | 0.001 | 0.001 | 0.000 | 0.000 | 0.004 | 0.004 | 0.007 | 0.007 | 0.000 | 0.000 |
| 1A1; Gaseous Fuels | CO2 | 243.40 | 499.46 | 5 | 5 | 0.004 | 0.004 | 0.006 | 0.010 | 0.068 | 0.068 | 0.005 | 0.005 | 0.005 | 0.005 |
| 1A1; Gaseous Fuels | CH4 | 0.11 | 0.22 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A1; Gaseous Fuels | N2O | 0.13 | 0.26 | 80 | 80 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A1; Liquid Fuels | CO2 | 685.81 | 273.32 | 1 | 1 | 0.000 | 0.000 | 0.005 | 0.005 | 0.005 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A1; Liquid Fuels | CH4 | 0.52 | 0.14 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A1; Liquid Fuels | N2O | 1.11 | 0.20 | 80 | 80 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 |
| 1A1; Other Fuels | CO2 | 1'491.55 | 2'479.59 | 18 | 18 | 1.098 | 1.098 | 0.025 | 0.048 | 0.338 | 0.338 | 0.417 | 0.417 | 0.288 | 0.288 |
| 1A1; Other Fuels | N2O | 24.33 | 8.75 | 80 | 80 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.019 | 0.019 | 0.000 | 0.000 |
| 1A1; Solid Fuels | CO2 | 49.13 | 0.00 | 0 | 0 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A1; Solid Fuels | CH4 | 0.13 | 0.00 | 0 | 0 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A1; Solid Fuels | N2O | 0.24 | 0.00 | 0 | 0 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A2; Biomass | CH4 | 3.59 | 2.05 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A2; Biomass | N2O | 5.20 | 15.88 | 80 | 80 | 0.001 | 0.001 | 0.000 | 0.000 | 0.004 | 0.004 | 0.018 | 0.018 | 0.000 | 0.000 |
| 1A2; Gaseous Fuels | CO2 | 1'091.14 | 2'140.66 | 5 | 5 | 0.066 | 0.066 | 0.024 | 0.041 | 0.291 | 0.291 | 0.023 | 0.023 | 0.085 | 0.085 |
| 1A2; Gaseous Fuels | CH4 | 0.48 | 0.95 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A2; Gaseous Fuels | N2O | 0.58 | 1.14 | 80 | 80 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 |
| 1A2; Liquid Fuels | CO2 | 3'974.32 | 1'535.07 | 1 | 1 | 0.001 | 0.001 | 0.032 | 0.030 | 0.029 | 0.029 | 0.003 | 0.003 | 0.001 | 0.001 |
| 1A2; Liquid Fuels | CH4 | 4.59 | 0.99 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.002 | 0.000 | 0.000 |
| 1A2; Liquid Fuels | N2O | 13.35 | 10.15 | 80 | 80 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 |
| 1A2; Other Fuels | CO2 | 192.36 | 443.68 | 10 | 10 | 0.012 | 0.012 | 0.006 | 0.009 | 0.060 | 0.060 | 0.051 | 0.051 | 0.006 | 0.006 |
| 1A2; Other Fuels | CH4 | 0.77 | 0.61 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A2; Other Fuels | N2O | 2.32 | 7.13 | 80 | 80 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.016 | 0.016 | 0.000 | 0.000 |
| 1A2; Solid Fuels | CO2 | 1'274.70 | 338.55 | 7 | 7 | 0.003 | 0.003 | 0.013 | 0.007 | 0.046 | 0.046 | 0.067 | 0.067 | 0.007 | 0.007 |
| 1A2; Solid Fuels | CH4 | 0.31 | 0.19 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A2; Solid Fuels | N2O | 6.14 | 1.59 | 80 | 80 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.005 | 0.005 | 0.000 | 0.000 |
| 1A3a; Kerosene | CO2 | 252.55 | 78.64 | 1 | 1 | 0.000 | 0.000 | 0.002 | 0.002 | 0.002 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3a; Kerosene | CH4 | 0.17 | 0.08 | 60 | 60 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3a; Kerosene | N2O | 2.06 | 0.64 | 90 | 191 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.002 | 0.000 | 0.000 |
| 1A3b; Biomass | CH4 | 0.00 | 0.57 | 60 | 60 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 |
| 1A3b; Biomass | N2O | 0.00 | 6.82 | 91 | 191 | 0.000 | 0.001 | 0.000 | 0.000 | 0.002 | 0.002 | 0.012 | 0.012 | 0.000 | 0.000 |
| 1A3b; Diesel oil | CO2 | 2'631.94 | 6'946.36 | 1 | 1 | 0.022 | 0.022 | 0.093 | 0.134 | 0.167 | 0.167 | 0.013 | 0.013 | 0.028 | 0.028 |
| 1A3b; Diesel oil | CH4 | 2.26 | 5.53 | 20 | 20 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 |
| 1A3b; Diesel oil | N2O | 6.15 | 95.44 | 22 | 22 | 0.003 | 0.003 | 0.002 | 0.002 | 0.002 | 0.002 | 0.038 | 0.038 | 0.001 | 0.001 |
| 1A3b; Gaseous Fuels | CO2 | 0.00 | 29.22 | 5 | 5 | 0.000 | 0.000 | 0.001 | 0.001 | 0.004 | 0.004 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3b; Gaseous Fuels | CH4 | 0.00 | 0.17 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3b; Gaseous Fuels | N2O | 0.00 | 0.66 | 80 | 80 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 |
| 1A3b; Gasoline | CO2 | 11'342.40 | 6'210.88 | 1 | 1 | 0.011 | 0.011 | 0.056 | 0.120 | 0.116 | 0.116 | 0.022 | 0.022 | 0.014 | 0.014 |
| 1A3b; Gasoline | CH4 | 115.09 | 12.24 | 37 | 37 | 0.000 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.057 | 0.057 | 0.003 | 0.003 |
| 1A3b; Gasoline | N2O | 159.33 | 17.64 | 50 | 50 | 0.000 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.106 | 0.106 | 0.011 | 0.011 |
| 1A3b; Liquefied Petroleum Gas | CO2 | 0.00 | 1.30 | 10 | 10 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3b; Liquefied Petroleum Gas | CH4 | 0.00 | 0.00 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3b; Liquefied Petroleum Gas | N2O | 0.00 | 0.01 | 80 | 80 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3c; Biomass | CH4 | 0.00 | 0.00 | 60 | 60 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3c; Biomass | N2O | 0.00 | 0.01 | 91 | 191 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3c; Liquid Fuels | CO2 | 28.69 | 27.97 | 1 | 1 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3c; Liquid Fuels | CH4 | 0.03 | 0.01 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3c; Liquid Fuels | N2O | 0.43 | 0.41 | 80 | 80 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3d; Biomass | CH4 | 0.00 | 0.01 | 60 | 60 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3d; Biomass | N2O | 0.00 | 0.03 | 91 | 191 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3d; Liquid Fuels | CO2 | 114.27 | 110.54 | 1 | 1 | 0.000 | 0.000 | 0.000 | 0.002 | 0.002 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3d; Liquid Fuels | CH4 | 1.68 | 0.31 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 |
| 1A3d; Liquid Fuels | N2O | 1.16 | 1.19 | 90 | 191 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3e; Gaseous Fuels | CO2 | 31.42 | 30.35 | 5 | 5 | 0.000 | 0.000 | 0.000 | 0.001 | 0.004 | 0.004 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3e; Gaseous Fuels | CH4 | 0.07 | 0.03 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3e; Gaseous Fuels | N2O | 0.02 | 0.02 | 80 | 80 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

## Table A – 3 (continued)

| A | B | C | D | G | | H | | I | J | K | | L | | M | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code | Gas | Emissions 1990 | Emissions 2020 | Emission combined uncertainty 2020 | | Category contribution to inventory variance 2020 | | Sensitivi-ty if corr. (type A) | Sensitivi-ty if not corr. (type B) | Contribution to inventory trend uncertainty from AD | | Contribution to inventory trend uncertainty from EF | | Contribution to inventory trend uncertainty from EM | |
| | | | | (-)% | (+)% | (-)% | (+)% | | | (-)% | (+)% | (-)% | (+)% | (-)% | (+)% |
| 1A4a; Biomass | CH4 | 7.01 | 4.00 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.001 | 0.001 | 0.000 | 0.000 |
| 1A4a; Biomass | N2O | 3.50 | 11.86 | 80 | 80 | 0.001 | 0.001 | 0.000 | 0.000 | 0.003 | 0.003 | 0.014 | 0.014 | 0.000 | 0.000 |
| 1A4a; Gaseous Fuels | CO2 | 920.00 | 1'182.55 | 5 | 5 | 0.020 | 0.020 | 0.009 | 0.023 | 0.161 | 0.161 | 0.013 | 0.013 | 0.026 | 0.026 |
| 1A4a; Gaseous Fuels | CH4 | 0.68 | 1.20 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A4a; Gaseous Fuels | N2O | 0.49 | 0.63 | 80 | 80 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A4a; Liquid Fuels | CO2 | 3'918.47 | 2'051.94 | 1 | 1 | 0.001 | 0.001 | 0.021 | 0.040 | 0.038 | 0.038 | 0.002 | 0.002 | 0.001 | 0.001 |
| 1A4a; Liquid Fuels | CH4 | 15.17 | 7.39 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.003 | 0.003 | 0.000 | 0.000 |
| 1A4a; Liquid Fuels | N2O | 9.51 | 5.02 | 80 | 80 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.004 | 0.004 | 0.000 | 0.000 |
| 1A4b; Biomass | CH4 | 80.94 | 19.96 | 30 | 30 | 0.000 | 0.000 | 0.001 | 0.000 | 0.005 | 0.005 | 0.025 | 0.025 | 0.001 | 0.001 |
| 1A4b; Biomass | N2O | 25.86 | 20.70 | 80 | 80 | 0.002 | 0.002 | 0.000 | 0.000 | 0.006 | 0.006 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A4b; Gaseous Fuels | CO2 | 1'450.97 | 2'652.34 | 5 | 5 | 0.102 | 0.102 | 0.029 | 0.051 | 0.361 | 0.361 | 0.028 | 0.028 | 0.131 | 0.131 |
| 1A4b; Gaseous Fuels | CH4 | 0.70 | 1.38 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A4b; Gaseous Fuels | N2O | 0.77 | 1.41 | 80 | 80 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 |
| 1A4b; Liquid Fuels | CO2 | 10'099.07 | 4'387.08 | 1 | 1 | 0.005 | 0.005 | 0.072 | 0.084 | 0.082 | 0.082 | 0.006 | 0.006 | 0.007 | 0.007 |
| 1A4b; Liquid Fuels | CH4 | 34.83 | 15.00 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.007 | 0.007 | 0.000 | 0.000 |
| 1A4b; Liquid Fuels | N2O | 24.53 | 10.68 | 80 | 80 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.014 | 0.014 | 0.000 | 0.000 |
| 1A4b; Solid Fuels | CO2 | 58.40 | 9.27 | 7 | 7 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 | 0.001 | 0.004 | 0.004 | 0.000 | 0.000 |
| 1A4b; Solid Fuels | CH4 | 4.73 | 0.75 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.002 | 0.000 | 0.000 |
| 1A4b; Solid Fuels | N2O | 0.28 | 0.04 | 80 | 80 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A4c; Biomass | CH4 | 1.03 | 1.21 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A4c; Biomass | N2O | 0.51 | 1.39 | 80 | 80 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 |
| 1A4c; Gaseous Fuels | CO2 | 70.06 | 122.77 | 5 | 5 | 0.000 | 0.000 | 0.001 | 0.002 | 0.017 | 0.017 | 0.001 | 0.001 | 0.000 | 0.000 |
| 1A4c; Gaseous Fuels | CH4 | 0.03 | 0.05 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A4c; Gaseous Fuels | N2O | 0.04 | 0.07 | 80 | 80 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A4c; Liquid Fuels | CO2 | 742.30 | 454.04 | 1 | 1 | 0.000 | 0.000 | 0.003 | 0.009 | 0.008 | 0.008 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A4c; Liquid Fuels | CH4 | 6.72 | 1.16 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.002 | 0.000 | 0.000 |
| 1A4c; Liquid Fuels | N2O | 4.82 | 4.56 | 80 | 80 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 |
| 1A5; Biomass | CH4 | 0.00 | 0.00 | 60 | 60 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A5; Biomass | N2O | 0.00 | 0.01 | 91 | 191 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A5; Liquid Fuels | CO2 | 217.65 | 118.39 | 1 | 1 | 0.000 | 0.000 | 0.001 | 0.002 | 0.002 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A5; Liquid Fuels | CH4 | 0.12 | 0.04 | 30 | 30 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A5; Liquid Fuels | N2O | 1.84 | 1.04 | 90 | 191 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 |
| 1B; CH4 (indirect) | CO2 | 36.90 | 20.40 | 27 | 27 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 1B; NMVOC (indirect) | CO2 | 37.55 | 3.70 | 22 | 22 | 0.000 | 0.000 | 0.001 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 1B2; All Fuels | CO2 | 26.34 | 26.40 | 7 | 7 | 0.000 | 0.000 | 0.000 | 0.001 | 0.004 | 0.004 | 0.001 | 0.001 | 0.000 | 0.000 |
| 1B2; All Fuels | CH4 | 335.78 | 185.45 | 30 | 30 | 0.018 | 0.018 | 0.002 | 0.004 | 0.025 | 0.025 | 0.048 | 0.048 | 0.003 | 0.003 |
| 1B2; All Fuels | N2O | 0.03 | 0.00 | 80 | 80 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2A; CO (indirect) | CO2 | 0.04 | 0.02 | 200 | 200 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2A; NMVOC (indirect) | CO2 | 0.10 | 0.06 | 200 | 200 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2A1 | CO2 | 2'580.79 | 1'679.25 | 4 | 4 | 0.032 | 0.032 | 0.008 | 0.032 | 0.091 | 0.091 | 0.030 | 0.030 | 0.009 | 0.009 |
| 2A2 | CO2 | 53.35 | 47.91 | 3 | 3 | 0.000 | 0.000 | 0.000 | 0.001 | 0.003 | 0.003 | 0.003 | 0.003 | 0.000 | 0.000 |
| 2A3 | CO2 | 15.25 | 6.66 | 4 | 4 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 |
| 2A4 | CO2 | 160.16 | 64.63 | 3 | 3 | 0.000 | 0.000 | 0.001 | 0.001 | 0.004 | 0.004 | 0.004 | 0.004 | 0.000 | 0.000 |
| 2B; CH4 (indirect) | CO2 | 0.39 | 0.71 | 20 | 20 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2B; CO (indirect) | CO2 | 6.33 | 10.50 | 50 | 50 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2B; NMVOC (indirect) | CO2 | 1.29 | 0.01 | 40 | 40 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2B2 | N2O | 65.49 | 0.00 | 0 | 0 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2B5 | CO2 | 15.36 | 18.22 | 10 | 10 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.001 | 0.001 | 0.000 | 0.000 |
| 2B5 | CH4 | 3.47 | 6.44 | 20 | 20 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 |
| 2B8 | CO2 | 94.08 | 98.33 | 10 | 10 | 0.001 | 0.001 | 0.000 | 0.002 | 0.005 | 0.005 | 0.027 | 0.027 | 0.001 | 0.001 |
| 2B10 | CO2 | 17.34 | 17.60 | 60 | 60 | 0.001 | 0.001 | 0.000 | 0.000 | 0.001 | 0.001 | 0.004 | 0.004 | 0.000 | 0.000 |
| 2B10 | CH4 | 0.09 | 0.00 | 0 | 0 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2B10 | N2O | 432.38 | 573.92 | 60 | 60 | 0.682 | 0.682 | 0.004 | 0.011 | 0.031 | 0.031 | 0.938 | 0.938 | 0.880 | 0.880 |
| 2C; CO (indirect) | CO2 | 1.10 | 0.14 | 40 | 40 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2C; NMVOC (indirect) | CO2 | 2.25 | 0.27 | 100 | 100 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2C1 | CO2 | 11.91 | 9.73 | 5 | 5 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.001 | 0.001 | 0.000 | 0.000 |
| 2C3 | CO2 | 139.26 | 0.00 | 0 | 0 | 0.000 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2C3 | PFC | 116.46 | 0.00 | 0 | 0 | 0.000 | 0.000 | 0.002 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2C4 | SF6 | 0.00 | 0.00 | 0 | 0 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2C7 | CO2 | 0.00 | 1.47 | 20 | 20 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 |
| 2D | CO2 | 58.21 | 50.47 | 14 | 14 | 0.000 | 0.000 | 0.000 | 0.001 | 0.014 | 0.014 | 0.001 | 0.001 | 0.000 | 0.000 |
| 2D; CO (indirect) | CO2 | 0.00 | 0.00 | 200 | 200 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2D; NMVOC (indirect) | CO2 | 192.80 | 34.41 | 200 | 200 | 0.027 | 0.027 | 0.002 | 0.001 | d.EM | d.EM | d.EM | d.EM | 0.035 | 0.035 |
| 2E1 | HFC | 0.00 | 0.90 | 39 | 48 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2E1 | PFC | 0.00 | 12.86 | 56 | 79 | 0.000 | 0.001 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.001 |
| 2E1 | SF6 | 0.00 | 10.31 | 53 | 73 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2E3 | NF3 | 0.00 | 0.41 | 77 | 133 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2E5 | PFC | 0.00 | 0.07 | 45 | 59 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2F1 | HFC | 0.02 | 1'346.12 | 17 | 19 | 0.306 | 0.365 | 0.026 | 0.026 | d.EM | d.EM | d.EM | d.EM | 0.394 | 0.471 |
| 2F1 | PFC | 0.05 | 1.19 | 61 | 89 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2F2 | HFC | 0.00 | 25.75 | 76 | 130 | 0.002 | 0.006 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.003 | 0.008 |
| 2F4 | HFC | 0.00 | 6.41 | 41 | 41 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2F5 | HFC | 0.00 | 0.16 | 53 | 53 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |

Table A – 3 (continued)

| A | B | C | D | G | | H | | I | J | K | | L | | M | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code | Gas | Emissions 1990 | Emissions 2020 | Emission combined uncertainty 2020 | | Category contribution to inventory variance 2020 | | Sensitivi-ty if corr. (type A) | Sensitivi-ty if not corr. (type B) | Contribution to inventory trend uncertainty from AD | | Contribution to inventory trend uncertainty from EF | | Contribution to inventory trend uncertainty from EM | |
| | | | | (-)% | (+)% | (-)% | (+)% | | | (-)% | (+)% | (-)% | (+)% | (-)% | (+)% |
| 2G | CO2 | 6.07 | 31.76 | 14 | 14 | 0.000 | 0.000 | 0.001 | 0.001 | 0.009 | 0.009 | 0.005 | 0.005 | 0.000 | 0.000 |
| 2G | N2O | 104.01 | 31.32 | 80 | 80 | 0.004 | 0.004 | 0.001 | 0.001 | 0.001 | 0.001 | 0.080 | 0.080 | 0.006 | 0.006 |
| 2G | HFC | 0.00 | 7.86 | 8 | 8 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2G | PFC | 0.00 | 20.31 | 11 | 12 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2G | SF6 | 136.99 | 127.28 | 39 | 48 | 0.014 | 0.022 | 0.000 | 0.002 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2G; CO (indirect) | CO2 | 0.01 | 0.01 | 202 | 202 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2G; NMVOC (indirect) | CO2 | 129.07 | 47.30 | 150 | 150 | 0.029 | 0.029 | 0.001 | 0.001 | d.EM | d.EM | d.EM | d.EM | 0.037 | 0.037 |
| 2H | CO2 | 1.04 | 0.25 | 8 | 8 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2H; CO (indirect) | CO2 | 1.27 | 0.31 | 200 | 200 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 2H; NMVOC (indirect) | CO2 | 1.56 | 0.57 | 100 | 100 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 3A | CH4 | 3'543.96 | 3'254.22 | 19 | 20 | 2.153 | 2.534 | 0.008 | 0.063 | 0.572 | 0.572 | 1.565 | 1.565 | 2.777 | 2.777 |
| 3B1-4 | CH4 | 706.15 | 568.21 | 54 | 54 | 0.548 | 0.548 | 0.000 | 0.011 | 0.100 | 0.100 | 0.835 | 0.835 | 0.707 | 0.707 |
| 3B1-4 | N2O | 189.14 | 122.20 | 57 | 75 | 0.028 | 0.048 | 0.001 | 0.002 | 0.076 | 0.076 | 0.174 | 0.174 | 0.036 | 0.036 |
| 3B5 | N2O | 234.58 | 259.97 | 109 | 404 | 0.459 | 6.340 | 0.001 | 0.005 | 0.304 | 0.388 | 0.138 | 0.138 | 0.111 | 0.169 |
| 3Da | N2O | 1'275.80 | 1'110.78 | 85 | 157 | 5.110 | 17.539 | 0.002 | 0.021 | 0.496 | 0.540 | 2.519 | 2.519 | 6.591 | 6.636 |
| 3Db | N2O | 583.28 | 396.74 | 102 | 284 | 0.946 | 7.280 | 0.001 | 0.008 | 0.313 | 0.365 | 1.059 | 1.059 | 1.220 | 1.255 |
| 3G | CO2 | 22.25 | 32.74 | 40 | 40 | 0.001 | 0.001 | 0.000 | 0.001 | 0.036 | 0.036 | 0.001 | 0.001 | 0.001 | 0.001 |
| 3H | CO2 | 26.66 | 12.10 | 7 | 7 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.002 | 0.001 | 0.001 | 0.000 | 0.000 |
| 4A1 | CO2 | -1'109.63 | -2'180.19 | 47 | 47 | 5.963 | 5.963 | 0.025 | 0.042 | 0.027 | 0.027 | 1.159 | 1.159 | 1.345 | 1.345 |
| 4A2 | CO2 | -546.96 | -628.09 | 47 | 47 | 0.495 | 0.495 | 0.004 | 0.012 | 0.006 | 0.006 | 0.170 | 0.170 | 0.029 | 0.029 |
| 4B1 | CO2 | 288.69 | -8.22 | 5'615 | 5'615 | 1.224 | 1.224 | 0.005 | 0.000 | 0.023 | 0.023 | 1.257 | 1.257 | 1.579 | 1.579 |
| 4B2 | CO2 | 32.24 | 29.08 | 149 | 149 | 0.011 | 0.011 | 0.000 | 0.001 | 0.000 | 0.000 | 0.118 | 0.118 | 0.014 | 0.014 |
| 4C1 | CO2 | -103.15 | 401.07 | 293 | 293 | 7.928 | 7.928 | 0.009 | 0.008 | 0.049 | 0.049 | 3.197 | 3.197 | 10.224 | 10.224 |
| 4C2 | CO2 | 93.89 | 256.25 | 43 | 43 | 0.071 | 0.071 | 0.003 | 0.005 | 0.018 | 0.018 | 0.301 | 0.301 | 0.091 | 0.091 |
| 4D1 | CO2 | 67.78 | 66.21 | 116 | 116 | 0.034 | 0.034 | 0.000 | 0.001 | 0.021 | 0.021 | 0.016 | 0.016 | 0.001 | 0.001 |
| 4D2 | CO2 | 20.82 | 46.73 | 21 | 21 | 0.001 | 0.001 | 0.001 | 0.001 | 0.002 | 0.002 | 0.026 | 0.026 | 0.001 | 0.001 |
| 4E1 | CO2 | -45.60 | -42.66 | 50 | 50 | 0.003 | 0.003 | 0.000 | 0.001 | 0.001 | 0.001 | 0.006 | 0.006 | 0.000 | 0.000 |
| 4E2 | CO2 | 255.66 | 213.77 | 50 | 50 | 0.066 | 0.066 | 0.000 | 0.004 | 0.001 | 0.001 | 0.008 | 0.008 | 0.000 | 0.000 |
| 4F2 | CO2 | 87.53 | 129.55 | 50 | 50 | 0.024 | 0.024 | 0.001 | 0.002 | 0.004 | 0.004 | 0.057 | 0.057 | 0.003 | 0.003 |
| 4G | CO2 | -1'168.76 | -51.14 | 56 | 56 | 0.005 | 0.005 | 0.017 | 0.001 | 0.191 | 0.191 | 0.937 | 0.937 | 0.914 | 0.914 |
| 4II | CH4 | 10.00 | 10.00 | 71 | 71 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.003 | 0.003 | 0.000 | 0.000 |
| 4II | N2O | 2.95 | 2.94 | 83 | 83 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.001 | 0.001 | 0.000 | 0.000 |
| 4III | N2O | 36.11 | 41.32 | 124 | 217 | 0.015 | 0.046 | 0.000 | 0.001 | 0.020 | 0.020 | 0.022 | 0.022 | 0.001 | 0.001 |
| 4IV | N2O | 5.58 | 5.53 | 128 | 249 | 0.000 | 0.001 | 0.000 | 0.000 | 0.002 | 0.002 | 0.002 | 0.002 | 0.000 | 0.000 |
| 4V | CH4 | 18.34 | 1.91 | 76 | 76 | 0.000 | 0.000 | 0.000 | 0.000 | 0.007 | 0.007 | 0.017 | 0.017 | 0.000 | 0.000 |
| 4V | N2O | 10.60 | 0.66 | 76 | 76 | 0.000 | 0.000 | 0.000 | 0.000 | 0.005 | 0.005 | 0.011 | 0.011 | 0.000 | 0.000 |
| 5A | CO2 | 0.00 | 0.00 | 0 | 0 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 5A | CH4 | 769.74 | 272.04 | 30 | 30 | 0.038 | 0.038 | 0.007 | 0.005 | d.EM | d.EM | d.EM | d.EM | 0.040 | 0.040 |
| 5B | CH4 | 11.89 | 27.56 | 42 | 42 | 0.001 | 0.001 | 0.000 | 0.001 | 0.023 | 0.023 | 0.010 | 0.010 | 0.001 | 0.001 |
| 5B | N2O | 5.23 | 9.30 | 42 | 42 | 0.000 | 0.000 | 0.000 | 0.000 | 0.008 | 0.008 | 0.003 | 0.003 | 0.000 | 0.000 |
| 5C | CO2 | 40.23 | 8.90 | 40 | 40 | 0.000 | 0.000 | 0.000 | 0.000 | 0.007 | 0.007 | 0.012 | 0.012 | 0.000 | 0.000 |
| 5C | CH4 | 8.89 | 4.73 | 60 | 60 | 0.000 | 0.000 | 0.000 | 0.000 | 0.006 | 0.006 | 0.002 | 0.002 | 0.000 | 0.000 |
| 5C | N2O | 72.56 | 55.09 | 94 | 189 | 0.015 | 0.063 | 0.000 | 0.001 | 0.045 | 0.045 | 0.005 | 0.005 | 0.002 | 0.002 |
| 5C; CH4 (indirect) | CO2 | 0.26 | 0.13 | 60 | 60 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 5C; CO (indirect) | CO2 | 1.32 | 0.64 | 71 | 71 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 5C; NMVOC (indirect) | CO2 | 0.58 | 0.29 | 71 | 71 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 5D | CH4 | 129.00 | 191.94 | 48 | 48 | 0.049 | 0.049 | 0.002 | 0.004 | 0.188 | 0.188 | 0.054 | 0.054 | 0.038 | 0.038 |
| 5D | N2O | 80.68 | 104.05 | 96 | 194 | 0.057 | 0.234 | 0.001 | 0.002 | 0.091 | 0.091 | 0.068 | 0.068 | 0.013 | 0.013 |
| 5E; CO (indirect) | CO2 | 0.00 | 0.00 | 22 | 22 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 5E; NMVOC (indirect) | CO2 | 0.06 | 0.13 | 22 | 22 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6 | CO2 | 10.96 | 10.59 | 40 | 40 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 6 | CH4 | 0.66 | 0.57 | 60 | 60 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 6 | N2O | 0.60 | 0.47 | 150 | 150 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 6A; CH4 (indirect) | CO2 | 0.05 | 0.05 | 73 | 73 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 6A; CO (indirect) | CO2 | 0.85 | 0.78 | 90 | 90 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| 6A; NMVOC (indirect) | CO2 | 0.19 | 0.18 | 89 | 89 | 0.000 | 0.000 | 0.000 | 0.000 | d.EM | d.EM | d.EM | d.EM | 0.000 | 0.000 |
| Total | | | | | | 27.7 | 53.1 | | | | | | | 27.7 | 27.9 |
| Total | | 51'936.3 | 41'706.3 | Emissions 2020 uncertainty (%): | | 5.3 | 7.3 | | | Trend uncertainty (%): | | | | 5.3 | 5.3 |

## A2.3 Detailed results of approach 2 uncertainty analysis

Table A – 4 Uncertainty analysis of greenhouse gas emissions and removals, approach 2, for 2020 and for the trend 1990–2020, including LULUCF categories and indirect $CO_2$ emissions. d.EM stands for direct emission and indicates that input uncertainties are given for the emission but neither for AD nor for EF. Monte Carlo simulations were run 1’000’000 times. The reported uncertainties correspond to the borders of the narrowest 95% confidence interval. Contributions to inventory trend (mean, uncertainties, columns I and J) are values normalised by the total inventory base year emission. Columns A to J are labelled according to Table 3-3 in the IPCC guidelines, vol.1, chp. 3 (IPCC, 2006).

| A | B | C | D | E | | F | | G | | H | I | J | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IPCC category; fuel/source | Gas | Emissions 1990 | Emissions 2020 | Activity data uncertainty 2020 | | Emission factor uncertainty 2020 | | Emission combined uncertainty 2020 | | Emission contri-bution to variance 2020 | Contri-bution to trend | Contribution to uncertainty of trend | |
| | | kt CO2 equiv. | kt CO2 equiv. | (-)% | (+)% | (-)% | (+)% | (-)% | (+)% | Fraction | % | (-)% | (+)% |
| 1A1; Biomass | CH4 | 0.40 | 0.14 | 10 | 10 | 28 | 28 | 29 | 30 | 0.000 | -0.001 | 0.000 | 0.000 |
| 1A1; Biomass | N2O | 22.58 | 13.64 | 10 | 10 | 78 | 78 | 79 | 79 | 0.000 | -0.017 | 0.015 | 0.014 |
| 1A1; Gaseous Fuels | CO2 | 243.40 | 499.46 | 5 | 5 | 0 | 0 | 5 | 5 | 0.000 | 0.494 | 0.061 | 0.062 |
| 1A1; Gaseous Fuels | CH4 | 0.11 | 0.22 | 5 | 5 | 29 | 29 | 30 | 29 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A1; Gaseous Fuels | N2O | 0.13 | 0.26 | 5 | 5 | 78 | 78 | 78 | 79 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A1; Liquid Fuels | CO2 | 685.81 | 273.32 | 1 | 1 | 0 | 0 | 1 | 1 | 0.000 | -0.795 | 0.050 | 0.053 |
| 1A1; Liquid Fuels | CH4 | 0.52 | 0.14 | 1 | 1 | 29 | 30 | 29 | 29 | 0.000 | -0.001 | 0.000 | 0.000 |
| 1A1; Liquid Fuels | N2O | 1.11 | 0.20 | 1 | 1 | 79 | 78 | 78 | 79 | 0.000 | -0.002 | 0.001 | 0.001 |
| 1A1; Other Fuels | CO2 | 1'491.55 | 2'479.59 | 5 | 5 | 17 | 17 | 17 | 17 | 0.027 | 1.904 | 0.424 | 0.433 |
| 1A1; Other Fuels | N2O | 24.33 | 8.75 | 5 | 5 | 78 | 78 | 78 | 78 | 0.000 | -0.030 | 0.039 | 0.039 |
| 1A1; Solid Fuels | CO2 | 49.13 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0.000 | -0.095 | 0.009 | 0.009 |
| 1A1; Solid Fuels | CH4 | 0.13 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A1; Solid Fuels | N2O | 0.24 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A2; Biomass | CH4 | 3.59 | 2.05 | 10 | 10 | 28 | 28 | 29 | 30 | 0.000 | -0.003 | 0.001 | 0.001 |
| 1A2; Biomass | N2O | 5.20 | 15.88 | 10 | 10 | 78 | 78 | 78 | 79 | 0.000 | 0.021 | 0.016 | 0.017 |
| 1A2; Gaseous Fuels | CO2 | 1'091.14 | 2'140.66 | 5 | 5 | 0 | 0 | 5 | 5 | 0.002 | 2.023 | 0.265 | 0.264 |
| 1A2; Gaseous Fuels | CH4 | 0.48 | 0.95 | 5 | 5 | 29 | 29 | 29 | 29 | 0.000 | 0.001 | 0.000 | 0.000 |
| 1A2; Gaseous Fuels | N2O | 0.58 | 1.14 | 5 | 5 | 78 | 79 | 78 | 79 | 0.000 | 0.001 | 0.001 | 0.001 |
| 1A2; Liquid Fuels | CO2 | 3'974.32 | 1'535.07 | 1 | 1 | 0 | 0 | 1 | 1 | 0.000 | -4.702 | 0.291 | 0.317 |
| 1A2; Liquid Fuels | CH4 | 4.59 | 0.99 | 1 | 1 | 30 | 29 | 29 | 30 | 0.000 | -0.007 | 0.002 | 0.002 |
| 1A2; Liquid Fuels | N2O | 13.35 | 10.15 | 1 | 1 | 79 | 78 | 79 | 78 | 0.000 | -0.006 | 0.005 | 0.005 |
| 1A2; Other Fuels | CO2 | 192.36 | 443.68 | 5 | 5 | 9 | 9 | 10 | 10 | 0.000 | 0.484 | 0.070 | 0.071 |
| 1A2; Other Fuels | CH4 | 0.77 | 0.61 | 5 | 5 | 29 | 29 | 29 | 29 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A2; Other Fuels | N2O | 2.32 | 7.13 | 5 | 5 | 78 | 78 | 79 | 77 | 0.000 | 0.009 | 0.011 | 0.011 |
| 1A2; Solid Fuels | CO2 | 1'274.70 | 338.55 | 5 | 5 | 5 | 5 | 7 | 7 | 0.000 | -1.804 | 0.191 | 0.189 |
| 1A2; Solid Fuels | CH4 | 0.31 | 0.19 | 5 | 5 | 29 | 29 | 29 | 30 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A2; Solid Fuels | N2O | 6.14 | 1.59 | 5 | 5 | 79 | 78 | 78 | 79 | 0.000 | -0.009 | 0.007 | 0.007 |
| 1A3a; Kerosene | CO2 | 252.55 | 78.64 | 1 | 1 | 0 | 0 | 1 | 1 | 0.000 | -0.335 | 0.021 | 0.023 |
| 1A3a; Kerosene | CH4 | 0.17 | 0.08 | 1 | 1 | 59 | 59 | 59 | 59 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3a; Kerosene | N2O | 2.06 | 0.64 | 1 | 1 | 99 | 147 | 99 | 147 | 0.000 | -0.003 | 0.004 | 0.003 |
| 1A3b; Biomass | CH4 | 0.00 | 0.57 | 10 | 10 | 58 | 58 | 58 | 60 | 0.000 | 0.001 | 0.001 | 0.001 |
| 1A3b; Biomass | N2O | 0.00 | 6.82 | 10 | 10 | 99 | 147 | 99 | 147 | 0.000 | 0.013 | 0.013 | 0.019 |
| 1A3b; Diesel oil | CO2 | 2'631.94 | 6'946.36 | 1 | 1 | 0 | 0 | 1 | 1 | 0.001 | 8.316 | 0.565 | 0.524 |
| 1A3b; Diesel oil | CH4 | 2.26 | 5.53 | 1 | 1 | 20 | 20 | 20 | 20 | 0.000 | 0.006 | 0.001 | 0.001 |
| 1A3b; Diesel oil | N2O | 6.15 | 95.44 | 1 | 1 | 22 | 21 | 22 | 22 | 0.000 | 0.172 | 0.039 | 0.039 |
| 1A3b; Gaseous Fuels | CO2 | 0.00 | 29.22 | 5 | 5 | 0 | 0 | 5 | 5 | 0.000 | 0.056 | 0.005 | 0.004 |
| 1A3b; Gaseous Fuels | CH4 | 0.00 | 0.17 | 5 | 5 | 29 | 29 | 30 | 29 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3b; Gaseous Fuels | N2O | 0.00 | 0.66 | 5 | 5 | 78 | 79 | 79 | 78 | 0.000 | 0.001 | 0.001 | 0.001 |
| 1A3b; Gasoline | CO2 | 11'342.40 | 6'210.88 | 1 | 1 | 0 | 0 | 1 | 1 | 0.000 | -9.892 | 0.624 | 0.673 |
| 1A3b; Gasoline | CH4 | 115.09 | 12.24 | 1 | 1 | 36 | 36 | 36 | 36 | 0.000 | -0.198 | 0.073 | 0.072 |
| 1A3b; Gasoline | N2O | 159.33 | 17.64 | 1 | 1 | 49 | 49 | 49 | 49 | 0.000 | -0.273 | 0.134 | 0.135 |
| 1A3b; Liquefied Petroleum Gas | CO2 | 0.00 | 1.30 | 1 | 1 | 10 | 10 | 10 | 10 | 0.000 | 0.003 | 0.000 | 0.000 |
| 1A3b; Liquefied Petroleum Gas | CH4 | 0.00 | 0.00 | 1 | 1 | 30 | 29 | 29 | 29 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3b; Liquefied Petroleum Gas | N2O | 0.00 | 0.01 | 1 | 1 | 79 | 78 | 79 | 78 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3c; Biomass | CH4 | 0.00 | 0.00 | 10 | 10 | 58 | 58 | 59 | 59 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3c; Biomass | N2O | 0.00 | 0.01 | 10 | 10 | 99 | 147 | 99 | 147 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3c; Liquid Fuels | CO2 | 28.69 | 27.97 | 1 | 1 | 0 | 0 | 1 | 1 | 0.000 | -0.001 | 0.001 | 0.001 |
| 1A3c; Liquid Fuels | CH4 | 0.03 | 0.01 | 1 | 1 | 30 | 29 | 29 | 29 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3c; Liquid Fuels | N2O | 0.43 | 0.41 | 1 | 1 | 79 | 78 | 79 | 78 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3d; Biomass | CH4 | 0.00 | 0.01 | 10 | 10 | 58 | 58 | 59 | 59 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3d; Biomass | N2O | 0.00 | 0.03 | 10 | 10 | 99 | 146 | 99 | 147 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3d; Liquid Fuels | CO2 | 114.27 | 110.54 | 1 | 1 | 0 | 0 | 1 | 1 | 0.000 | -0.007 | 0.002 | 0.002 |
| 1A3d; Liquid Fuels | CH4 | 1.68 | 0.31 | 1 | 1 | 29 | 30 | 29 | 30 | 0.000 | -0.003 | 0.001 | 0.001 |
| 1A3d; Liquid Fuels | N2O | 1.16 | 1.19 | 1 | 1 | 99 | 147 | 99 | 147 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3e; Gaseous Fuels | CO2 | 31.42 | 30.35 | 5 | 5 | 0 | 0 | 5 | 5 | 0.000 | -0.002 | 0.004 | 0.004 |
| 1A3e; Gaseous Fuels | CH4 | 0.07 | 0.03 | 5 | 5 | 29 | 29 | 29 | 30 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A3e; Gaseous Fuels | N2O | 0.02 | 0.02 | 5 | 5 | 78 | 79 | 78 | 78 | 0.000 | 0.000 | 0.000 | 0.000 |

Table A – 4 (continued)

| A | B | C | D | E | | F | | G | | H | I | J | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IPCC category; fuel/source | Gas | Emissions 1990 | Emissions 2020 | Activity data uncertainty 2020 | | Emission factor uncertainty 2020 | | Emission combined uncertainty 2020 | | Emission contri-bution to variance 2020 | Contri-bution to trend | Contribution to uncertainty of trend | |
| | | kt CO2 equiv. | kt CO2 equiv. | (-)% | (+)% | (-)% | (+)% | (-)% | (+)% | Fraction | % | (-)% | (+)% |
| 1A4a; Biomass | CH4 | 7.01 | 4.00 | 10 | 10 | 28 | 28 | 29 | 30 | 0.000 | -0.006 | 0.002 | 0.002 |
| 1A4a; Biomass | N2O | 3.50 | 11.86 | 10 | 10 | 78 | 77 | 79 | 78 | 0.000 | 0.016 | 0.013 | 0.013 |
| 1A4a; Gaseous Fuels | CO2 | 920.00 | 1'182.55 | 5 | 5 | 0 | 0 | 5 | 5 | 0.000 | 0.506 | 0.147 | 0.148 |
| 1A4a; Gaseous Fuels | CH4 | 0.68 | 1.20 | 5 | 5 | 29 | 29 | 29 | 30 | 0.000 | 0.001 | 0.000 | 0.000 |
| 1A4a; Gaseous Fuels | N2O | 0.49 | 0.63 | 5 | 5 | 78 | 78 | 78 | 79 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A4a; Liquid Fuels | CO2 | 3'918.47 | 2'051.94 | 1 | 1 | 0 | 0 | 1 | 1 | 0.000 | -3.598 | 0.227 | 0.245 |
| 1A4a; Liquid Fuels | CH4 | 15.17 | 7.39 | 1 | 1 | 29 | 30 | 29 | 30 | 0.000 | -0.015 | 0.005 | 0.005 |
| 1A4a; Liquid Fuels | N2O | 9.51 | 5.02 | 1 | 1 | 78 | 78 | 79 | 78 | 0.000 | -0.009 | 0.007 | 0.007 |
| 1A4b; Biomass | CH4 | 80.94 | 19.96 | 10 | 10 | 28 | 28 | 29 | 30 | 0.000 | -0.118 | 0.037 | 0.037 |
| 1A4b; Biomass | N2O | 25.86 | 20.70 | 10 | 10 | 78 | 78 | 79 | 79 | 0.000 | -0.010 | 0.011 | 0.009 |
| 1A4b; Gaseous Fuels | CO2 | 1'450.97 | 2'652.34 | 5 | 5 | 0 | 0 | 5 | 5 | 0.002 | 2.316 | 0.324 | 0.329 |
| 1A4b; Gaseous Fuels | CH4 | 0.70 | 1.38 | 5 | 5 | 29 | 29 | 30 | 29 | 0.000 | 0.001 | 0.000 | 0.000 |
| 1A4b; Gaseous Fuels | N2O | 0.77 | 1.41 | 5 | 5 | 78 | 78 | 78 | 79 | 0.000 | 0.001 | 0.001 | 0.001 |
| 1A4b; Liquid Fuels | CO2 | 10'099.07 | 4'387.08 | 1 | 1 | 0 | 0 | 1 | 1 | 0.000 | -11.010 | 0.684 | 0.740 |
| 1A4b; Liquid Fuels | CH4 | 34.83 | 15.00 | 1 | 1 | 29 | 30 | 30 | 29 | 0.000 | -0.038 | 0.012 | 0.011 |
| 1A4b; Liquid Fuels | N2O | 24.53 | 10.68 | 1 | 1 | 79 | 78 | 79 | 78 | 0.000 | -0.027 | 0.021 | 0.021 |
| 1A4b; Solid Fuels | CO2 | 58.40 | 9.27 | 5 | 5 | 5 | 5 | 7 | 7 | 0.000 | -0.095 | 0.009 | 0.010 |
| 1A4b; Solid Fuels | CH4 | 4.73 | 0.75 | 5 | 5 | 29 | 29 | 29 | 30 | 0.000 | -0.008 | 0.002 | 0.002 |
| 1A4b; Solid Fuels | N2O | 0.28 | 0.04 | 5 | 5 | 78 | 78 | 78 | 79 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A4c; Biomass | CH4 | 1.03 | 1.21 | 10 | 10 | 28 | 28 | 29 | 29 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A4c; Biomass | N2O | 0.51 | 1.39 | 10 | 10 | 78 | 78 | 78 | 79 | 0.000 | 0.002 | 0.001 | 0.001 |
| 1A4c; Gaseous Fuels | CO2 | 70.06 | 122.77 | 5 | 5 | 0 | 0 | 5 | 5 | 0.000 | 0.102 | 0.015 | 0.015 |
| 1A4c; Gaseous Fuels | CH4 | 0.03 | 0.05 | 5 | 5 | 29 | 29 | 30 | 29 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A4c; Gaseous Fuels | N2O | 0.04 | 0.07 | 5 | 5 | 78 | 79 | 78 | 79 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A4c; Liquid Fuels | CO2 | 742.30 | 454.04 | 1 | 1 | 0 | 0 | 1 | 1 | 0.000 | -0.556 | 0.036 | 0.039 |
| 1A4c; Liquid Fuels | CH4 | 6.72 | 1.16 | 1 | 1 | 29 | 29 | 29 | 29 | 0.000 | -0.011 | 0.003 | 0.003 |
| 1A4c; Liquid Fuels | N2O | 4.82 | 4.56 | 1 | 1 | 78 | 79 | 78 | 78 | 0.000 | -0.001 | 0.000 | 0.000 |
| 1A5; Biomass | CH4 | 0.00 | 0.00 | 10 | 10 | 58 | 58 | 59 | 59 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A5; Biomass | N2O | 0.00 | 0.01 | 10 | 10 | 99 | 147 | 99 | 147 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A5; Liquid Fuels | CO2 | 217.65 | 118.39 | 1 | 1 | 0 | 0 | 1 | 1 | 0.000 | -0.191 | 0.012 | 0.013 |
| 1A5; Liquid Fuels | CH4 | 0.12 | 0.04 | 1 | 1 | 30 | 29 | 30 | 29 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1A5; Liquid Fuels | N2O | 1.84 | 1.04 | 1 | 1 | 99 | 147 | 99 | 147 | 0.000 | -0.002 | 0.002 | 0.002 |
| 1B; CH4 (indirect) | CO2 | 36.90 | 20.40 | d.EM | d.EM | d.EM | d.EM | 27 | 27 | 0.000 | -0.032 | 0.023 | 0.023 |
| 1B; NMVOC (indirect) | CO2 | 37.55 | 3.70 | d.EM | d.EM | d.EM | d.EM | 22 | 22 | 0.000 | -0.065 | 0.013 | 0.013 |
| 1B2; All Fuels | CO2 | 26.34 | 26.40 | 5 | 5 | 5 | 5 | 7 | 7 | 0.000 | 0.000 | 0.004 | 0.004 |
| 1B2; All Fuels | CH4 | 335.78 | 185.45 | 5 | 5 | 29 | 29 | 29 | 30 | 0.000 | -0.290 | 0.094 | 0.092 |
| 1B2; All Fuels | N2O | 0.03 | 0.00 | 5 | 5 | 78 | 78 | 78 | 79 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2A; CO (indirect) | CO2 | 0.04 | 0.02 | d.EM | d.EM | d.EM | d.EM | 194 | 198 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2A; NMVOC (indirect) | CO2 | 0.10 | 0.06 | d.EM | d.EM | d.EM | d.EM | 195 | 198 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2A1 | CO2 | 2'580.79 | 1'679.25 | 2 | 2 | 4 | 4 | 4 | 4 | 0.001 | -1.738 | 0.171 | 0.175 |
| 2A2 | CO2 | 53.35 | 47.91 | 2 | 2 | 2 | 2 | 3 | 3 | 0.000 | -0.010 | 0.004 | 0.004 |
| 2A3 | CO2 | 15.25 | 6.66 | 2 | 2 | 3 | 3 | 4 | 4 | 0.000 | -0.017 | 0.002 | 0.002 |
| 2A4 | CO2 | 160.16 | 64.63 | 2 | 2 | 2 | 2 | 3 | 3 | 0.000 | -0.184 | 0.015 | 0.015 |
| 2B; CH4 (indirect) | CO2 | 0.39 | 0.71 | d.EM | d.EM | d.EM | d.EM | 20 | 20 | 0.000 | 0.001 | 0.000 | 0.000 |
| 2B; CO (indirect) | CO2 | 6.33 | 10.50 | d.EM | d.EM | d.EM | d.EM | 49 | 49 | 0.000 | 0.008 | 0.012 | 0.012 |
| 2B; NMVOC (indirect) | CO2 | 1.29 | 0.01 | d.EM | d.EM | d.EM | d.EM | 39 | 39 | 0.000 | -0.002 | 0.001 | 0.001 |
| 2B2 | N2O | 65.49 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0.000 | -0.126 | 0.074 | 0.075 |
| 2B5 | CO2 | 15.36 | 18.22 | 2 | 2 | 10 | 10 | 10 | 10 | 0.000 | 0.006 | 0.001 | 0.001 |
| 2B5 | CH4 | 3.47 | 6.44 | 2 | 2 | 20 | 20 | 20 | 20 | 0.000 | 0.006 | 0.001 | 0.001 |
| 2B8 | CO2 | 94.08 | 98.33 | 2 | 2 | 10 | 10 | 10 | 10 | 0.000 | 0.008 | 0.026 | 0.026 |
| 2B10 | CO2 | 17.34 | 17.60 | 2 | 2 | 59 | 59 | 59 | 59 | 0.000 | 0.001 | 0.001 | 0.001 |
| 2B10 | CH4 | 0.09 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2B10 | N2O | 432.38 | 573.92 | 2 | 2 | 59 | 59 | 59 | 59 | 0.017 | 0.273 | 0.814 | 0.817 |
| 2C; CO (indirect) | CO2 | 1.10 | 0.14 | d.EM | d.EM | d.EM | d.EM | 39 | 39 | 0.000 | -0.002 | 0.001 | 0.001 |
| 2C; NMVOC (indirect) | CO2 | 2.25 | 0.27 | d.EM | d.EM | d.EM | d.EM | 98 | 98 | 0.000 | -0.004 | 0.004 | 0.004 |
| 2C1 | CO2 | 11.91 | 9.73 | 2 | 2 | 5 | 5 | 5 | 5 | 0.000 | -0.004 | 0.002 | 0.002 |
| 2C3 | CO2 | 139.26 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0.000 | -0.268 | 0.057 | 0.057 |
| 2C3 | PFC | 116.46 | 0.00 | d.EM | d.EM | d.EM | d.EM | 0 | 0 | 0.000 | -0.225 | 0.025 | 0.024 |
| 2C4 | SF6 | 0.00 | 0.00 | d.EM | d.EM | d.EM | d.EM | 0 | 0 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2C7 | CO2 | 0.00 | 1.47 | 2 | 2 | 20 | 20 | 20 | 20 | 0.000 | 0.003 | 0.001 | 0.001 |
| 2D | CO2 | 58.21 | 50.47 | 10 | 10 | 10 | 10 | 14 | 14 | 0.000 | -0.015 | 0.015 | 0.015 |
| 2D; CO (indirect) | CO2 | 0.00 | 0.00 | d.EM | d.EM | d.EM | d.EM | 196 | 197 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2D; NMVOC (indirect) | CO2 | 192.80 | 34.41 | d.EM | d.EM | d.EM | d.EM | 197 | 195 | 0.001 | -0.304 | 0.730 | 0.746 |
| 2E1 | HFC | 0.00 | 0.90 | d.EM | d.EM | d.EM | d.EM | 41 | 44 | 0.000 | 0.002 | 0.001 | 0.001 |
| 2E1 | PFC | 0.00 | 12.86 | d.EM | d.EM | d.EM | d.EM | 62 | 70 | 0.000 | 0.025 | 0.015 | 0.017 |
| 2E1 | SF6 | 0.00 | 10.31 | d.EM | d.EM | d.EM | d.EM | 59 | 65 | 0.000 | 0.020 | 0.012 | 0.013 |
| 2E3 | NF3 | 0.00 | 0.41 | d.EM | d.EM | d.EM | d.EM | 87 | 108 | 0.000 | 0.001 | 0.001 | 0.001 |
| 2E5 | PFC | 0.00 | 0.07 | d.EM | d.EM | d.EM | d.EM | 49 | 54 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2F1 | HFC | 0.02 | 1'346.12 | d.EM | d.EM | d.EM | d.EM | 18 | 18 | 0.009 | 2.594 | 0.485 | 0.502 |
| 2F1 | PFC | 0.05 | 1.19 | d.EM | d.EM | d.EM | d.EM | 68 | 77 | 0.000 | 0.002 | 0.002 | 0.002 |
| 2F2 | HFC | 0.00 | 25.75 | d.EM | d.EM | d.EM | d.EM | 86 | 107 | 0.000 | 0.050 | 0.043 | 0.053 |
| 2F4 | HFC | 0.00 | 6.41 | d.EM | d.EM | d.EM | d.EM | 41 | 40 | 0.000 | 0.012 | 0.005 | 0.005 |
| 2F5 | HFC | 0.00 | 0.16 | d.EM | d.EM | d.EM | d.EM | 51 | 52 | 0.000 | 0.000 | 0.000 | 0.000 |

Table A – 4 (continued)

| A | B | C | D | E | | F | | G | | H | I | J | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IPCC category; fuel/source | Gas | Emissions 1990 | Emissions 2020 | Activity data uncertainty 2020 | | Emission factor uncertainty 2020 | | Emission combined uncertainty 2020 | | Emission contri-bution to variance 2020 | Contri-bution to trend | Contribution to uncertainty of trend | |
| | | kt CO2 equiv. | kt CO2 equiv. | (-)% | (+)% | (-)% | (+)% | (-)% | (+)% | Fraction | % | (-)% | (+)% |
| 2G | CO2 | 6.07 | 31.76 | 10 | 10 | 10 | 10 | 14 | 14 | 0.000 | 0.050 | 0.008 | 0.008 |
| 2G | N2O | 104.01 | 31.32 | 1 | 1 | 78 | 78 | 79 | 78 | 0.000 | -0.140 | 0.110 | 0.110 |
| 2G | HFC | 0.00 | 7.86 | d.EM | d.EM | d.EM | d.EM | 8 | 8 | 0.000 | 0.015 | 0.002 | 0.002 |
| 2G | PFC | 0.00 | 20.31 | d.EM | d.EM | d.EM | d.EM | 11 | 12 | 0.000 | 0.039 | 0.005 | 0.005 |
| 2G | SF6 | 136.99 | 127.28 | d.EM | d.EM | d.EM | d.EM | 41 | 45 | 0.000 | -0.019 | 0.008 | 0.008 |
| 2G; CO (indirect) | CO2 | 0.01 | 0.01 | d.EM | d.EM | d.EM | d.EM | 198 | 197 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2G; NMVOC (indirect) | CO2 | 129.07 | 47.30 | d.EM | d.EM | d.EM | d.EM | 146 | 147 | 0.001 | -0.157 | 0.379 | 0.374 |
| 2H | CO2 | 1.04 | 0.25 | 3 | 3 | 7 | 7 | 8 | 8 | 0.000 | -0.002 | 0.000 | 0.000 |
| 2H; CO (indirect) | CO2 | 1.27 | 0.31 | d.EM | d.EM | d.EM | d.EM | 197 | 195 | 0.000 | -0.002 | 0.005 | 0.005 |
| 2H; NMVOC (indirect) | CO2 | 1.56 | 0.57 | d.EM | d.EM | d.EM | d.EM | 99 | 98 | 0.000 | -0.002 | 0.003 | 0.003 |
| 3A | CH4 | 3'543.96 | 3'254.22 | 6 | 6 | 18 | 19 | 19 | 20 | 0.060 | -0.555 | 1.750 | 1.732 |
| 3B1-4 | CH4 | 706.15 | 568.21 | 6 | 6 | 53 | 53 | 53 | 53 | 0.013 | -0.264 | 0.932 | 0.923 |
| 3B1-4 | N2O | 189.14 | 122.20 | 22 | 23 | 57 | 63 | 60 | 67 | 0.001 | -0.129 | 0.322 | 0.295 |
| 3B5 | N2O | 234.58 | 259.97 | 46 | 50 | 100 | 283 | 100 | 288 | 0.083 | 0.049 | 0.504 | 0.615 |
| 3Da | N2O | 1'275.80 | 1'110.78 | 17 | 17 | 94 | 123 | 94 | 125 | 0.284 | -0.277 | 5.269 | 4.730 |
| 3Db | N2O | 583.28 | 396.74 | 30 | 32 | 100 | 208 | 100 | 211 | 0.100 | -0.332 | 4.019 | 3.158 |
| 3G | CO2 | 22.25 | 32.74 | 40 | 39 | 5 | 5 | 40 | 39 | 0.000 | 0.020 | 0.030 | 0.030 |
| 3H | CO2 | 26.66 | 12.10 | 5 | 5 | 5 | 5 | 7 | 7 | 0.000 | -0.028 | 0.004 | 0.004 |
| 4A1 | CO2 | -1'109.63 | -2'180.19 | 1 | 1 | 46 | 45 | 46 | 46 | 0.146 | -2.066 | 0.977 | 0.969 |
| 4A2 | CO2 | -546.96 | -628.09 | 2 | 1 | 46 | 46 | 46 | 46 | 0.012 | -0.156 | 0.074 | 0.072 |
| 4B1 | CO2 | 288.69 | -8.22 | 5 | 5 | 5'705 | 5'687 | 5'709 | 5'697 | 0.030 | -0.570 | 1.345 | 1.351 |
| 4B2 | CO2 | 32.24 | 29.08 | 5 | 5 | 145 | 147 | 147 | 145 | 0.000 | -0.006 | 0.099 | 0.099 |
| 4C1 | CO2 | -103.15 | 401.07 | 5 | 5 | 288 | 286 | 288 | 287 | 0.195 | 0.987 | 3.278 | 3.298 |
| 4C2 | CO2 | 93.89 | 256.25 | 5 | 5 | 43 | 42 | 43 | 43 | 0.002 | 0.313 | 0.232 | 0.230 |
| 4D1 | CO2 | 67.78 | 66.21 | 90 | 88 | 71 | 71 | 104 | 122 | 0.001 | -0.003 | 0.004 | 0.003 |
| 4D2 | CO2 | 20.82 | 46.73 | 4 | 4 | 20 | 20 | 20 | 21 | 0.000 | 0.050 | 0.020 | 0.021 |
| 4E1 | CO2 | -45.60 | -42.66 | 4 | 4 | 49 | 49 | 49 | 50 | 0.000 | 0.006 | 0.003 | 0.003 |
| 4E2 | CO2 | 255.66 | 213.77 | 4 | 4 | 49 | 49 | 49 | 49 | 0.002 | -0.081 | 0.040 | 0.040 |
| 4F2 | CO2 | 87.53 | 129.55 | 3 | 3 | 49 | 49 | 49 | 49 | 0.001 | 0.081 | 0.040 | 0.040 |
| 4G | CO2 | -1'168.76 | -51.14 | 11 | 11 | 54 | 53 | 55 | 55 | 0.000 | 2.158 | 1.192 | 1.249 |
| 4II | CH4 | 10.00 | 10.00 | 10 | 10 | 68 | 69 | 69 | 70 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4II | N2O | 2.95 | 2.94 | 48 | 48 | 65 | 66 | 77 | 84 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4III | N2O | 36.11 | 41.32 | 82 | 82 | 100 | 153 | 104 | 195 | 0.001 | 0.010 | 0.011 | 0.020 |
| 4IV | N2O | 5.58 | 5.53 | 84 | 84 | 100 | 176 | 107 | 219 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4V | CH4 | 18.34 | 1.91 | 29 | 29 | 69 | 68 | 73 | 77 | 0.000 | -0.032 | 0.024 | 0.023 |
| 4V | N2O | 10.60 | 0.66 | 30 | 29 | 69 | 68 | 73 | 77 | 0.000 | -0.019 | 0.015 | 0.014 |
| 5A | CO2 | 0.00 | 0.00 | d.EM | d.EM | d.EM | d.EM | 0 | 0 | 0.000 | 0.000 | 0.000 | 0.000 |
| 5A | CH4 | 769.74 | 272.04 | d.EM | d.EM | d.EM | d.EM | 29 | 29 | 0.001 | -0.959 | 0.286 | 0.283 |
| 5B | CH4 | 11.89 | 27.56 | 29 | 29 | 30 | 29 | 40 | 42 | 0.000 | 0.030 | 0.019 | 0.020 |
| 5B | N2O | 5.23 | 9.30 | 29 | 30 | 29 | 29 | 40 | 42 | 0.000 | 0.008 | 0.006 | 0.007 |
| 5C | CO2 | 40.23 | 8.90 | 29 | 29 | 26 | 26 | 39 | 40 | 0.000 | -0.060 | 0.029 | 0.028 |
| 5C | CH4 | 8.89 | 4.73 | 49 | 49 | 32 | 33 | 57 | 60 | 0.000 | -0.008 | 0.010 | 0.010 |
| 5C | N2O | 72.56 | 55.09 | 30 | 29 | 98 | 144 | 99 | 148 | 0.001 | -0.034 | 0.092 | 0.059 |
| 5C; CH4 (indirect) | CO2 | 0.26 | 0.13 | d.EM | d.EM | d.EM | d.EM | 60 | 59 | 0.000 | 0.000 | 0.000 | 0.000 |
| 5C; CO (indirect) | CO2 | 1.32 | 0.64 | d.EM | d.EM | d.EM | d.EM | 70 | 70 | 0.000 | -0.001 | 0.002 | 0.002 |
| 5C; NMVOC (indirect) | CO2 | 0.58 | 0.29 | d.EM | d.EM | d.EM | d.EM | 70 | 69 | 0.000 | -0.001 | 0.001 | 0.001 |
| 5D | CH4 | 129.00 | 191.94 | 35 | 35 | 32 | 31 | 45 | 49 | 0.001 | 0.121 | 0.162 | 0.168 |
| 5D | N2O | 80.68 | 104.05 | 31 | 32 | 99 | 147 | 99 | 152 | 0.004 | 0.045 | 0.091 | 0.139 |
| 5E; CO (indirect) | CO2 | 0.00 | 0.00 | 10 | 10 | 20 | 20 | 22 | 22 | 0.000 | 0.000 | 0.000 | 0.000 |
| 5E; NMVOC (indirect) | CO2 | 0.06 | 0.13 | 10 | 10 | 20 | 20 | 22 | 22 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6 | CO2 | 10.96 | 10.59 | d.EM | d.EM | d.EM | d.EM | 39 | 39 | 0.000 | -0.001 | 0.000 | 0.000 |
| 6 | CH4 | 0.66 | 0.57 | d.EM | d.EM | d.EM | d.EM | 59 | 59 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6 | N2O | 0.60 | 0.47 | d.EM | d.EM | d.EM | d.EM | 149 | 146 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6A; CH4 (indirect) | CO2 | 0.05 | 0.05 | d.EM | d.EM | d.EM | d.EM | 71 | 72 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6A; CO (indirect) | CO2 | 0.85 | 0.78 | d.EM | d.EM | d.EM | d.EM | 89 | 89 | 0.000 | 0.000 | 0.002 | 0.002 |
| 6A; NMVOC (indirect) | CO2 | 0.19 | 0.18 | d.EM | d.EM | d.EM | d.EM | 87 | 88 | 0.000 | 0.000 | 0.000 | 0.000 |
| Total, Monte Carlo simulations | | 51'935.2 | 41'705.0 | | | | | 6.1 | 6.4 | 1.0 | -19.6 | 6.7 | 6.8 |
| Total, inventory | | 51'936.3 | 41'706.3 | | | | | | | | -19.7 | | |

# Annex 3 Other detailed methodological descriptions for individual source or sink categories

## A3.1 Sector Energy

### A3.1.1 Civil aviation

This paragraph contains further information on the emission modelling. More complete information is provided in FOCA (2006, 2006a, 2007–2021) and on request for reviewers by FOCA.

## Emission factors (1A3a)

Table A – 5 Aircraft cruise factors, used for cruise emission calculation (extract of list of 881 aircraft) GKL_ICAO = ICAO seat categories. Mass emissions are given in kilograms or grams per nautical mile (NM).

| **Aircraft Cruise _Factors** | | | | | | |
|---|---|---|---|---|---|---|
| Aircraft_ICAO | GKL_ICAO | Cruise_D_Source | kg_fuel_NM | kg_NOx_NM | g_VOC_NM | g_CO_NM |
| AA1 | 0 | P002FOCA | 0.21 | 0.0098 | 1.79 | 61.7 |
| AA5 | 0 | P002FOCA | 0.21 | 0.0098 | 1.79 | 61.7 |
| AC11 | 0 | P002FOCA | 0.21 | 0.0098 | 1.79 | 61.7 |
| AC14 | 0 | P002FOCA | 0.21 | 0.0098 | 1.79 | 61.7 |
| AC50 | 0 | P001FOCA | 0.77 | 0.021 | 4.14 | 364.17 |
| AC68 | 0 | P001FOCA | 0.77 | 0.0075 | 4.14 | 364.17 |
| AC6T | 1 | FOCAINV95-03.2T | 1.58 | 0.021 | 0.87 | 2.9 |
| AC90 | 1 | FOCAINV95-03.2T | 1.58 | 0.021 | 0.87 | 2.9 |
| AC95 | 1 | FOCAINV95-03.2T | 1.58 | 0.021 | 0.87 | 2.9 |
| AEST | 0 | P001FOCA | 0.77 | 0.021 | 4.14 | 364.17 |
| AJET | 0 | FOCAEDBJ014 | 2.92 | 0.0146 | 8.53 | 63 |
| ALO2 | 0 | FOCAHeli | 1.91 | 0.024 | 0.42 | 2.1 |
| ALO3 | 0 | FOCAHeli | 1.91 | 0.024 | 0.42 | 2.1 |
| AN12 | 0 | AN26*2 | 5.36 | 0.0062 | 143 | 348 |
| AN2 | 0 | FOCA/91/DC3 | 0.82 | 0.0002 | 13.7 | 1000 |
| AN22 | 6 | FOCAINV95-03.2T*2 | 3.16 | 0.042 | 1.74 | 5.8 |
| AN24 | 2 | AN26 | 2.68 | 0.0031 | 71.7 | 174 |
| AN26 | 1 | 500 | 2.68 | 0.0031 | 71.7 | 174 |
| AN72 | 2 | FOCAINV95-03.2J | 6.4 | 0.1 | 0.83 | 10 |
| AR7 | 0 | P002FOCA | 0.21 | 0.0098 | 1.79 | 61.7 |
| AR7A | 0 | P002FOCA | 0.21 | 0.0098 | 1.79 | 61.7 |
| AS02 | 0 | P002FOCA | 0.21 | 0.0098 | 1.79 | 61.7 |
| AS16 | 0 | P002FOCA | 0.21 | 0.0098 | 1.79 | 61.7 |
| AS20 | 0 | P002FOCA | 0.21 | 0.0098 | 1.79 | 61.7 |
| AS24 | 0 | P002FOCA | 0.21 | 0.0098 | 1.79 | 61.7 |
| AS25 | 0 | P002FOCA | 0.21 | 0.0098 | 1.79 | 61.7 |
| AS26 | 0 | P002FOCA | 0.21 | 0.0098 | 1.79 | 61.7 |
| AS2T | 0 | FOCAEDBT758 | 0.95 | 0.005 | 1.8 | 12 |
| AS30 | 0 | FOCAHeli*2 | 3.82 | 0.048 | 0.82 | 4.2 |
| AS32 | 1 | FOCAHeli*2 | 3.82 | 0.048 | 0.82 | 4.2 |
| AS33 | 0 | FOCAHeli*2 | 3.82 | 0.048 | 0.82 | 4.2 |
| AS35 | 0 | FOCAHeli | 1.91 | 0.024 | 0.42 | 2.1 |
| AS50 | 0 | FOCAHeli*2 | 3.82 | 0.048 | 0.82 | 4.2 |
| AS55 | 0 | FOCAHeli*2 | 3.82 | 0.048 | 0.82 | 4.2 |
| AS65 | 0 | FOCAHeli*2 | 3.82 | 0.048 | 0.82 | 4.2 |
| ASK1 | 0 | P002FOCA | 0.21 | 0.0098 | 1.79 | 61.7 |
| ASTA | 0 | FOCAINV95-03.B | 3.016 | 0.046 | 0.3 | 2.8 |
| ASTR | 0 | FOCAINV95-03.B | 3.016 | 0.046 | 0.3 | 2.8 |
| ASTRA | 0 | FOCAINV95-03.B | 3.016 | 0.046 | 0.3 | 2.8 |
| AT42 | 1 | FOCAINV95-03.2T | 1.58 | 0.021 | 0.87 | 2.9 |
| AT43 | 1 | 500 | 1.6 | 0.013 | 0 | 15 |

**Activity data (1A3a)**

LTO-cycle times (minutes). ICAO standard cycle times were originally designed for emissions certification, not for emissions modelling. Today, they do generally not match real world aircraft LTO operations. Swiss FOCA has therefore adjusted some of the ICAO standard cycle times for different aircraft categories. For jets, the mean time for taxi-in and taxi-out at Swiss airports has been determined 20 minutes instead of the standard 26 minutes (Aerocert 2012, FOCA 2007b, ZRH 2017).

Table A – 6 For jets, business jets, turboprops, piston engines and helicopters, the times in mode are shown and are based on ICAO, US EPA and Swiss FOCA data. “Type” is a classification variable. J = Jet, T = Turboprop, P = Piston, H = Helicopter, HP = Helicopter with Piston Engine, B = Business jet, SJ = Supersonic Jet, E = Electric Aircraft. The number in “Type” stands for the number of engines. For Jet Aircraft, the cycle times and associated thrust settings still lead to an overestimation of LTO emissions (FOCA 2007b).

| **LTO Cycle** | | | | |
|---|---|---|---|---|
| Type | Time_Take_Off | Time_Climbout | Time_Approach | Time_Taxi |
| 1J | 0.7 | 2.2 | 4 | 20 |
| 1T | 0.5 | 2.5 | 4.5 | 13 |
| 1P | 0.3 | 2.5 | 3 | 12 |
| 1H | 0 | 3 | 5.5 | 5 |
| 2B | 0.4 | 0.5 | 1.6 | 13 |
| 3B | 0.4 | 0.5 | 1.6 | 13 |
| 2T | 0.5 | 2.5 | 4.5 | 13 |
| 4T | 0.5 | 2.5 | 4.5 | 13 |
| 2J | 0.7 | 2.2 | 4 | 20 |
| 3J | 0.7 | 2.2 | 4 | 20 |
| 4J | 0.7 | 2.2 | 4 | 20 |
| 2P | 0.3 | 2.5 | 3 | 12 |
| 3P | 0.3 | 2.5 | 3 | 12 |
| 4P | 0.3 | 2.5 | 3 | 12 |
| 2H | 0 | 3 | 5.5 | 5 |
| 4SJ | 1.2 | 2 | 2.3 | 20 |
| 3H | 0 | 3 | 5.5 | 5 |
| 4H | 0 | 3 | 5.5 | 5 |
| 4B | 0.4 | 0.5 | 1.6 | 13 |
| 1HP | 0 | 4 | 5.5 | 5 |
| 2HP | 0 | 4 | 5.5 | 5 |
| 3HP | 0 | 4 | 5.5 | 5 |
| 4HP | 0 | 4 | 5.5 | 5 |
| 1B | 0.4 | 0.5 | 1.6 | 13 |
| 1E | 0.7 | 10 | 5 | 13 |
| 4E | 0.3 | 10 | 5 | 13 |
| 6J | 0.7 | 2.2 | 4 | 20 |

Table A – 7 Aircraft-Engine Combinations and associated codes for SWISS FOCA emissions database. (Extract from list of more than 40’000 individual aircraft)

| **Aircraft Engine Combinations** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Engine Name | Aircraft Name | Aircraft Registr. | No. Eng. | Code | Type | Aircr. ICAO | Source |
| V2527-A5 | AIRBUS A320-232 | ECHXA | 2 | J220 | 2J | A320 | 1IA003 |
| CF34-3B1 | BOMBARDIER CRJ200ER (CL-600-2B19) | ECHXM | 2 | J090 | 2J | CRJ2 | 1GE034 |
| CFM56-3C1 | BOEING 737-4K5 | ECHXT | 2 | J022 | 2J | B734 | 1CM007 |
| TPE331-11U-611G | FAIRCHILD (SWEARIN-GEN) SA227AC METR | ECHXY | 2 | T310 | 2T | SW4 | FOI |
| CFM56-5B4/P | AIRBUS A320-214 | ECHYC | 2 | J067 | 2J | A320 | 3CM026 |
| CFM56-5B4/P | AIRBUS A320-214 | ECHYD | 2 | J067 | 2J | A320 | 3CM026 |
| CF34-3B1 | BOMBARDIER CRJ200ER (CL-600-2B19) | ECHYG | 2 | J090 | 2J | CRJ2 | 1GE034 |
| CFEC-FE738-1-1B | DASSAULT FALCON 2000 | ECHYI | 2 | B130 | 2B | F2TH | FOI-Ho-neywell |
| GA TPE331-11U-612G | | ECHZH | 2 | T310 | 2T | FA3 | FOI |
| CF34-3B1 | BOMBARDIER CRJ200ER (CL-600-2B19) | ECHZR | 2 | J090 | 2J | CRJ2 | 1GE034 |
| CFM56-7B27B1 | BOEING 737-86Q (WINGLETS) | ECHZS | 2 | J075 | 2J | B738 | 3CM034 |
| CFM56-5B4/P | AIRBUS A320-214 | ECHZU | 2 | J067 | 2J | A320 | 3CM026 |
| CF34-3B1 | BOMBARDIER CRJ200ER (CL-600-2B19) | ECIAA | 2 | J090 | 2J | CRJ2 | 1GE034 |
| FJ44-1A | CESSNA 525 CITATIONJET | ECIAB | 2 | B001 | 2B | C525 | FOCA |
| CFM56-5B4/P | AIRBUS A320-214 | ECIAG | 2 | J067 | 2J | A320 | 3CM026 |
| V2527-A5 | AIRBUS A320-232 | ECIAZ | 2 | J220 | 2J | A320 | 1IA003 |
| BRBR700-710A2-20 | BOMBARDIER BD-700-1A10 GLOBAL EX-PRE | ECIBD | 2 | J854 | 2J | GLEX | 4BR009 |
| PT6A-60A | BEECH-CRAFT KING AIR 350 (RAYTHEON B | ECIBK | 2 | T738 | 2T | B350 | FOI |
| CF34-3B1 | BOMBARDIER CRJ200ER (CL-600-2B19) | ECIBM | 2 | J090 | 2J | CRJ2 | 1GE034 |
| CFM56-7B27B1 | BOEING 737-81Q (WINGLETS) | ECICD | 2 | J075 | 2J | B738 | 3CM034 |
| CFM56-5B4/P | AIRBUS A320-214 | ECICK | 2 | J067 | 2J | A320 | 3CM026 |

## Emissions (1A3a)

The output of the FOCA emission modelling consists of tables with the following structure:

Table A – 8 Extract of the output file of FOCA emission and fuel consumption modelling (example for 2004). Emissions and fuel consumption in tonnes.

| Airport | Distance | Type Traffic | Move-ments | Type | Aircraft ICAO | Engine Name | Fuel (LTO) tons | Emissions (LTO) in tons | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Km | | No. | | | | | $CO_2$ | $H_2O$ | $SO_2$ | $NO_x$ | VOC | CO |
| LSGG | 181501.69 | Taxi | 165 | 2B | C550 | JT15D-4 | 5673.492 | 17871.5 | 6978.395 | 5.673 | 26.04 | 139 | 359.2 |
| LSGG | 164165.197 | Taxi | 77 | 2J | B752 | RB211-535E4 | 47470.5 | 149532.1 | 58388.72 | 47.47 | 554.91 | 0 | 361.47 |
| LSGG | 133166.837 | Taxi | 118 | 2B | F2TH | CFE738-1-1B | 6164.2728 | 19417.46 | 7582.056 | 6.164 | 87.539 | 40.59 | 185.53 |
| LSGG | 117228.943 | Taxi | 99 | 3B | F900 | TFE731-60-1C | 5668.542 | 17855.91 | 6972.307 | 5.669 | 46.937 | 28.13 | 163.44 |
| LSGG | 114258.902 | Taxi | 134 | 2B | LJ45 | TFE731-20R | 4725.108 | 14884.09 | 5811.883 | 4.725 | 31.31 | 53.62 | 169.01 |
| LSGG | 112510.267 | Taxi | 100 | 2B | F2TH | CFE738-1-1B | 5223.96 | 16455.47 | 6425.471 | 5.224 | 74.186 | 34.4 | 157.23 |
| LSGG | 107945.477 | Taxi | 96 | 2B | C560 | JT15D-5D | 3795.3216 | 11955.26 | 4668.246 | 3.795 | 16.959 | 271.6 | 287.98 |
| LSGG | 181501.69 | Taxi | 165 | 2B | C550 | JT15D-4 | 307732.68 | 969357.9 | 378511.2 | 307.7 | 4513 | 29.43 | 274.71 |
| LSGG | 164165.197 | Taxi | 77 | 2J | B752 | RB211-535E4 | 673698.47 | 2122150 | 828649.1 | 673.7 | 7986.4 | 647.8 | 1038.2 |
| LSGG | 133166.837 | Taxi | 118 | 2B | F2TH | CFE738-1-1B | 225781.85 | 711212.8 | 277711.7 | 225.8 | 3311.2 | 21.59 | 201.55 |
| LSGG | 117228.943 | Taxi | 99 | 3B | F900 | TFE731-60-1C | 298139.18 | 939138.4 | 366711.2 | 298.1 | 4372.3 | 28.52 | 266.14 |
| LSGG | 114258.902 | Taxi | 134 | 2B | LJ45 | TFE731-20R | 193723.81 | 610230 | 238280.3 | 193.7 | 2841 | 18.53 | 172.93 |
| LSGG | 106761.289 | Taxi | 100 | 2B | F2TH | CFE738-1-1B | 181011.75 | 570187 | 222644.4 | 181 | 2654.6 | 17.31 | 161.58 |
| LSGG | 103217.159 | Taxi | 96 | 2B | C560 | JT15D-5D | 175002.74 | 551258.6 | 215253.4 | 175 | 2566.5 | 16.74 | 156.22 |

### A3.1.2 Road transportation

**Base emission factors (1A3b)**

The derivation of the emission factors for road transport is described in detail in INFRAS (2019a) and Matzer et al. (2019). The emission factors are contained in the “Handbook Emission Factors for Road Transport (HBEFA)” (version 4.1), which is available publicly as a database application (INFRAS 2019b). Some important features of the emission factor methodologies are summarised in the following paragraphs.

HBEFA differentiates emission factors by emission category, vehicle types and traffic situations.

The following **emission categories** are accounted for:

a) Hot emissions – the emissions caused by vehicles on the road with hot engines;

b) Cold start (excess) emissions – the excess emissions caused by vehicles after cold start when the engine is still cold (note that these emission can be negative in some cases, when the cold engine produces less emissions than in the hot state)

c) Evaporation emissions – evaporation of hydrocarbons (i.e. methane, NMVOC) from the fuel tank of gasoline vehicles. Three sub-processes are distinguished:

- Soak emissions: evaporation after stopping when the engine is still hot;
- Diurnal emissions: evaporation caused by the daily temperature variation;
- Running losses: evaporation during driving.

The hot emissions are generally the most relevant emission category; results show that for $CO_2$ the hot exhaust emissions contribute to about 98% of the total. Only 2% stem from cold start excess emissions. For $CH_4$, however, the picture is different. Hot exhaust emissions contribute about two thirds to the total, cold start emissions about one third. For $N_2O$, the cold start emission factors are based on the EMEP guidebook (EMEP/EEA 2019). According to these emission factors, the share of cold start emissions amounts to roughly 7% of total emissions in the year 2019.

Regarding **vehicle types**, HBEFA distinguishes six vehicle categories at the highest aggregation level (i.e. passenger cars, light commercial vehicles, urban buses, coaches, heavy goods vehicles and motorcycles). Each vehicle category is further differentiated by technology (in turn related to fuel type), emission standard, and (optionally) size class. The following table illustrates the segmentation of passenger cars. Similar “segmentations” hold for the other vehicle categories, too.

Table A – 9 Vehicle segmentation of passenger cars for different fuel types (according to HBEFA 4.1, INFRAS 2019b).

| Technology | Vehicle sub-segment |
|---|---|
| Gasoline | <ECE |
| | AGV82 (CH) |
| | ECE-15'00 |
| | ECE-15'01/02 |
| | ECE-15'03 |
| | PreEuro 3WCat <1987 |
| | PreEuro 3WCat 1987-90 |
| | Euro-1 |
| | Euro-2 |
| | Euro-3 |
| | Euro-4 |
| | Euro-5 |
| | Euro-6ab |
| | Euro-6c |
| | Euro-6d-temp |
| | Euro-6d |
| Diesel | conv |
| | 1986-1988 |
| | Euro-1 |
| | Euro-2 |
| | Euro-3 |
| | Euro-4 |
| | Euro-5 |
| | Euro-5 EA189 before software update |
| | Euro-5 EA189 after software update |
| | Euro-6ab |
| | Euro-6c |
| | Euro-6d-temp |
| | Euro-6d |

| Technology | Vehicle sub-segments |
|---|---|
| Bifuel CNG/Gasoline | Euro-2 |
| | Euro-3 |
| | Euro-4 |
| | Euro-5 |
| | Euro-6 |
| Bifuel LPG/Gasoline | Euro-2 |
| | Euro-3 |
| | Euro-4 |
| | Euro-5 |
| | Euro-6 |
| Flex-fuel E85 | Euro-3 |
| | Euro-4 |
| | Euro-5 |
| | Euro-6 |
| PHEV | Euro-4 |
| | Euro-5 |
| | Euro-6d |
| | Euro-6ab |
| Electricity | BEV |
| FuelCell | FuelCell |

**Traffic situations** are relevant for hot emissions. They are defined by a scheme (see table below) taking into account 4 parameters: area type (urban/rural areas), 10 road types, speed limits and 5 levels of service (i.e. traffic density classes). This leads to the definition of 365 different traffic situations in total. Each traffic situation implies a typical driving behaviour. The traffic situations have been defined based on driving behaviour studies in Germany and in Switzerland (see Ericsson et al. 2019, INFRAS 2015b).

Table A – 10 Traffic situation-scheme in HBEFA 4.1 (INFRAS 2019b). Every traffic situation is characterised by a typical driving pattern (i.e. a speed-time curve). Legend: Orange colour = urban, blue colour = rural, green colour = motorway.

| | | | Speed Limit [km/h] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area | Road type | Levels of service | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | >130 |
| Rural | Motorway-Nat. | 5 levels of service | | | | | | green | green | green | green | green | green | green |
| | Semi-Motorway | 5 levels of service | | | | | | | green | | green | | | |
| | TrunkRoad/Primary-Nat. | 5 levels of service | | | | orange | blue | blue | blue | blue | blue | | | |
| | Distributor/Secondary | 5 levels of service | | | orange | orange | blue | blue | blue | blue | | | | |
| | Distributor/Secondary(sinuous) | 5 levels of service | | | orange | orange | blue | blue | blue | blue | | | | |
| | Local/Collector | 5 levels of service | | | orange | orange | blue | blue | | | | | | |
| | Local/Collector(sinuous) | 5 levels of service | | | orange | orange | blue | blue | | | | | | |
| | Access-residential | 5 levels of service | orange | orange | orange | | | | | | | | | |
| Urban | Motorway-Nat. | 5 levels of service | | | | | | green | green | green | green | green | green | |
| | Motorway-City | 5 levels of service | | | | orange | orange | orange | orange | orange | orange | | | |
| | TrunkRoad/Primary-Nat. | 5 levels of service | | | | | orange | blue | blue | blue | blue | | | |
| | TrunkRoad/Primary-City | 5 levels of service | | | orange | orange | orange | blue | blue | | | | | |
| | Distributor/Secondary | 5 levels of service | orange | orange | orange | orange | orange | blue | | | | | | |
| | Local/Collector | 5 levels of service | orange | orange | orange | orange | | | | | | | | |
| | Access-residential | 5 levels of service | orange | orange | orange | | | | | | | | | |

Traffic situations are defined independently of vehicle categories (LDV, HDV, 2-wheelers). But for the same traffic situation, each vehicle category is assigned its own “driving pattern” which is expressed as a speed curve (i.e. speed time series).

(Hot) emission factors for these driving patterns are developed by first creating engine maps (i.e. emissions by torque and engine speed) based on measurements performed both on laboratory test benches and on the road using Portable Emission Measurement Systems (PEMS); the PHEM model (Passenger car and Heavy duty Emission model) is then used to simulate emissions for the HBEFA driving patterns by using the emission maps as input. This process is described in detail in Matzer et al. (2019).

For **cold start and evaporation emission factors**, not the driving pattern is determining but ambient conditions. These include climatic parameters (diurnal temperature and humidity profiles for all seasons) but also diurnal profiles of traffic volumes, trip length and parking time distributions. The methodology for the development of cold start emission factors is described in INFRAS (2004, 2019a). The methodology for the evaporation emission factors is adopted from EMEP/EEA guidebook (EMEP/EEA 2016); its implementation in HBEFA is described in INFRAS (2019a).

**Cold start excess emissions for $N_2O$** are estimated on the basis of the Tier 3 emission factors for cold-start and hot-start urban conditions published in Tables 3-56 ff. in the EMEP/EEA guidebook (EMEP/EEA 2019). Based on these emission factors, two $N_2O$ emission calculations are carried out for Switzerland – one hypothetical calculation assuming all starts are hot starts, and a second calculation using the actual cold start share in Switzerland. The difference between the two emission values are the cold start excess emissions. These are divided by the number of cold starts in order to obtain the cold start excess emission factors in g/start.

**Activity data (1A3b)**

Activity data for the emission model include (see also chp. 3.2.9.2.2.):

a) mileage (vehicle kilometres) for hot emissions and evaporation running losses.

b) the number of starts for cold start excess emissions.

c) the number of stops for evaporation soak emissions.

d) the number of vehicles for evaporation diurnal emissions.

Mileage must be differentiated by vehicle types and traffic situation in order to be able to link it to the hot emission factors differentiated by the same parameters. To do so, three steps must be carried out:

1. Vehicle turnover: The vehicle fleet is built up for each year accounting for stock changes. This vehicle turnover is modelled

a) for historical periods (ex-post) on the basis of vehicle stock and age distributions, and

b) for future periods on the basis of new registrations and by applying survival probabilities.

Trends in traffic volume per vehicle category and segment, including structural changes (size distributions, shares of diesel vehicles) are then combined to draw the continual substitution of older technologies by new ones constantly altering the fleet composition or mileage by emission concepts (Euro classes) in all vehicle categories, see also the following Figure A-1 (INFRAS 2017).

2. The total mileage is an input dataset by the Swiss Federal Statistical Office (SFSO 2021f/g).

3. Assignment of the traffic situations to the mileage for all vehicle categories: This step requires the use of a traffic model: Each road network link carries the information on modelled traffic volume and can be characterized with the parameters defining traffic situations (described above), which allows the assignment sought.

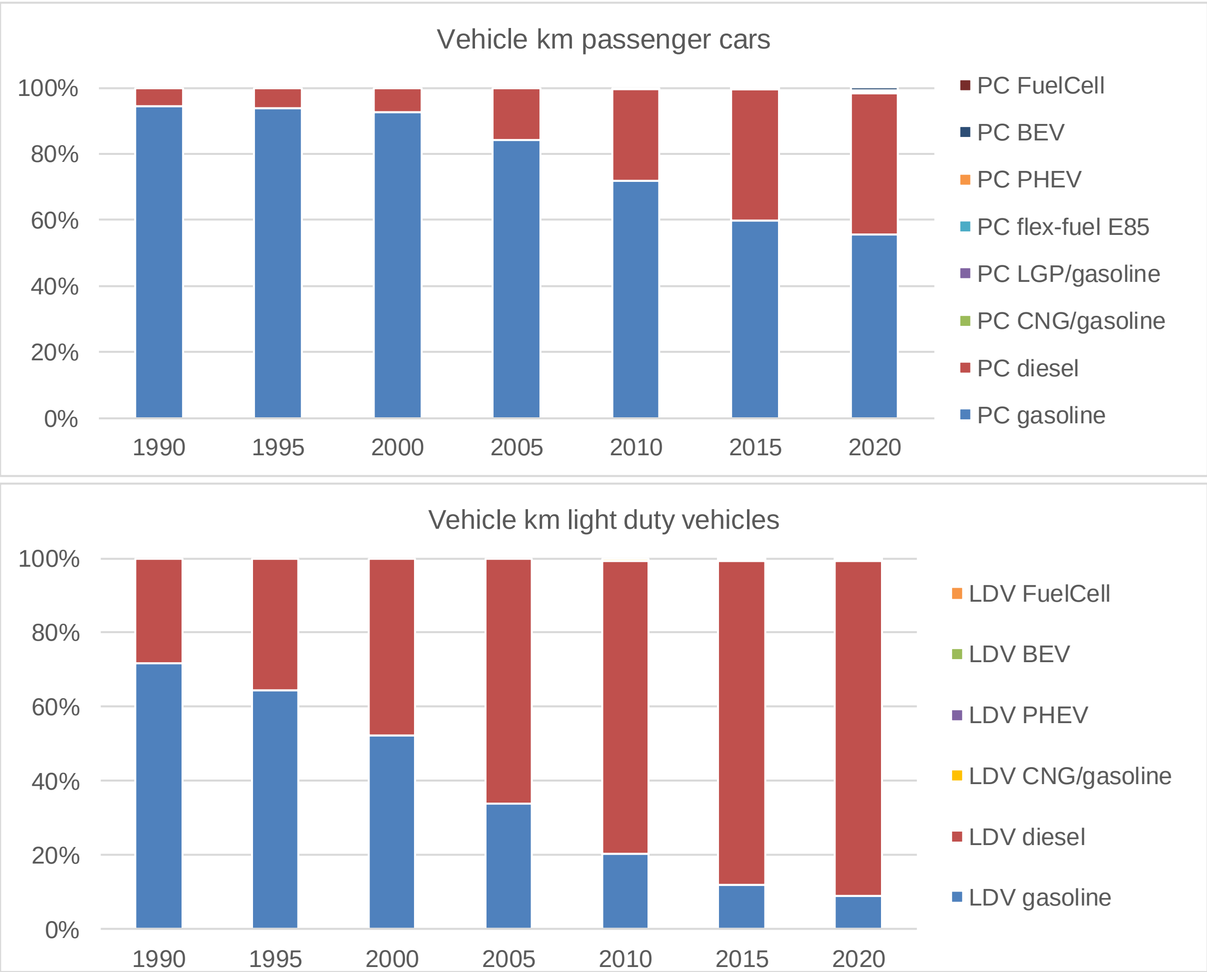



Figure A – 1 Vehicle kilometres per fleet composition for passenger cars (PC, above) and light duty vehicles (LDV, below). Data source: INFRAS (2019b).

**Aggregated emission factors (1A3b)**

From the base emission factors differentiated by vehicle type and traffic situations, aggregated emissions can be derived by using the activity data described above – i.e. taking into account the fleet composition, which varies from year to year, and the distribution of vehicle kilometres across traffic situations (temporally dynamic as well, derived from traffic models – see section on activity data below).

Average emission factors by vehicle and emission category for Switzerland are shown in the next table.

Table A – 11 Mean emission factors of passenger cars (PC), light duty vehicles (LDV), heavy duty vehicles (HDV), coaches, urban buses (Bus) and Motorcycles (MC) in grams per kilometre (from HBEFA 4.1). Cold start excess emissions are given in g/start.

| **Pollutant** | **Year** | **PC** | **LDV** | **HDV** | **Coach** | **Bus** | **MC** | **PC** | **LDV** |
|---|---|---|---|---|---|---|---|---|---|
| | | **Emission factors in** gram per vehicle kilometre | | | | | | **Cold starts in** gram per start | |
| $CH_4$ | 1990 | 0.031 | 0.054 | 0.035 | 0.025 | 0.058 | 0.183 | 0.675 | 0.725 |
| $CH_4$ | 1995 | 0.017 | 0.038 | 0.028 | 0.023 | 0.051 | 0.125 | 0.423 | 0.496 |
| $CH_4$ | 2000 | 0.012 | 0.026 | 0.018 | 0.020 | 0.039 | 0.152 | 0.282 | 0.288 |
| $CH_4$ | 2005 | 0.010 | 0.015 | 0.012 | 0.014 | 0.021 | 0.141 | 0.186 | 0.149 |
| $CH_4$ | 2010 | 0.006 | 0.007 | 0.005 | 0.008 | 0.015 | 0.127 | 0.124 | 0.074 |
| $CH_4$ | 2015 | 0.005 | 0.004 | 0.004 | 0.004 | 0.010 | 0.095 | 0.076 | 0.037 |
| $CH_4$ | 2020 | 0.006 | 0.005 | 0.001 | 0.002 | 0.006 | 0.078 | 0.052 | 0.023 |
| CO | 1990 | 6.9 | 24.2 | 3.8 | 3.0 | 6.5 | 12.2 | 41.2 | 60.8 |
| CO | 1995 | 3.0 | 17.9 | 3.3 | 2.8 | 6.1 | 12.5 | 29.4 | 46.9 |
| CO | 2000 | 1.6 | 12.2 | 2.4 | 2.5 | 4.9 | 12.2 | 22.0 | 31.3 |
| CO | 2005 | 1.1 | 6.6 | 2.0 | 2.1 | 3.3 | 10.9 | 15.7 | 17.5 |
| CO | 2010 | 0.8 | 3.1 | 1.9 | 2.1 | 1.7 | 9.0 | 10.6 | 9.1 |
| CO | 2015 | 0.5 | 1.3 | 1.4 | 1.6 | 1.2 | 5.9 | 6.8 | 4.9 |
| CO | 2020 | 0.4 | 0.7 | 0.7 | 0.9 | 0.6 | 3.6 | 5.3 | 3.4 |
| $CO_2$ (fossil) | 1990 | 233 | 299 | 835 | 932 | 1199 | 110 | 108 | 140 |
| $CO_2$ (fossil) | 1995 | 238 | 297 | 864 | 926 | 1226 | 122 | 102 | 134 |
| $CO_2$ (fossil) | 2000 | 242 | 293 | 861 | 906 | 1234 | 109 | 99 | 126 |
| $CO_2$ (fossil) | 2005 | 231 | 284 | 900 | 882 | 1235 | 117 | 101 | 115 |
| $CO_2$ (fossil) | 2010 | 219 | 273 | 875 | 848 | 1188 | 111 | 103 | 106 |
| $CO_2$ (fossil) | 2015 | 198 | 266 | 840 | 755 | 1138 | 116 | 90 | 99 |
| $CO_2$ (fossil) | 2020 | 178 | 244 | 793 | 693 | 1075 | 113 | 80 | 93 |
| VOC | 1990 | 0.86 | 1.57 | 1.48 | 1.03 | 2.41 | 3.01 | 7.16 | 6.84 |
| VOC | 1995 | 0.36 | 0.97 | 1.19 | 0.96 | 2.14 | 2.32 | 5.75 | 5.59 |
| VOC | 2000 | 0.17 | 0.48 | 0.77 | 0.83 | 1.61 | 2.40 | 4.69 | 4.14 |
| VOC | 2005 | 0.08 | 0.20 | 0.47 | 0.60 | 0.86 | 1.56 | 3.32 | 2.50 |
| VOC | 2010 | 0.04 | 0.07 | 0.20 | 0.32 | 0.26 | 1.06 | 2.27 | 1.34 |
| VOC | 2015 | 0.02 | 0.03 | 0.14 | 0.15 | 0.11 | 0.67 | 1.39 | 0.69 |
| VOC | 2020 | 0.01 | 0.02 | 0.05 | 0.07 | 0.05 | 0.00 | 0.98 | 0.43 |
| $N_2O$ | 1990 | 0.0095 | 0.0054 | 0.0088 | 0.0085 | 0.0120 | 0.0016 | 0.0171 | 0.0018 |
| $N_2O$ | 1995 | 0.0130 | 0.0073 | 0.0093 | 0.0084 | 0.0120 | 0.0018 | 0.0364 | 0.0182 |
| $N_2O$ | 2000 | 0.0114 | 0.0092 | 0.0096 | 0.0083 | 0.0112 | 0.0018 | 0.0413 | 0.0310 |
| $N_2O$ | 2005 | 0.0050 | 0.0075 | 0.0078 | 0.0069 | 0.0085 | 0.0019 | 0.0029 | 0.0360 |
| $N_2O$ | 2010 | 0.0033 | 0.0057 | 0.0295 | 0.0139 | 0.0172 | 0.0019 | 0.0100 | 0.0363 |
| $N_2O$ | 2015 | 0.0033 | 0.0058 | 0.0404 | 0.0250 | 0.0303 | 0.0019 | 0.0093 | 0.0238 |
| N2O | 2020 | 0.0042 | 0.0079 | 0.0451 | 0.0307 | 0.0382 | 0.0019 | 0.0067 | 0.0085 |
| NMVOC | 1990 | 0.82 | 1.52 | 1.44 | 1.01 | 2.35 | 2.83 | 6.48 | 6.11 |
| NMVOC | 1995 | 0.35 | 0.93 | 1.16 | 0.93 | 2.08 | 2.19 | 5.33 | 5.10 |
| NMVOC | 2000 | 0.15 | 0.46 | 0.75 | 0.81 | 1.57 | 2.24 | 4.40 | 3.86 |
| NMVOC | 2005 | 0.08 | 0.18 | 0.46 | 0.58 | 0.84 | 1.42 | 3.14 | 2.35 |
| NMVOC | 2010 | 0.03 | 0.07 | 0.19 | 0.32 | 0.25 | 0.93 | 2.15 | 1.27 |
| NMVOC | 2015 | 0.01 | 0.02 | 0.14 | 0.14 | 0.10 | 0.58 | 1.32 | 0.66 |
| NMVOC | 2020 | 0.01 | 0.01 | 0.05 | 0.07 | 0.04 | 0.39 | 0.93 | 0.41 |
| $NO_x$ | 1990 | 0.98 | 2.38 | 12.57 | 14.10 | 19.13 | 0.15 | 0.56 | 0.03 |
| $NO_x$ | 1995 | 0.58 | 1.90 | 11.90 | 13.22 | 18.56 | 0.20 | 1.20 | 0.53 |
| $NO_x$ | 2000 | 0.45 | 1.49 | 10.50 | 11.88 | 16.89 | 0.19 | 1.20 | 0.57 |
| $NO_x$ | 2005 | 0.42 | 1.36 | 8.77 | 9.89 | 13.81 | 0.21 | 0.75 | 0.24 |
| $NO_x$ | 2010 | 0.43 | 1.55 | 5.67 | 7.31 | 9.68 | 0.24 | 0.39 | 0.02 |
| $NO_x$ | 2015 | 0.45 | 1.54 | 3.39 | 4.49 | 6.53 | 0.20 | 0.29 | -0.06 |
| NOx | 2020 | 0.33 | 1.03 | 1.64 | 2.36 | 3.11 | 0.13 | 0.22 | 0.04 |
| $SO_2$ | 1990 | 0.039 | 0.107 | 0.742 | 0.828 | 1.066 | 0.014 | 0.018 | 0.043 |
| $SO_2$ | 1995 | 0.031 | 0.047 | 0.187 | 0.201 | 0.265 | 0.016 | 0.013 | 0.021 |
| $SO_2$ | 2000 | 0.022 | 0.038 | 0.149 | 0.157 | 0.213 | 0.010 | 0.009 | 0.016 |
| $SO_2$ | 2005 | 0.001 | 0.002 | 0.006 | 0.006 | 0.008 | 0.001 | 0.001 | 0.001 |
| $SO_2$ | 2010 | 0.001 | 0.002 | 0.006 | 0.005 | 0.007 | 0.001 | 0.001 | 0.001 |
| $SO_2$ | 2015 | 0.001 | 0.002 | 0.005 | 0.005 | 0.007 | 0.001 | 0.000 | 0.001 |
| $SO_3$ | 2020 | 0.001 | 0.002 | 0.005 | 0.005 | 0.007 | 0.001 | 0.000 | 0.001 |

**Modelling total emissions (1A3b)**

In order to calculate total emissions, the activity data is multiplied with the respective emission factors resulting in total emissions.

These results correspond to territorial emissions; they do not yet contain the emissions from fuel tourism and statistical differences. Emissions from fuel tourism and statistical differences are calculated by assigning the fuel consumption to categories 1A3bi, 1A3bii, and 1A3biii (as described in chp. 3.2.9.2.2), and using mean emission factors averaged over all vehicle categories.

### A3.1.3 Non-road vehicles and machinery: supplementary activity data

The following table shows some aggregated information on stock numbers and annual operation hours of non-road vehicles and machinery. Detailed information is available in the report FOEN (2015j) and most disaggregated information is available by query from the online non-road database INFRAS (2015a):
https://www.bafu.admin.ch/bafu/en/home/topics/air/state/non-road-datenbank.html

Table A – 12 Overview over stock and operating hours of non-road vehicles and machinery (FOEN 2015j): Upper table: Number of vehicles; middle table Specific operating hours per year; lower table: Total operating hours per year (in million hours)

| **Category** | **1980** | **1990** | **2000** | **2010** | **2020** | **2030** |
|---|---|---|---|---|---|---|
| | number of vehicles | | | | | |
| Construction machinery | 63'364 | 58'816 | 52'729 | 57'102 | 60'384 | 62'726 |
| Industrial machinery | 26'714 | 43'244 | 70'671 | 69'786 | 69'757 | 70'083 |
| Agricultural machinery | 292'773 | 324'567 | 337'869 | 318'876 | 309'825 | 305'235 |
| Forestry machinery | 11'815 | 13'844 | 13'055 | 11'857 | 10'831 | 10'170 |
| Garden-care / hobby appliances | 1'198'841 | 1'539'624 | 1'944'373 | 2'322'737 | 2'464'323 | 2'499'627 |
| Navigation machinery | 94'866 | 103'383 | 93'912 | 95'055 | 97'522 | 99'104 |
| Railway machinery | 529 | 1'300 | 1'255 | 697 | 640 | 640 |
| Military machinery | 13'092 | 13'373 | 14'272 | 13'083 | 12'853 | 12'856 |
| **Total** | **1'701'994** | **2'098'151** | **2'528'136** | **2'889'193** | **3'026'135** | **3'060'441** |

| **Category** | **1980** | **1990** | **2000** | **2010** | **2020** | **2030** |
|---|---|---|---|---|---|---|
| | Specific operating hours per year | | | | | |
| Construction machinery | 247 | 322 | 406 | 417 | 424 | 429 |
| Industrial machinery | 666 | 670 | 684 | 680 | 675 | 671 |
| Agricultural machinery | 136 | 119 | 112 | 103 | 99 | 95 |
| Forestry machinery | 203 | 199 | 203 | 193 | 188 | 182 |
| Garden-care / hobby appliances | 12 | 17 | 20 | 64 | 77 | 81 |
| Navigation machinery | 39 | 38 | 38 | 36 | 35 | 35 |
| Railway machinery | 877 | 613 | 617 | 783 | 719 | 719 |
| Military machinery | 64 | 64 | 63 | 73 | 74 | 74 |

| **Category** | **1980** | **1990** | **2000** | **2010** | **2020** | **2030** |
|---|---|---|---|---|---|---|
| | million operating hours per year | | | | | |
| Construction machinery | 16 | 19 | 21 | 24 | 26 | 27 |
| Industrial machinery | 18 | 29 | 48 | 48 | 47 | 47 |
| Agricultural machinery | 40 | 39 | 38 | 33 | 31 | 29 |
| Forestry machinery | 2.4 | 2.8 | 2.6 | 2.3 | 2.0 | 1.9 |
| Garden-care / hobby appliances | 15 | 26 | 39 | 150 | 191 | 201 |
| Navigation machinery | 3.7 | 3.9 | 3.5 | 3.4 | 3.4 | 3.4 |
| Railway machinery | 0.50 | 0.80 | 0.80 | 0.50 | 0.50 | 0.50 |
| Military machinery | 0.80 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 |
| **Total** | **95** | **121** | **155** | **261** | **301** | **311** |

### A3.1.4 Sulphur dioxide ($SO_2$)

Table A – 13 shows sulphur contents and $SO_2$ emission factors per fuel type. Explanations:

- For liquid and solid fuels the $SO_2$ emission factors are determined by the sulphur content. The upper table depicts the maximum values as defined in the Federal Ordinance on Air Pollution Control OAPC (Swiss Confederation 1985).
- The middle table contains the effective sulphur contents. They are based on measurements: Summary and annual reports of Avenergy Suisse (formerly Erdöl-Vereinigung EV), reports by the Federal Office for Customs and Border Security (FOCBS) since 2000, as well as their measurement project 'Schwerpunktaktion Brenn und Treibstoffe'. For diesel oil and gasoline, the measurement project 'Tankstellensurvey', arranged by the FOEN, is a central data source.
- The lower table shows the emission factors in kg/TJ. They are calculated from the effective sulphur content S, the net calorific value NCV and the quotient of the molar masses of S and $SO_2$.
- $EF_{SO_2} = \frac{M_{SO_2}}{M_S} * \frac{S}{NCV} = 2\frac{S}{NCV}$
- Gas oil: starting from 1990 and for each fifth subsequent year up to and including 2015 the values for the $SO_2$ emission factors are based on five-year averages (e.g. the value for 1995 is based on an average of the years 1993–1997). 1990 is the exception: for this year, the value is based on an average of the three years 1990–1992. The values for all other years are linear interpolations between the years 2015 and 2025 (value 2025: 2 g/GJ). Furthermore, 2006 saw the introduction to the market of low-sulphur eco-grade gas oil with a maximum legal sulphur limit of 50 ppm. From this year onwards, FOCBS measurements include both standard Euro- and eco-grade gas oil. For each year, the two grades are weighted by the respective total annual fuel consumption. Additionally, since 2018, heating gas is also classified as gas oil.
- (Bituminous) coal: The legal limit of sulphur content depends on the size of the heat capacity of the combustion system. The value of 1% sulphur content (350 kg $SO_2$/TJ; see Table A – 13) holds for heat capacity below 1 MW (see OAPC Annex 3, §513 (Swiss Confederation 1985)). For larger capacities, the value is 3% (OAPC Annex 5, §2, Swiss Confederation 1985). For industrial combustion plants, the limit for the exhaust emissions actually sets the corresponding maximum sulphur content to 1.4% (500 kg $SO_2$/TJ).
- Residual fuel oil: OAPC Annex 5, §11, lit.2 sets 2.8% for the legal limit (denoted as class B in the upper table). Simultaneously, OAPC dispenses from emission control measurements if residual fuel oil of class A is used with sulphur content of maximum 1% (see OAPC Annex 3, §421, lit.2, Swiss Confederation 1985), which holds for most combustion plants. The emission factors are based on five-year averages in the case of 1995, 2000 and 2015. 1990 is based on an average of the years 1990–1992 because no non-interpolated data is available for 1988 and 1989. Similarly, because the emission factors of the years 2006–2008 are not available, the average of 2005 is based on the years 2003–2005 and that of 2010 on 2009–2012. The values for all other years are linear interpolations between the years 2015 and 2035 (value 2035: 500 g/GJ).
- Natural gas: OAPC Annex 5, §42 sets 190 ppm as the legal limit for natural gas.

Table A – 13 Sulphur content (legal limits and effective) and $SO_2$ emission factors. Legal limits that did not change in a specific year are printed in grey colour.

| Year | Maximum legal limit of sulphur content | | | | | | |
|---|---|---|---|---|---|---|---|
| | Diesel oil ppm | Gasoline ppm | Gas oil (Euro) ppm | Natural gas ppm | Res. fuel oil Class A, % | Res. fuel oil Class B, % | Coal % |
| 1990 | 1400 | 200 | 2000 | 190 | 1.0 | 2.8 | 1-3 |
| 1991 | 1300 | 200 | 2000 | 190 | 1.0 | 2.8 | 1-3 |
| 1992 | 1200 | 200 | 2000 | 190 | 1.0 | 2.8 | 1-3 |
| 1993 | 1000 | 200 | 2000 | 190 | 1.0 | 2.8 | 1-3 |
| 1994 | 500 | 200 | 2000 | 190 | 1.0 | 2.8 | 1-3 |
| 2000 | 350 | 150 | 2000 | 190 | 1.0 | 2.8 | 1-3 |
| 2005 | 50 | 50 | 2000 | 190 | 1.0 | 2.8 | 1-3 |
| 2008 | 50 | 50 | 1000 | 190 | 1.0 | 2.8 | 1-3 |
| 2009 | 10 | 50 | 1000 | 190 | 1.0 | 2.8 | 1-3 |
| 2010-2020 | 10 | 10 | 1000 | 190 | 1.0 | 2.8 | 1-3 |

| Year | Effective sulphur content | | | | |
|---|---|---|---|---|---|
| | Diesel oil ppm | Gasoline ppm | Gas oil (Euro) ppm | Gas oil (Oeko) ppm | Res. fuel oil % |
| 1990 | 1400 | 200 | 1600 | NO | 0.97 |
| 1991 | 1300 | 200 | 1300 | NO | 0.89 |
| 1992 | 1200 | 200 | 1200 | NO | 0.86 |
| 1993 | 1000 | 200 | 1000 | NO | 0.87 |
| 1994 | 434 | 200 | 1350 | NO | 0.77 |
| 1995 | 341 | 200 | 1170 | NO | 0.78 |
| 1996 | 372 | 200 | 1160 | NO | 0.78 |
| 1997 | 353 | 200 | 1250 | NO | 0.70 |
| 1998 | 402 | 200 | 926 | NO | 0.83 |
| 1999 | 443 | 200 | 650 | NO | 0.62 |
| 2000 | 272 | 142 | 680 | NO | 0.66 |
| 2001 | 250 | 121 | 830 | NO | 0.82 |
| 2002 | 235 | 101 | 798 | NO | 0.82 |
| 2003 | 200 | 81 | 700 | NO | 0.79 |
| 2004 | 10 | 8.0 | 700 | NO | 0.76 |
| 2005 | 10 | 8.0 | 800 | NO | 0.78 |
| 2006 | 10 | 8.0 | 740 | NO | 0.74 |
| 2007 | 10 | 8.0 | 680 | NO | 0.71 |
| 2008 | 10 | 8.0 | 620 | NO | 0.67 |
| 2009 | 7.6 | 5.3 | 549 | NO | 0.92 |
| 2010 | 6.7 | 4.7 | 519 | NO | 0.88 |
| 2011 | 6.6 | 5.0 | 417 | NO | 0.90 |
| 2012 | 7.0 | 5.3 | 503 | NO | 0.91 |
| 2013 | 7.1 | 4.8 | 224 | NO | 0.90 |
| 2014 | 6.8 | 4.8 | 516 | 14 | 1.11 |
| 2015 | 7.7 | 4.5 | 516 | 14 | 1.93 |
| 2016 | 7.0 | 4.6 | 246 | 10 | 1.92 |
| 2017 | 7.7 | 5.2 | 248 | 19 | 0.98 |
| 2018 | 7.2 | 4.4 | 486 | 5 | 0.91 |
| 2019 | No measurements in the year 2019 | | | | |
| 2020 | 6.2 | Not measured | 319 | 18 | 0.55 |

| Year | $SO_2$ emission factor used for Switzerland's emission inventory | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Diesel oil (average in 1A3b) | Gasoline (average in 1A3b) | Gas oil (boilers and engines in 1A1a, 1A2, 1A4) * | Natural gas (boilers and engines in 1A1, 1A2, 1A4, 1A3e) | Natural gas (for 1A3b only) | Res. fuel oil (boilers in 1A1a, 1A2) * | Lignite (boilers in 1A2g) | Bituminous coal (boilers in 1A4b) | Kerosene (average) |
| | kg/TJ | | | | | | | | |
| 1990 | 65 | 9.4 | 64 | | | 440 | | | 23.2 |
| 1991 | 61 | 9.4 | *62* | | | *428* | | | 23.2 |
| 1992 | 56 | 9.4 | *61* | | | *416* | | | 23.2 |
| 1993 | 47 | 9.4 | *59* | | | *404* | | | 23.3 |
| 1994 | 20 | 9.4 | *58* | | | *392* | | | 23.3 |
| 1995 | 16 | 9.4 | 56 | | | 380 | | | 23.3 |
| 1996 | 17 | 9.4 | *52* | | | *376* | | | 23.3 |
| 1997 | 16 | 9.4 | *48* | | | *372* | NO | | 23.3 |
| 1998 | 19 | 9.4 | *45* | | | *368* | | | 23.2 |
| 1999 | 21 | 9.4 | *41* | | | *364* | | | 23.2 |
| 2000 | 13 | 6.7 | 37 | | | 360 | | | 23.2 |
| 2001 | 12 | 5.7 | *36* | | | *364* | | | 23.2 |
| 2002 | 11 | 4.8 | *35* | | | *368* | | | 23.2 |
| 2003 | 9.3 | 3.8 | *35* | | | *372* | | | 23.2 |
| 2004 | 0.47 | 0.38 | *34* | | | *376* | | | 23.2 |
| 2005 | 0.47 | 0.38 | 33 | 0.5 | NE | 380 | | 350 | 23.2 |
| 2006 | 0.47 | 0.38 | *31* | | | *392* | | | 23.1 |
| 2007 | 0.47 | 0.38 | *30* | | | *404* | | | 23.2 |
| 2008 | 0.47 | 0.38 | *28* | | | *416* | | | 23.2 |
| 2009 | 0.47 | 0.38 | *27* | | | *428* | | | 23.2 |
| 2010 | 0.47 | 0.38 | 25 | | | 440 | | | 23.2 |
| 2011 | 0.47 | 0.38 | *22* | | | *480* | | | 23.2 |
| 2012 | 0.47 | 0.38 | *19* | | | *520* | 500 | | 23.2 |
| 2013 | 0.47 | 0.38 | *17* | | | *560* | | | 23.1 |
| 2014 | 0.47 | 0.38 | *14* | | | *600* | | | 23.1 |
| 2015 | 0.47 | 0.38 | 11 | | | 640 | | | 23.1 |
| 2016 | 0.47 | 0.38 | *10* | | | *633* | | | 23.1 |
| 2017 | 0.47 | 0.38 | *9.2* | | | *626* | | | 23.1 |
| 2018 | 0.47 | 0.38 | *8.3* | | | *619* | | | 23.2 |
| 2019 | 0.47 | 0.38 | *7.4* | | | *612* | | | 23.2 |
| 2020 | 0.47 | 0.38 | *6.5* | | | *605* | | | 23.1 |

** blue cells = interpolation*

## A3.2 Industrial processes and product use (illustrative example of mobile air conditioning)

The use of HFCs as substitutes of ODSs in 2F1 refrigeration and air conditioning is the main factor for the increase of HFC emissions from 1990 to 2015. Refrigerants contained in installed equipment lead to a considerable stock with annual losses of between 0.5% to 20% depending on the equipment type (see Table 4-47). Emissions are calculated for the production, operation, service and disposal of equipment. The following illustrative example shows the calculations for the example of mobile air conditioning (HFC-134a use as refrigerant). The example is calculated bottom-up, based on vehicle statistics and information on air conditioning equipment. There is no production of air conditioning equipment for cars in Switzerland, equipment is imported already charged.

Table A – 14 Applied model parameters and assumption for mobile air conditioning of cars.

| **Characteristic values** | | | |
|---|---|---|---|
| Initial charge in kg HFC per unit AC | 1994 | 0.81 | kg |
| | 2002 | 0.70 | kg |
| | 2014 | 0.55 | kg |
| | Extrapolation of other years | | |
| Lifetime | | 15 | years |
| **Production** | | | |
| Import of precharged equipment | | 100 | % |
| **Operation** | | | |
| Annual losses | | 8.5 | % |
| Recharge of losses (7.2% of 8.5%) | | 85 | % |
| Additional service losses over lifetime | | 10 | % |
| Disposal | | | |
| Export rate | | 31-72 | % |
| Share with total loss of refrigerant | | 40 | % |
| Disposal loss of professional recovery | | 15 | % |

Since 1991 HFC-134a has been used to replace ODS in the mobile air conditioning sector leading to a considerable stock of about 1’860 t of HFC-134a in registered cars at present (peak value of stock 2’418 t of HFC-134a in 2014). A phase-out of HFC-134a and replacement with HFO-1234yf is under way, due to regulations in the European Union and their implementation in Switzerland. AC-refrigerants exceeding a GWP of 150 are not allowed for new car models since 2011. Since 2017, no new cars with AC-refrigerant exceeding a GWP of 150 are allowed. Due to safety concerns with alternative use of HFO-1234yf (GWP 4), there has been a delay in the replacement of HFC-134a.

Interviews were carried out 2014, 2017 and 2018 with garages in Switzerland to follow the development of HFC-134a replacement. The first interviews held in 2014 showed that only few of the imported brands switched to HFO-1234yf (GWP 4). In 2014, garages confirmed a minor portion below 5% of equipment with HFO-1234yf. In 2017 feedback of garages on the sold vehicles of the former year varied widely depending on the models sold and origin of cars. In interviews carried out in 2018, garages confirmed complete phase-out of HFC-134a in new vehicles sold in 2017 (excluding sold vehicles from former years in stock and second-hand vehicles). Most of them switched to HFO-1234yf, few models apply $CO_2$ (R744). A complete replacement of HFC-134a was assumed for all new vehicles models sold in 2020.

Table A – 15 Bottom-up calculations to identify the number of air conditioning equipment and amount of HFC-134a

| Year | New registered vehicles | Vehicles in use | Disposed vehicles | New equipment: number of air conditioning units with HFC-134a in new registered cars | | | Equipment stock: Number of air conditioning units with HFC-134a in use | | Equipment disposal | Initial equipment charge |
|---|---|---|---|---|---|---|---|---|---|---|
| | Statistics | Statistics | Calculated | Portion of vehicles with AC [%] | HFC-134a as refrigerant [%] | AC units with HFC-134 [units] | Portion of vehicles with HFC-134a [%] | AC units with HFC-134 [units] | Units AC with HFC-134a [units] | Filled in amount [kg HFC/ unit] |
| 1989 | 335'094 | 2'895'842 | | 5 | 0 | 0 | 0 | 0 | 0 | 0.85 |
| 1990 | 327'456 | 2'985'399 | 237'899 | 6 | 0 | 0 | 0 | 0 | 0 | 0.84 |
| 1991 | 314'824 | 3'057'800 | 242'423 | 7 | 10 | 2'204 | 0 | 2'204 | 0 | 0.83 |
| 1992 | 296'009 | 3'091'230 | 262'579 | 9 | 30 | 7'992 | 0 | 10'196 | 0 | 0.83 |
| 1993 | 262'814 | 3'109'524 | 244'520 | 14 | 66 | 24'284 | 1 | 34'480 | 0 | 0.82 |
| 1994 | 270'009 | 3'165'043 | 214'490 | 19 | 90 | 46'172 | 3 | 80'652 | 0 | 0.81 |
| 1995 | 272'897 | 3'229'169 | 208'771 | 24 | 100 | 65'495 | 5 | 146'147 | 0 | 0.78 |
| 1996 | 269'529 | 3'268'073 | 230'625 | 38 | 100 | 102'421 | 8 | 248'568 | 0 | 0.77 |
| 1997 | 272'441 | 3'323'421 | 217'093 | 52 | 100 | 141'669 | 12 | 390'237 | 0 | 0.76 |
| 1998 | 297'336 | 3'383'275 | 237'482 | 68 | 100 | 202'188 | 18 | 592'426 | 0 | 0.75 |
| 1999 | 317'985 | 3'467'275 | 233'985 | 75 | 100 | 238'489 | 24 | 830'914 | 0 | 0.73 |
| 2000 | 315'398 | 3'545'247 | 237'426 | 77 | 100 | 242'856 | 30 | 1'073'771 | 0 | 0.72 |
| 2001 | 317'126 | 3'629'713 | 232'660 | 85 | 100 | 269'557 | 37 | 1'343'328 | 0 | 0.71 |
| 2002 | 295'109 | 3'704'822 | 220'000 | 87 | 100 | 256'745 | 43 | 1'600'073 | 0 | 0.70 |
| 2003 | 271'541 | 3'754'000 | 222'363 | 89 | 100 | 241'671 | 49 | 1'841'744 | 0 | 0.69 |
| 2004 | 269'211 | 3'811'351 | 211'860 | 91 | 100 | 244'982 | 55 | 2'086'726 | 0 | 0.68 |
| 2005 | 259'426 | 3'863'807 | 206'970 | 92 | 100 | 238'672 | 60 | 2'325'398 | 0 | 0.66 |
| 2006 | 269'421 | 3'899'917 | 233'311 | 96 | 100 | 258'644 | 66 | 2'581'839 | 2'204 | 0.65 |
| 2007 | 284'674 | 3'955'787 | 228'804 | 96 | 100 | 273'287 | 72 | 2'847'133 | 7'992 | 0.64 |
| 2008 | 288'525 | 4'030'965 | 213'347 | 96 | 100 | 276'984 | 77 | 3'099'833 | 24'284 | 0.63 |
| 2009 | 266'018 | 4'051'569 | 245'414 | 96 | 100 | 255'377 | 82 | 3'309'039 | 46'172 | 0.61 |
| 2010 | 294'239 | 4'119'370 | 226'438 | 96 | 100 | 282'469 | 86 | 3'526'013 | 65'495 | 0.60 |
| 2011 | 327'896 | 4'209'300 | 237'966 | 96 | 100 | 314'780 | 90 | 3'738'372 | 102'421 | 0.59 |
| 2012 | 328'139 | 4'254'725 | 282'714 | 96 | 100 | 315'013 | 92 | 3'911'717 | 141'669 | 0.58 |
| 2013 | 310'154 | 4'320'885 | 243'994 | 96 | 92 | 273'928 | 92 | 3'983'456 | 202'188 | 0.56 |
| 2014 | 304'083 | 4'384'490 | 240'478 | 96 | 85 | 248'132 | 91 | 3'993'099 | 238'489 | 0.55 |
| 2015 | 327'143 | 4'458'069 | 253'564 | 96 | 77 | 241'510 | 90 | 3'991'753 | 242'856 | 0.55 |
| 2016 | 319'331 | 4'524'029 | 253'371 | 96 | 69 | 211'525 | 87 | 3'933'720 | 269'557 | 0.55 |
| 2017 | 315'032 | 4'570'823 | 268'238 | 96 | 30 | 90'729 | 82 | 3'767'705 | 256'745 | 0.55 |
| 2018 | 300'887 | 4'602'688 | 271'541 | 97 | 10 | 29'186 | 77 | 3'555'219 | 241'671 | 0.55 |
| 2019 | 305'701 | 4'623'952 | 284'437 | 97 | 6 | 17'792 | 72 | 3'328'029 | 244'982 | 0.55 |
| 2020 | 268'664 | 4'658'335 | 259'426 | 97 | 0 | 0 | 66 | 3'089'357 | 238'672 | 0.55 |

Table A – 16 Results and structure of emission calculations of HFC-134a from mobile air conditioning of cars for 1990 to 2020.

| HFC-134a | Activity | | | Emissions | | | | Recharge | Disposal |
|---|---|---|---|---|---|---|---|---|---|
| | Input with vehicles | Stock | Retiring vehicles (incl. Export) | Production | Stock incl. Recharge | Disposal | Total | import in bulk | recovered for disposal |
| | [t] | [t] | [t] | [t] | [t] | [t] | [t] | [t] | [t] |
| 1990 | 0 | 0 | 0 | NO | 0 | 0 | 0 | 0 | 0 |
| 1991 | 2 | 2 | 0 | NO | 0 | 0 | 0 | 0 | 0 |
| 1992 | 7 | 8 | 0 | NO | 1 | 0 | 1 | 0 | 0 |
| 1993 | 20 | 28 | 0 | NO | 3 | 0 | 3 | 1 | 0 |
| 1994 | 37 | 65 | 0 | NO | 6 | 0 | 6 | 2 | 0 |
| 1995 | 51 | 115 | 0 | NO | 11 | 0 | 11 | 5 | 0 |
| 1996 | 79 | 193 | 0 | NO | 18 | 0 | 18 | 9 | 0 |
| 1997 | 107 | 297 | 0 | NO | 27 | 0 | 27 | 15 | 0 |
| 1998 | 151 | 444 | 0 | NO | 41 | 0 | 41 | 23 | 0 |
| 1999 | 175 | 612 | 0 | NO | 56 | 0 | 56 | 35 | 0 |
| 2000 | 175 | 779 | 0 | NO | 71 | 0 | 71 | 48 | 0 |
| 2001 | 191 | 960 | 0 | NO | 88 | 0 | 88 | 61 | 0 |
| 2002 | 180 | 1'126 | 0 | NO | 103 | 0 | 103 | 75 | 0 |
| 2003 | 166 | 1'277 | 0 | NO | 117 | 0 | 117 | 88 | 0 |
| 2004 | 165 | 1'425 | 0 | NO | 131 | 0 | 131 | 100 | 0 |
| 2005 | 158 | 1'563 | 0 | NO | 143 | 0 | 143 | 111 | 0 |
| 2006 | 168 | 1'709 | 1 | NO | 157 | 0 | 157 | 122 | 1 |
| 2007 | 174 | 1'856 | 4 | NO | 170 | 1 | 171 | 133 | 2 |
| 2008 | 173 | 1'992 | 12 | NO | 183 | 3 | 186 | 145 | 6 |
| 2009 | 156 | 2'096 | 25 | NO | 192 | 8 | 200 | 155 | 13 |
| 2010 | 169 | 2'206 | 31 | NO | 202 | 9 | 211 | 163 | 16 |
| 2011 | 185 | 2'311 | 50 | NO | 212 | 14 | 226 | 172 | 26 |
| 2012 | 181 | 2'379 | 81 | NO | 218 | 18 | 236 | 180 | 41 |
| 2013 | 155 | 2'412 | 90 | NO | 221 | 24 | 245 | 185 | 46 |
| 2014 | 136 | 2'418 | 96 | NO | 222 | 26 | 248 | 188 | 49 |
| 2015 | 133 | 2'416 | 102 | NO | 221 | 26 | 248 | 188 | 52 |
| 2016 | 117 | 2'388 | 111 | NO | 219 | 28 | 247 | 188 | 57 |
| 2017 | 50 | 2'287 | 118 | NO | 210 | 31 | 240 | 186 | 60 |
| 2018 | 16 | 2'152 | 119 | NO | 197 | 32 | 228 | 178 | 61 |
| 2019 | 10 | 2'003 | 130 | NO | 184 | 29 | 216 | 168 | 66 |
| 2020 | 0 | 1'860 | 115 | NO | 171 | 29 | 200 | 156 | 59 |

# A3.3 Agriculture

## A3.3.1 Additional data for estimating $CH_4$ emission from 3A Enteric fermentation

Table A – 17 Data for estimating enteric fermentation emission factors for cattle (Table according to outline in IPCC 1997c, p 4.31–4.33).

| Type | Age [a] | Weight [a] kg | Weight Gain [a] $kg*day^{-1}$ | Feeding Situation / Further Specification [a] | Milk [b] $kg*day^{-1}$ | Work $hrs*day^{-1}$ | Pregnant [a] % | Digestibility of Feed % [d] | $Y_m$ [d] % | Em. Factor $kg*head^{-1}*year^{-1}$ [e] |
|---|---|---|---|---|---|---|---|---|---|---|
| Mature Dairy Cattle | NA | 650 | 0 | | 15.8-23.4 [c] | 0 | 305 days of lactation | 72 | 6.90 | 115.5 - 139.8 |
| Other Mature Cattle | NA | 650 | 0 | | 8.2 | 0 | | 60 | 6.50 | 106.8 |
| Fattening Calves | 0-98 days | 124 | 1.43 | Rations of unskimmed milk and supplementary milk feed when life weight exceeds 100 kg. Rations are apportioned on two servings per day. | 0 | 0 | 0 | 65 | 0.00 | 0.0 |
| Pre-Weaned Calves | 0-300 days | 195 | 0.88 | "Natura beef" production, milk from mother cow and additional feed. | 0 | 0 | 0 | 65 | 4.13 | 16.3 |
| Breeding Calves | 0-105 days | 85 | 0.67 | Feeding plan for a dismission with 14 to 15 weeks. Milk, feed concentrate (100kg in total), hay (80 kg in total). | 0 | 0 | 0 | 65 | 4.12 | 30.0 |
| Breeding Cattle (4-12 months) | 4-12 month | 210 | 0.80 | Premature race (Milk-race) | 0 | 0 | 0 | 60 | 6.50 | |
| Breeding Cattle (> 1 year) | 12-28/30 month | 450 | 0.80 | Premature race (Milk-race) | 0 | 0 | 0 | 60 | 6.50 | 61.2 |
| Fattening Calves (0-4 months) | 0-132 days | 115 | 0.83 | Diet based on milk or milk-powder and feed concentrate, hay and/or silage | 0 | 0 | 0 | 65 | 5.72 | 43.2 |
| Fattening Cattle (4-12 months) | 4-12 month | 361 | 1.37 | Feeding recommendations for fattening steers, concentrate based | 0 | 0 | 0 | 60 | 6.50 | |

[a] Data source: RAP 1999 and calculations according to Soliva 2006.

[b] Milk production in kg/day is calculated by dividing the average annual milk production per head by 305 days (lactation period).

[c] data source: Swiss farmers union (MISTA 2015).

[d] data source: IPCC 2006 and Zeitz et al. 2012.

[e] For better comparability emission factors of young cattle were converted to $kg*head^{-1}*year^{-1}$ although the time span of most of the individual categories is less than 365 days.

# Table A – 18 Gross energy intake of Swiss livestock.

| Gross Energy Intake | | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MJ/head/day | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cattle | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Mature Dairy Cattle | | 255.2 | 258.5 | 259.7 | 262.9 | 261.5 | 265.0 | 264.9 | 268.7 | 273.1 | 276.5 | 279.2 | 280.0 | 282.0 | 284.9 | 290.8 | 294.1 | 294.1 | 296.7 | 299.9 | 301.4 | 302.4 | 303.6 | 304.5 | 302.1 | 304.3 | 305.9 | 306.6 | 305.9 | 307.9 | 307.5 | 309.0 |
| Other Mature Cattle | | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 |
| Growing Cattle (weighted average) | | 103.3 | 103.4 | 103.6 | 103.3 | 103.7 | 103.9 | 103.6 | 104.1 | 103.1 | 101.4 | 103.6 | 102.5 | 102.3 | 102.0 | 101.6 | 101.0 | 101.1 | 100.9 | 101.0 | 100.3 | 99.8 | 99.9 | 100.2 | 100.1 | 99.9 | 99.7 | 99.2 | 99.0 | 98.6 | 98.4 | 98.0 |
| | *Fattening Calves* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* |
| | *Pre-Weaned Calves* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* |
| | *Breeding Calves* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* |
| | *Breeding Cattle (4-12 months)* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* | *90.1* |
| | *Breeding Cattle (> 1 year)* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* |
| | *Fattening Calves (0-4 months)* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* | *56.9* |
| | *Fattening Cattle (4-12 months)* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* | *126.3* |
| Sheep | | 21.2 | 21.7 | 22.2 | 22.4 | 23.8 | 24.0 | 22.0 | 22.1 | 21.5 | 22.9 | 22.4 | 22.9 | 22.8 | 22.7 | 23.3 | 22.8 | 22.6 | 22.2 | 22.0 | 22.7 | 22.6 | 22.6 | 22.5 | 22.4 | 22.6 | 22.5 | 22.9 | 23.0 | 23.3 | 23.4 | 24.0 |
| Swine | | 25.7 | 26.2 | 26.2 | 26.0 | 25.1 | 26.5 | 26.6 | 27.4 | 25.9 | 25.4 | 25.1 | 24.6 | 24.4 | 24.4 | 24.8 | 24.5 | 23.9 | 24.2 | 24.6 | 24.9 | 24.7 | 24.6 | 24.4 | 25.1 | 25.1 | 25.4 | 25.8 | 25.5 | 25.2 | 26.4 | 25.6 |
| Buffalo (weighted average) | | NA | NA | 134.7 | 138.2 | 137.5 | 136.6 | 137.0 | 136.5 | 137.0 | 130.6 | 146.9 | 137.5 | 140.8 | 137.2 | 140.0 | 140.6 | 138.9 | 130.4 | 129.1 | 134.8 | 136.9 | 139.8 | 135.9 | 136.0 | 134.6 | 134.5 | 134.4 | 133.1 | 162.8 | 159.8 | 159.1 |
| | *Bisons < 3 years* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* | *91.0* |
| | *Bisons > 3 years* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* | *197.1* |
| Camels (weighted average) | | NA | NA | NA | NA | NA | NA | 37.9 | 37.9 | 37.9 | 34.6 | 34.8 | 32.2 | 33.0 | 34.0 | 32.8 | 31.7 | 31.7 | 31.7 | 31.6 | 31.5 | 31.0 | 31.4 | 31.6 | 31.9 | 31.8 | 31.6 | 31.2 | 31.2 | 31.0 | 31.2 | 31.4 |
| | *Llamas < 2 years* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* | *24.8* |
| | *Llamas > 2 years* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* | *43.0* |
| | *Alpacas < 2 years* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* | *15.2* |
| | *Alpacas > 2 years* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* | *27.8* |
| Deer (weighted average) | | 50.5 | 51.6 | 53.6 | 54.5 | 55.0 | 55.3 | 59.7 | 55.4 | 54.8 | 55.5 | 56.4 | 55.8 | 56.7 | 55.2 | 55.6 | 55.4 | 55.8 | 55.9 | 56.5 | 56.8 | 56.5 | 56.7 | 57.0 | 58.1 | 58.0 | 58.0 | 58.5 | 58.8 | 59.3 | 59.6 | 59.6 |
| | *Fallow Deer* [1] | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* | *50.5* |
| | *Red Deer* [1] | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* | *101.1* |
| Goats | | 25.0 | 24.6 | 25.0 | 25.4 | 25.5 | 27.9 | 25.3 | 25.6 | 26.9 | 25.8 | 25.7 | 26.0 | 25.2 | 25.4 | 25.2 | 25.4 | 25.3 | 25.0 | 25.0 | 25.3 | 25.1 | 25.6 | 25.6 | 25.6 | 25.0 | 25.5 | 25.1 | 25.2 | 25.1 | 25.5 | 26.4 |
| Horses (weighted average) | | 107.3 | 107.3 | 107.3 | 107.3 | 107.1 | 106.9 | 107.1 | 107.3 | 107.3 | 107.2 | 107.4 | 107.5 | 107.6 | 107.6 | 107.6 | 107.7 | 107.7 | 107.7 | 107.7 | 107.8 | 107.9 | 107.9 | 107.9 | 108.0 | 108.1 | 108.3 | 108.4 | 108.4 | 108.5 | 108.5 | 108.5 |
| | *Horses <3 years* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* |
| | *Horses >3 years* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* |
| Mules and Asses (weighted average) | | 39.2 | 39.2 | 39.2 | 39.2 | 39.5 | 39.7 | 39.7 | 39.8 | 39.6 | 39.8 | 39.5 | 39.6 | 39.6 | 39.6 | 39.5 | 39.4 | 39.5 | 39.3 | 39.2 | 40.0 | 40.2 | 39.9 | 39.9 | 39.6 | 39.6 | 39.6 | 39.6 | 39.5 | 38.4 | 38.4 | 38.4 |
| | *Mules* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* |
| | *Asses* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* |
| Poultry [2] | | 1.2 | 1.2 | 1.2 | 1.2 | 1.3 | 1.2 | 1.4 | 1.4 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.1 | 1.0 | 1.1 | 1.1 | 1.0 | 1.0 |
| Rabbits | | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Livestock NCAC (weighted average) | | 90.2 | 89.4 | 88.9 | 87.2 | 91.0 | 72.0 | 36.5 | 32.6 | 32.2 | 32.7 | 32.9 | 32.6 | 34.0 | 34.2 | 34.6 | 34.3 | 34.5 | 35.4 | 35.3 | 36.2 | 37.8 | 37.8 | 37.8 | 39.0 | 38.7 | 39.3 | 40.3 | 40.4 | 36.9 | 37.6 | 38.3 |
| | *Sheep Non-Agr.* | *21.2* | *21.7* | *22.2* | *22.4* | *23.8* | *24.0* | *22.0* | *22.1* | *21.5* | *22.9* | *22.4* | *22.9* | *22.8* | *22.7* | *23.3* | *22.8* | *22.6* | *22.2* | *22.0* | *22.7* | *22.6* | *22.6* | *22.5* | *22.4* | *22.6* | *22.5* | *22.9* | *23.0* | *23.3* | *23.4* | *24.0* |
| | *Goats Non-Agr.* | *25.0* | *24.6* | *25.0* | *25.4* | *25.5* | *27.9* | *25.3* | *25.6* | *26.9* | *25.8* | *25.7* | *26.0* | *25.2* | *25.4* | *25.2* | *25.4* | *25.3* | *25.0* | *25.0* | *25.3* | *25.1* | *25.6* | *25.6* | *25.6* | *25.0* | *25.5* | *25.1* | *25.2* | *25.1* | *25.5* | *26.4* |
| | *Horses <3 years Non-Agr.* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* | *101.4* |
| | *Horses >3 years Non-Agr.* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* |
| | *Mules Non-Agr.* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* | *86.0* |
| | *Asses Non-Agr.* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* | *37.9* |

1) Deer: Gross energy intake per animal place (mother with offspring)

2) Poultry data is not Gross Energy intake (GE) but Metabolizable Energy intake (ME)

Table A – 19 Livestock population. For some categories the numbers of the total population is not equal to the sum of the numbers of the subcategories because the latter refer to animal places instead of head. See also ART/SHL 2012.

| Population Size | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | 1000 head | | | | | | | | | | | | | | | |
| Cattle | 1855.2 | 1828.9 | 1782.6 | 1745.1 | 1755.4 | 1748.3 | 1747.1 | 1672.9 | 1640.9 | 1608.7 | 1588.0 | 1611.4 | 1593.7 | 1570.2 | 1544.5 | 1554.7 | 1566.9 | 1571.8 | 1604.3 | 1597.5 | 1591.2 | 1577.4 | 1564.6 | 1557.5 | 1562.8 | 1554.3 | 1555.4 | 1544.6 | 1543.3 | 1524.8 | 1515.1 |
| Mature Dairy Cattle | 783.1 | 780.5 | 763.5 | 744.5 | 749.7 | 739.6 | 736.0 | 711.6 | 701.3 | 683.5 | 669.4 | 669.4 | 657.9 | 638.3 | 621.0 | 620.7 | 618.1 | 614.8 | 628.5 | 599.4 | 589.0 | 589.2 | 591.2 | 586.6 | 587.4 | 583.3 | 575.8 | 569.2 | 564.2 | 554.6 | 546.5 |
| Other Mature Cattle | 12.0 | 14.0 | 17.0 | 18.0 | 20.0 | 23.0 | 28.0 | 32.0 | 36.0 | 41.2 | 44.9 | 50.6 | 58.1 | 65.1 | 70.0 | 78.5 | 87.3 | 93.5 | 98.4 | 108.4 | 111.3 | 110.7 | 114.4 | 116.9 | 118.0 | 117.9 | 120.8 | 123.4 | 125.5 | 128.3 | 131.4 |
| Growing Cattle | 1060.1 | 1034.4 | 1002.1 | 982.6 | 985.7 | 985.6 | 983.0 | 929.3 | 903.5 | 884.0 | 873.7 | 891.3 | 877.7 | 866.7 | 853.6 | 855.5 | 861.5 | 863.4 | 877.4 | 889.7 | 890.9 | 877.5 | 859.0 | 854.0 | 857.4 | 853.1 | 858.8 | 852.0 | 853.7 | 842.0 | 837.3 |
| *Fattening Calves* | *112.3* | *111.4* | *109.5* | *111.1* | *101.4* | *101.7* | *112.0* | *106.0* | *108.1* | *116.4* | *103.3* | *114.7* | *114.4* | *113.9* | *111.3* | *105.6* | *101.2* | *100.5* | *95.0* | *107.3* | *113.5* | *111.1* | *103.1* | *101.9* | *102.5* | *102.6* | *107.0* | *107.6* | *111.0* | *110.0* | *110.5* |
| *Pre-Weaned Calves* | *9.6* | *11.2* | *13.6* | *14.4* | *16.0* | *18.4* | *22.4* | *25.6* | *28.8* | *33.2* | *35.7* | *40.4* | *46.9* | *52.3* | *56.6* | *62.5* | *67.3* | *72.2* | *76.1* | *83.9* | *86.3* | *85.8* | *88.4* | *90.3* | *91.1* | *91.1* | *93.5* | *95.5* | *97.1* | *99.5* | *101.9* |
| *Breeding Cattle 1st Year* | *346.4* | *336.7* | *324.0* | *308.2* | *306.2* | *294.7* | *286.1* | *260.1* | *253.5* | *218.7* | *236.0* | *238.1* | *229.5* | *219.8* | *214.7* | *222.0* | *223.3* | *223.3* | *232.4* | *224.5* | *221.6* | *215.7* | *210.4* | *207.7* | *209.5* | *210.2* | *211.3* | *209.3* | *207.8* | *201.0* | *198.6* |
| *Breeding Cattle 2nd Year* | *253.3* | *251.9* | *250.5* | *238.7* | *237.2* | *238.6* | *243.0* | *232.9* | *217.4* | *187.5* | *221.9* | *219.3* | *219.1* | *212.7* | *205.4* | *204.7* | *210.2* | *210.5* | *212.7* | *215.9* | *214.9* | *212.7* | *210.7* | *209.5* | *210.4* | *209.0* | *209.2* | *207.5* | *207.3* | *204.4* | *202.8* |
| *Breeding Cattle 3rd Year* | *150.7* | *148.4* | *146.7* | *142.3* | *141.3* | *139.4* | *139.9* | *139.3* | *132.7* | *117.9* | *129.8* | *130.4* | *126.0* | *124.0* | *120.9* | *113.3* | *110.1* | *109.1* | *109.6* | *111.7* | *110.8* | *108.9* | *106.3* | *103.0* | *101.3* | *98.5* | *97.1* | *97.8* | *94.4* | *91.0* | *87.0* |
| *Fattening Cattle* | *187.8* | *174.8* | *157.8* | *168.0* | *183.5* | *192.9* | *179.6* | *165.4* | *163.1* | *210.2* | *147.1* | *148.5* | *141.7* | *144.1* | *144.7* | *147.5* | *149.3* | *148.0* | *151.6* | *146.5* | *143.8* | *143.2* | *140.0* | *141.5* | *142.7* | *141.7* | *140.8* | *134.3* | *136.1* | *136.2* | *136.5* |
| Sheep | 395.2 | 409.4 | 414.7 | 424.0 | 405.4 | 386.7 | 418.6 | 420.4 | 422.3 | 423.5 | 420.7 | 420.0 | 429.5 | 444.8 | 440.5 | 446.4 | 447.5 | 443.6 | 446.2 | 431.9 | 434.1 | 424.0 | 417.3 | 409.5 | 402.8 | 395.3 | 396.8 | 398.3 | 403.0 | 399.7 | 398.4 |
| *Fattening Sheep* | *190.6* | *200.8* | *201.0* | *211.1* | *201.2* | *191.4* | *207.6* | *208.0* | *208.7* | *221.7* | *216.6* | *216.6* | *219.9* | *228.6* | *227.5* | *229.4* | *230.6* | *230.0* | *229.4* | *227.3* | *228.2* | *221.8* | *219.3* | *216.2* | *209.5* | *204.0* | *205.0* | *206.9* | *208.2* | *206.7* | *206.3* |
| *Milksheep* | *4.3* | *4.0* | *3.8* | *3.5* | *3.3* | *3.0* | *2.8* | *3.1* | *4.4* | *5.8* | *6.7* | *7.0* | *7.2* | *8.0* | *8.1* | *8.9* | *9.5* | *10.2* | *10.7* | *11.7* | *12.4* | *12.4* | *12.8* | *13.3* | *13.7* | *13.6* | *12.9* | *13.7* | *14.5* | *14.5* | *13.8* |
| Swine | 1965.5 | 1899.3 | 1888.6 | 1893.0 | 1780.0 | 1739.0 | 1542.6 | 1521.5 | 1602.8 | 1660.1 | 1669.8 | 1740.9 | 1731.6 | 1691.5 | 1685.7 | 1744.4 | 1797.2 | 1747.9 | 1671.0 | 1690.9 | 1750.5 | 1726.2 | 1678.2 | 1614.5 | 1630.9 | 1604.6 | 1553.5 | 1546.2 | 1501.1 | 1446.5 | 1448.3 |
| *Piglets* | *299.4* | *282.5* | *290.8* | *299.6* | *287.2* | *274.8* | *240.9* | *252.2* | *261.8* | *281.0* | *296.6* | *318.8* | *326.6* | *322.8* | *327.8* | *337.6* | *366.5* | *344.8* | *336.1* | *338.4* | *350.9* | *352.7* | *344.7* | *333.3* | *339.2* | *330.0* | *314.4* | *313.7* | *305.7* | *293.2* | *284.9* |
| *Fattening Pig over 25 kg* | *1203.1* | *1166.3* | *1155.7* | *1144.2* | *1066.8* | *1061.3* | *942.0* | *906.1* | *953.3* | *941.2* | *922.4* | *955.7* | *942.7* | *914.3* | *901.5* | *931.7* | *948.5* | *941.7* | *894.2* | *913.1* | *949.6* | *934.7* | *909.7* | *877.9* | *892.4* | *886.1* | *862.2* | *859.7* | *833.4* | *799.7* | *807.8* |
| *Dry Sows* | *129.3* | *126.0* | *124.9* | *125.3* | *117.1* | *108.9* | *98.8* | *104.3* | *110.9* | *101.2* | *104.8* | *108.0* | *108.6* | *105.3* | *107.9* | *112.7* | *115.2* | *105.7* | *105.4* | *104.7* | *106.1* | *103.4* | *97.4* | *95.8* | *94.2* | *93.3* | *90.9* | *88.9* | *84.7* | *82.8* | *81.0* |
| *Nursing Sows* | *37.4* | *36.8* | *36.8* | *37.3* | *35.1* | *33.0* | *30.2* | *29.9* | *31.4* | *35.0* | *36.7* | *37.5* | *36.5* | *35.8* | *35.3* | *36.0* | *36.5* | *34.9* | *32.6* | *33.1* | *33.5* | *32.3* | *31.0* | *29.4* | *29.4* | *29.4* | *28.7* | *27.9* | *27.3* | *26.5* | *26.3* |
| *Boars* | *8.4* | *8.1* | *8.0* | *8.2* | *7.7* | *7.1* | *6.3* | *6.4* | *6.4* | *6.2* | *6.2* | *6.1* | *5.8* | *5.3* | *5.2* | *5.1* | *4.9* | *4.2* | *4.0* | *3.8* | *3.7* | *3.3* | *3.0* | *3.2* | *2.9* | *2.7* | *2.6* | *2.7* | *2.6* | *2.4* | *2.4* |
| Buffalo | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.4 | 0.3 | 0.4 | 0.5 | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 |
| *Bisons < 3 years* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.1* | *0.1* | *0.0* | *0.1* | *0.2* | *0.1* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.2* | *0.2* | *0.2* |
| *Bisons > 3 years* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.1* | *0.0* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.4* | *0.3* | *0.3* |
| Camels | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.3 | 0.4 | 1.0 | 1.0 | 1.6 | 1.6 | 1.7 | 2.2 | 3.1 | 3.3 | 3.9 | 4.4 | 4.7 | 6.1 | 6.0 | 5.8 | 5.9 | 6.1 | 6.4 | 6.5 | 6.6 | 6.7 | 6.6 | 6.5 |
| *Llamas < 2 years* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.1* | *0.1* | *0.1* | *0.2* | *0.2* | *0.3* | *0.3* | *0.3* | *0.4* | *0.5* | *0.5* | *0.6* | *0.7* | *0.8* | *0.8* | *0.8* | *0.7* | *0.7* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* |
| *Llamas > 2 years* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.2* | *0.2* | *0.3* | *0.5* | *0.5* | *0.7* | *0.7* | *0.9* | *1.0* | *1.1* | *1.3* | *1.5* | *1.8* | *1.9* | *2.1* | *2.2* | *2.3* | *2.4* | *2.3* | *2.4* | *2.3* | *2.3* | *2.3* | *2.3* | *2.3* |
| *Alpacas < 2 years* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.2* | *0.1* | *0.1* | *0.2* | *0.3* | *0.4* | *0.5* | *0.6* | *0.7* | *0.8* | *0.7* | *0.8* | *0.8* | *0.7* | *0.9* | *0.9* | *0.8* | *0.9* | *0.8* | *0.7* |
| *Alpacas > 2 years* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.2* | *0.2* | *0.5* | *0.5* | *0.4* | *0.6* | *1.2* | *1.1* | *1.2* | *1.3* | *1.4* | *2.3* | *2.3* | *2.0* | *2.1* | *2.4* | *2.6* | *2.6* | *2.8* | *2.8* | *2.9* | *2.8* |
| Deer | 0.2 | 0.4 | 0.7 | 0.9 | 1.2 | 1.4 | 1.9 | 1.9 | 2.2 | 2.6 | 2.8 | 2.9 | 3.1 | 3.2 | 3.5 | 3.8 | 4.2 | 4.4 | 4.8 | 5.1 | 5.5 | 5.7 | 5.7 | 5.7 | 5.7 | 6.0 | 6.0 | 6.0 | 6.4 | 6.6 | 6.6 |
| *Fallow Deer* | *0.2* | *0.4* | *0.6* | *0.8* | *1.1* | *1.3* | *1.6* | *1.8* | *2.0* | *2.4* | *2.5* | *2.6* | *2.7* | *2.9* | *3.2* | *3.5* | *3.7* | *4.0* | *4.3* | *4.4* | *4.9* | *5.0* | *5.0* | *4.8* | *4.9* | *5.1* | *5.1* | *5.0* | *5.3* | *5.4* | *5.4* |
| *Red Deer* | *0.0* | *0.0* | *0.0* | *0.1* | *0.1* | *0.1* | *0.4* | *0.2* | *0.2* | *0.3* | *0.3* | *0.3* | *0.4* | *0.3* | *0.4* | *0.4* | *0.4* | *0.5* | *0.6* | *0.6* | *0.7* | *0.7* | *0.7* | *0.8* | *0.8* | *0.9* | *0.9* | *1.0* | *1.1* | *1.2* | *1.2* |
| Goats | 68.3 | 65.2 | 58.2 | 56.7 | 54.9 | 53.2 | 56.8 | 58.0 | 60.1 | 61.6 | 62.5 | 63.0 | 66.0 | 67.4 | 70.6 | 74.0 | 76.3 | 79.1 | 81.4 | 81.2 | 82.8 | 83.0 | 84.7 | 84.5 | 84.7 | 83.7 | 84.9 | 87.6 | 91.0 | 91.6 | 90.1 |
| *Goat Places* | *44.8* | *43.1* | *38.4* | *37.3* | *35.9* | *34.6* | *37.1* | *37.7* | *39.8* | *40.8* | *41.4* | *42.1* | *43.0* | *44.9* | *46.2* | *48.5* | *50.5* | *51.9* | *53.4* | *54.3* | *54.7* | *55.9* | *57.4* | *57.4* | *57.9* | *56.1* | *56.9* | *58.7* | *60.9* | *61.3* | *60.4* |
| Horses | 28.2 | 30.2 | 32.3 | 34.5 | 37.9 | 41.4 | 43.0 | 45.8 | 46.3 | 48.5 | 50.3 | 50.1 | 51.2 | 52.7 | 53.7 | 55.1 | 56.4 | 57.7 | 59.0 | 60.2 | 62.1 | 57.2 | 58.0 | 57.2 | 57.2 | 55.5 | 55.7 | 55.5 | 45.9 | 47.1 | 47.0 |
| *Horses <3 years* | *6.1* | *6.5* | *7.0* | *7.4* | *9.2* | *11.0* | *10.7* | *10.0* | *10.0* | *11.0* | *10.1* | *9.7* | *9.5* | *9.4* | *9.4* | *9.4* | *9.5* | *9.6* | *9.6* | *9.0* | *8.7* | *8.3* | *8.0* | *7.1* | *6.5* | *4.7* | *4.3* | *4.1* | *3.1* | *3.2* | *3.1* |
| *Horses >3 years* | *22.1* | *23.7* | *25.4* | *27.1* | *28.7* | *30.4* | *32.3* | *35.8* | *36.3* | *37.5* | *40.2* | *40.4* | *41.7* | *43.3* | *44.3* | *45.8* | *46.9* | *48.1* | *49.4* | *51.1* | *53.4* | *49.0* | *50.1* | *50.2* | *50.7* | *50.8* | *51.4* | *51.4* | *42.8* | *43.9* | *43.9* |
| Mules and Asses | 5.9 | 6.3 | 6.7 | 7.2 | 7.4 | 7.6 | 8.5 | 9.4 | 9.9 | 11.3 | 11.8 | 12.5 | 13.2 | 14.1 | 14.8 | 16.0 | 16.5 | 17.2 | 17.8 | 19.2 | 20.4 | 19.0 | 20.1 | 19.6 | 19.6 | 19.7 | 20.2 | 20.7 | 34.0 | 33.6 | 33.1 |
| *Mules* | *0.2* | *0.2* | *0.2* | *0.2* | *0.2* | *0.3* | *0.3* | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* | *0.5* | *0.5* | *0.5* | *0.5* | *0.5* | *0.5* | *0.5* | *0.8* | *1.0* | *0.8* | *0.9* | *0.7* | *0.7* | *0.7* | *0.7* | *0.7* | *0.4* | *0.4* | *0.4* |
| *Asses* | *5.7* | *6.1* | *6.6* | *7.0* | *7.1* | *7.3* | *8.1* | *9.0* | *9.6* | *10.9* | *11.4* | *12.0* | *12.8* | *13.6* | *14.4* | *15.5* | *15.9* | *16.7* | *17.3* | *18.4* | *19.4* | *18.2* | *19.3* | *18.9* | *18.9* | *19.0* | *19.5* | *20.0* | *33.7* | *33.2* | *32.7* |
| Poultry [1)] | 7310.4 | 6887.4 | 7139.7 | 7022.2 | 6691.9 | 6656.3 | 6467.9 | 6626.5 | 6870.5 | 6957.1 | 7159.8 | 7124.1 | 7370.4 | 7556.3 | 8103.3 | 8910.6 | 8107.4 | 9303.1 | 9813.1 | 10098.9 | 10628.6 | 10903.9 | 11409.2 | 11844.3 | 12445.5 | 12540.6 | 13179.6 | 13207.4 | 13983.9 | 14417.1 | 15199.4 |
| *Growers* | *718.9* | *664.2* | *709.6* | *719.2* | *716.8* | *714.4* | *732.1* | *732.9* | *793.5* | *760.9* | *831.7* | *745.3* | *753.9* | *809.0* | *853.1* | *867.7* | *888.4* | *901.8* | *919.0* | *966.7* | *925.5* | *969.7* | *1075.6* | *1054.5* | *1195.6* | *1033.0* | *959.3* | *1084.0* | *1078.4* | *1242.1* | *1149.7* |
| *Layers* | *3083.0* | *2645.4* | *2535.8* | *2517.6* | *2317.9* | *2118.2* | *2226.0* | *2277.5* | *2270.1* | *2222.8* | *2150.3* | *2069.5* | *2154.1* | *2117.2* | *2088.8* | *2188.5* | *2147.3* | *2197.7* | *2254.9* | *2318.3* | *2438.1* | *2437.0* | *2520.6* | *2588.6* | *2665.1* | *2821.9* | *3055.9* | *3173.5* | *3371.3* | *3485.7* | *3854.0* |
| *Broilers* | *3392.1* | *3439.2* | *3733.6* | *3602.5* | *3472.3* | *3636.6* | *3320.6* | *3416.0* | *3633.2* | *3797.0* | *3984.5* | *4177.8* | *4330.0* | *4487.4* | *5013.4* | *5710.6* | *4918.4* | *6077.0* | *6570.7* | *6745.7* | *7183.8* | *7410.4* | *7736.6* | *8125.7* | *8505.9* | *8613.8* | *9063.7* | *8857.0* | *9429.9* | *9593.4* | *10083.4* |
| *Turkey* | *94.7* | *117.4* | *140.1* | *162.8* | *166.5* | *170.2* | *173.8* | *184.4* | *157.8* | *154.6* | *172.6* | *123.0* | *123.9* | *133.8* | *138.8* | *132.3* | *137.1* | *112.5* | *53.8* | *52.4* | *58.1* | *57.8* | *51.2* | *55.1* | *57.2* | *49.3* | *70.9* | *77.1* | *84.4* | *75.1* | *88.4* |
| *Other Poultry* | *21.8* | *21.2* | *20.6* | *20.0* | *18.4* | *16.9* | *15.3* | *15.8* | *15.9* | *21.9* | *20.7* | *8.6* | *8.5* | *8.8* | *9.3* | *11.5* | *16.1* | *14.2* | *14.7* | *15.9* | *23.2* | *29.0* | *25.1* | *20.4* | *21.7* | *22.6* | *29.8* | *15.7* | *19.8* | *20.9* | *24.0* |
| Rabbits | 60.9 | 56.8 | 52.7 | 48.7 | 44.6 | 40.5 | 36.5 | 37.4 | 32.8 | 31.3 | 27.9 | 25.1 | 33.4 | 31.1 | 20.5 | 25.4 | 24.5 | 27.2 | 24.9 | 27.8 | 35.0 | 34.3 | 27.9 | 27.5 | 27.0 | 25.3 | 24.7 | 21.9 | 21.8 | 21.4 | 19.0 |
| Livestock NCAC | 16.3 | 15.3 | 14.5 | 13.0 | 13.0 | 18.6 | 74.1 | 85.3 | 85.9 | 88.2 | 88.3 | 90.7 | 91.2 | 93.6 | 88.2 | 89.3 | 86.5 | 85.7 | 93.0 | 95.6 | 95.3 | 102.8 | 113.9 | 111.4 | 108.9 | 120.1 | 113.4 | 109.8 | 107.7 | 103.1 | 102.2 |
| *Total Sheep* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *53.4* | *66.9* | *67.1* | *67.3* | *66.9* | *69.3* | *66.7* | *68.7* | *63.4* | *62.4* | *60.3* | *58.8* | *63.4* | *65.5* | *62.5* | *65.0* | *73.5* | *69.5* | *67.9* | *73.8* | *68.7* | *66.5* | *64.6* | *59.9* | *58.9* |
| *Fattening Sheep* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *26.7* | *33.3* | *33.1* | *34.8* | *34.0* | *34.9* | *33.5* | *34.8* | *32.1* | *31.4* | *30.1* | *30.0* | *33.1* | *34.6* | *33.2* | *36.5* | *43.4* | *40.7* | *39.7* | *42.2* | *39.1* | *37.8* | *36.8* | *34.3* | *33.5* |
| *Milksheep* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.4* | *0.4* | *0.6* | *0.8* | *0.9* | *0.9* | *0.9* | *0.9* | *0.9* | *0.7* | *0.6* | *0.5* | *0.6* | *0.6* | *0.7* | *0.6* | *0.4* | *0.5* | *0.4* | *0.3* | *0.4* | *0.3* | *0.3* | *0.3* | *0.4* |
| *Total Goats* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *5.7* | *5.5* | *5.2* | *5.4* | *7.6* | *7.4* | *7.7* | *8.5* | *7.9* | *8.9* | *10.8* | *9.9* | *9.1* | *10.6* | *9.7* | *10.1* | *13.6* | *13.6* | *13.6* | *13.4* | *14.8* | *13.6* | *12.9* | *14.0* | *14.1* | *13.8* |
| *Goat Places* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *4.0* | *3.7* | *3.3* | *3.5* | *5.3* | *4.9* | *5.2* | *5.6* | *5.2* | *5.9* | *7.3* | *6.5* | *5.8* | *6.9* | *6.2* | *6.3* | *9.4* | *9.5* | *9.5* | *9.4* | *10.0* | *9.1* | *8.6* | *9.5* | *9.4* | *9.2* |
| *Horses <3 years Non-Agr.* | *0.8* | *0.8* | *0.7* | *0.8* | *0.8* | *0.8* | *0.9* | *0.7* | *0.7* | *0.9* | *0.8* | *0.8* | *0.8* | *0.8* | *0.8* | *0.7* | *0.5* | *0.5* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.7* | *0.5* | *0.4* | *0.4* | *0.3* | *0.2* | *0.2* | *0.2* |
| *Horses >3 years Non-Agr.* | *11.2* | *10.3* | *9.7* | *8.3* | *8.9* | *9.0* | *10.6* | *8.7* | *8.8* | *8.3* | *8.9* | *8.4* | *9.9* | *10.5* | *9.7* | *9.9* | *10.0* | *11.1* | *12.1* | *12.7* | *14.3* | *15.5* | *17.4* | *18.5* | *17.7* | *20.4* | *20.3* | *19.7* | *14.0* | *13.9* | *14.0* |
| *Mules Non-Agr.* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | *0.0* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | *0.1* | *0.2* | *0.3* | *0.3* | *0.3* | *0.2* | *0.3* | *0.3* | *0.3* | *0.3* | *0.2* | *0.2* | *0.2* |
| *Asses Non-Agr.* | *4.2* | *4.1* | *4.0* | *3.9* | *3.2* | *3.1* | *3.6* | *3.8* | *3.8* | *4.0* | *4.2* | *4.4* | *5.2* | *5.7* | *5.2* | *5.5* | *5.7* | *6.0* | *6.1* | *6.9* | *7.5* | *7.8* | *8.5* | *9.0* | *9.1* | *10.4* | *10.1* | *10.1* | *14.8* | *14.8* | *15.1* |

1) Other Poultry: Geese, Ducks, Ostriches, Quails

### A3.3.2 Additional data for estimating $CH_4$ and $N_2O$ emission from 3B Manure management

Table A – 20 Data for estimating manure management $CH_4$ emission factors (Table according to outline in IPCC 1997c, Tables B-1 to B-7).

| Type | Weight kg [a] | Digestibility of Feed % [b] | Energy Intake $MJ*day^{-1}$ | Feed Intake $kg*day^{-1}$ | % Ash Dry Basis [b] | VS $kg*head^{-1}*day^{-1}$ | $B_0$ $m^3$ $CH_4*kgVS^{-1}$ [b] |
|---|---|---|---|---|---|---|---|
| Mature Dairy Cattle | 650 | 72 | 255 - 309 | 15.34 [c] | 8.8 - 9.1 | 3.51 - 4.27 | 0.24 |
| Other Mature Cattle | 650 | 60 | 251 | 13.70 [c] | 8 | 5.00 | 0.18 |
| Fattening Calves | 124 | 65 | 47 | 2.02 [a] | 8 | 0.82 | 0.18 |
| Pre-Weaned Calves | 195 | 65 | 60 | 2.99 [a] | 8 | 0.67 | 0.18 |
| Breeding Calves | 85 | 65 | 44 | 2.19 [a] | 8 | 0.49 | 0.18 |
| Breeding Cattle (4-12 months) | 210 | 60 | 90 | 4.88 [a] | 8 | 1.80 | 0.18 |
| Breeding Cattle (> 1 year) | 450 | 60 | 144 | 7.78 [a] | 8 | 2.86 | 0.18 |
| Fattening Calves (0-4 months) | 115 | 65 | 57 | 3.00 [a] | 8 | 0.87 | 0.18 |
| Fattening Cattle (4-12 months) | 361 | 60 | 126 | 6.84 [a] | 8 | 2.52 | 0.18 |
| Sheep | NA | 60 | 21 - 24 | 1.08-1.24 [c] | 8 | 0.40 [b] | 0.19 |
| Swine | NA | 75 | 24 - 27 | NA | 2 | 0.31 [b#] | 0.45 |
| Buffalo | NA | 55 | 129 - 163 | 7.00-8.82 [c] | 8 | 3.57 | 0.10 |
| Camels | NA | 60 [d] | 31 - 38 | 1.68-2.05 [c] | 8 | 0.63 | 0.26 |
| Deer | NA | 60 | 51 - 60 | 2.74-3.24 [c] | 8 | 1.19 | 0.19 |
| Goats | NA | 60 | 25 - 28 | 1.34-1.40 [c] | 8 | 0.30 [b] | 0.18 |
| Horses | NA | 70 | 107 - 108 | 7.73-7.89 [c] | 4 | 1.90 | 0.33 |
| Mules and Asses | NA | 70 | 38 - 40 | 2.76-2.83 [c] | 4 | 0.94 [b] | 0.33 |
| Poultry | NA | NA | 1.0 - 1.4 [e] | NA | NA | 0.01 [b#] | 0.37 [#] |
| Rabbits | NA | NA | 1.2 | NA | NA | 0.1 [b] | 0.32 |
| Livestock NCAC | NA | NA | NA | NA | NA | 0.68 | 0.27 |

[a] RAP 1999

[b] IPCC 1997c and IPCC 2006

[c] Richner et al. 2017

[d] Llamas and alpacas: same value as for sheep

[e] metabolizable energy (ME)

[#] weighted average

Table A – 21 Manure management system distribution for volatile solids (VS) in Switzerland.

| MS Distribution for VS | 1990 | | | | | 1995 | | | | | 2002 | | | | | 2007 | | | | | 2010 | | | | | 2015 | | | | | 2019 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | | | | | % | | | | | % | | | | | % | | | | | % | | | | | % | | | | | % | | | | |
| | Liquid / Slurry | Solid manure | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) | Liquid / Slurry | Solid manure | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) | Liquid / Slurry | Solid manure | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) | Liquid / Slurry | Solid manure | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) | Liquid / Slurry | Solid manure | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) | Liquid / Slurry | Solid manure | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) | Liquid / Slurry | Solid manure | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) |
| Mature Dairy Cattle | 43.2 | 48.1 | 8.3 | 0.5 | 0.0 | 48.0 | 42.0 | 9.6 | 0.4 | 0.0 | 48.7 | 33.9 | 16.9 | 0.5 | 0.0 | 52.3 | 28.9 | 17.3 | 1.4 | 0.0 | 50.9 | 29.9 | 17.2 | 2.0 | 0.0 | 54.0 | 25.7 | 16.5 | 3.8 | 0.0 | 52.3 | 24.9 | 16.7 | 6.0 | 0.0 |
| Other Mature Cattle | 26.9 | 43.1 | 29.6 | 0.5 | 0.0 | 23.2 | 46.8 | 29.6 | 0.4 | 0.0 | 22.7 | 40.1 | 36.7 | 0.5 | 0.0 | 30.4 | 40.4 | 27.8 | 1.4 | 0.0 | 30.5 | 38.1 | 29.3 | 2.0 | 0.0 | 34.7 | 32.3 | 29.2 | 3.8 | 0.0 | 29.9 | 33.2 | 31.0 | 6.0 | 0.0 |
| Growing Cattle (weighted average) | 32.9 | 45.2 | 15.9 | 0.5 | 5.5 | 33.8 | 44.3 | 16.0 | 0.4 | 5.6 | 27.7 | 38.8 | 27.1 | 0.5 | 5.8 | 28.1 | 39.7 | 25.7 | 1.4 | 5.2 | 27.8 | 39.1 | 25.3 | 2.0 | 5.8 | 30.7 | 35.4 | 24.9 | 3.8 | 5.1 | 30.6 | 33.1 | 25.1 | 6.0 | 5.2 |
| *Fattening Calves* | 6.0 | 0.0 | 0.0 | 0.5 | 93.5 | 6.0 | 0.0 | 0.0 | 0.4 | 93.6 | 5.4 | 0.0 | 0.7 | 0.5 | 93.3 | 9.4 | 0.0 | 0.4 | 1.4 | 88.8 | 8.7 | 0.0 | 1.0 | 2.0 | 88.3 | 11.7 | 0.0 | 1.2 | 3.8 | 83.2 | 14.7 | 0.0 | 1.7 | 6.0 | 77.5 |
| *Pre-Weaned Calves* | 26.9 | 43.1 | 29.6 | 0.5 | 0.0 | 23.2 | 46.8 | 29.6 | 0.4 | 0.0 | 23.1 | 40.9 | 35.5 | 0.5 | 0.0 | 29.8 | 39.7 | 29.2 | 1.4 | 0.0 | 29.1 | 36.4 | 32.5 | 2.0 | 0.0 | 33.0 | 30.7 | 32.4 | 3.8 | 0.0 | 29.0 | 32.2 | 32.7 | 6.0 | 0.0 |
| *Breeding Cattle 1st Year* | 18.4 | 67.1 | 14.1 | 0.5 | 0.0 | 19.7 | 65.7 | 14.2 | 0.4 | 0.0 | 17.1 | 55.0 | 27.4 | 0.5 | 0.0 | 19.9 | 53.9 | 24.8 | 1.4 | 0.0 | 23.0 | 50.8 | 24.2 | 2.0 | 0.0 | 24.3 | 48.5 | 23.4 | 3.8 | 0.0 | 25.1 | 45.5 | 23.3 | 6.0 | 0.0 |
| *Breeding Cattle 2nd Year* | 28.9 | 45.2 | 25.4 | 0.5 | 0.0 | 30.8 | 43.0 | 25.7 | 0.4 | 0.0 | 23.4 | 38.9 | 37.1 | 0.5 | 0.0 | 23.8 | 39.5 | 35.3 | 1.4 | 0.0 | 25.4 | 37.7 | 34.8 | 2.0 | 0.0 | 26.3 | 34.8 | 35.0 | 3.8 | 0.0 | 29.2 | 30.9 | 33.8 | 6.0 | 0.0 |
| *Breeding Cattle 3rd Year* | 33.0 | 46.5 | 20.0 | 0.5 | 0.0 | 34.1 | 45.1 | 20.4 | 0.4 | 0.0 | 27.4 | 37.8 | 34.2 | 0.5 | 0.0 | 28.9 | 37.2 | 32.6 | 1.4 | 0.0 | 29.8 | 36.4 | 31.8 | 2.0 | 0.0 | 32.9 | 33.0 | 30.2 | 3.8 | 0.0 | 31.1 | 32.2 | 30.7 | 6.0 | 0.0 |
| *Fattening Cattle* | 65.3 | 26.2 | 0.0 | 0.5 | 8.0 | 59.7 | 31.7 | 0.0 | 0.4 | 8.2 | 57.1 | 34.0 | 4.0 | 0.5 | 4.3 | 49.3 | 38.5 | 6.8 | 1.4 | 4.0 | 41.9 | 45.2 | 5.9 | 2.0 | 4.9 | 49.5 | 36.4 | 6.3 | 3.8 | 3.9 | 44.3 | 36.5 | 9.2 | 6.0 | 3.9 |
| Sheep (weighted average) | 0.0 | 0.0 | 30.1 | 0.0 | 69.9 | 0.0 | 0.0 | 30.3 | 0.0 | 69.7 | 0.0 | 0.0 | 48.7 | 0.0 | 51.3 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 38.8 | 0.0 | 61.2 | 0.0 | 0.0 | 45.3 | 0.0 | 54.7 | 0.0 | 0.0 | 42.9 | 0.0 | 57.1 |
| *Fattening Sheep* | 0.0 | 0.0 | 30.7 | 0.0 | 69.3 | 0.0 | 0.0 | 30.7 | 0.0 | 69.3 | 0.0 | 0.0 | 49.0 | 0.0 | 51.0 | 0.0 | 0.0 | 46.2 | 0.0 | 53.8 | 0.0 | 0.0 | 39.9 | 0.0 | 60.1 | 0.0 | 0.0 | 46.3 | 0.0 | 53.7 | 0.0 | 0.0 | 44.4 | 0.0 | 55.6 |
| *Milksheep* | 0.0 | 0.0 | 11.4 | 0.0 | 88.6 | 0.0 | 0.0 | 11.4 | 0.0 | 88.6 | 0.0 | 0.0 | 43.0 | 0.0 | 57.0 | 0.0 | 0.0 | 33.4 | 0.0 | 66.6 | 0.0 | 0.0 | 24.6 | 0.0 | 75.4 | 0.0 | 0.0 | 33.2 | 0.0 | 66.8 | 0.0 | 0.0 | 27.2 | 0.0 | 72.8 |
| Swine (weighted average) | 98.9 | 0.0 | 0.0 | 1.1 | 0.0 | 99.0 | 0.0 | 0.0 | 1.0 | 0.0 | 97.3 | 1.1 | 0.3 | 1.3 | 0.0 | 95.3 | 0.2 | 0.8 | 3.7 | 0.0 | 93.9 | 0.5 | 0.3 | 5.3 | 0.0 | 89.2 | 0.1 | 0.1 | 10.7 | 0.0 | 81.6 | 0.1 | 0.0 | 18.3 | 0.0 |
| *Piglets* | 98.9 | 0.0 | 0.0 | 1.1 | 0.0 | 99.0 | 0.0 | 0.0 | 1.0 | 0.0 | 96.5 | 2.2 | 0.0 | 1.3 | 0.0 | 95.0 | 0.8 | 0.6 | 3.7 | 0.0 | 92.7 | 1.9 | 0.0 | 5.3 | 0.0 | 89.2 | 0.1 | 0.0 | 10.7 | 0.0 | 81.3 | 0.4 | 0.0 | 18.3 | 0.0 |
| *Fattening Pig over 25 kg* | 98.9 | 0.0 | 0.0 | 1.1 | 0.0 | 99.0 | 0.0 | 0.0 | 1.0 | 0.0 | 97.6 | 0.7 | 0.4 | 1.3 | 0.0 | 95.4 | 0.0 | 0.9 | 3.7 | 0.0 | 94.3 | 0.0 | 0.4 | 5.3 | 0.0 | 89.1 | 0.1 | 0.1 | 10.7 | 0.0 | 81.7 | 0.0 | 0.0 | 18.3 | 0.0 |
| *Dry Sows* | 98.9 | 0.0 | 0.0 | 1.1 | 0.0 | 99.0 | 0.0 | 0.0 | 1.0 | 0.0 | 97.7 | 0.7 | 0.3 | 1.3 | 0.0 | 95.1 | 0.2 | 1.0 | 3.7 | 0.0 | 94.2 | 0.2 | 0.3 | 5.3 | 0.0 | 89.2 | 0.0 | 0.1 | 10.7 | 0.0 | 81.6 | 0.0 | 0.1 | 18.3 | 0.0 |
| *Nursing Sows* | 98.9 | 0.0 | 0.0 | 1.1 | 0.0 | 99.0 | 0.0 | 0.0 | 1.0 | 0.0 | 95.7 | 3.0 | 0.0 | 1.3 | 0.0 | 95.4 | 0.5 | 0.5 | 3.7 | 0.0 | 94.3 | 0.4 | 0.0 | 5.3 | 0.0 | 89.3 | 0.0 | 0.0 | 10.7 | 0.0 | 81.7 | 0.0 | 0.1 | 18.3 | 0.0 |
| *Boars* | 98.9 | 0.0 | 0.0 | 1.1 | 0.0 | 99.0 | 0.0 | 0.0 | 1.0 | 0.0 | 97.2 | 1.0 | 0.5 | 1.3 | 0.0 | 95.2 | 0.0 | 1.1 | 3.7 | 0.0 | 93.4 | 0.7 | 0.6 | 5.3 | 0.0 | 89.1 | 0.0 | 0.2 | 10.7 | 0.0 | 80.9 | 0.0 | 0.9 | 18.3 | 0.0 |
| Buffalo (weighted average) | NA | NA | NA | NA | NA | 0.0 | 70.8 | 29.2 | 0.0 | 0.0 | 0.0 | 64.2 | 35.8 | 0.0 | 0.0 | 0.0 | 63.8 | 36.2 | 0.0 | 0.0 | 0.0 | 65.0 | 35.0 | 0.0 | 0.0 | 0.0 | 64.4 | 35.6 | 0.0 | 0.0 | 0.0 | 65.6 | 34.4 | 0.0 | 0.0 |
| *Bisons < 3 years* | 0.0 | 70.8 | 29.2 | 0.0 | 0.0 | 0.0 | 70.8 | 29.2 | 0.0 | 0.0 | 0.0 | 64.2 | 35.8 | 0.0 | 0.0 | 0.0 | 63.8 | 36.2 | 0.0 | 0.0 | 0.0 | 65.0 | 35.0 | 0.0 | 0.0 | 0.0 | 64.4 | 35.6 | 0.0 | 0.0 | 0.0 | 65.6 | 34.4 | 0.0 | 0.0 |
| *Bisons > 3 years* | 0.0 | 70.8 | 29.2 | 0.0 | 0.0 | 0.0 | 70.8 | 29.2 | 0.0 | 0.0 | 0.0 | 64.2 | 35.8 | 0.0 | 0.0 | 0.0 | 63.8 | 36.2 | 0.0 | 0.0 | 0.0 | 65.0 | 35.0 | 0.0 | 0.0 | 0.0 | 64.4 | 35.6 | 0.0 | 0.0 | 0.0 | 65.6 | 34.4 | 0.0 | 0.0 |
| Camels (weighted average) | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.0 | 0.0 | 47.2 | 0.0 | 52.8 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 38.4 | 0.0 | 61.6 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 43.7 | 0.0 | 56.3 |
| *Llamas < 2 years* | 0.0 | 0.0 | 35.7 | 0.0 | 64.3 | 0.0 | 0.0 | 35.7 | 0.0 | 64.3 | 0.0 | 0.0 | 47.2 | 0.0 | 52.8 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 38.4 | 0.0 | 61.6 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 43.7 | 0.0 | 56.3 |
| *Llamas > 2 years* | 0.0 | 0.0 | 35.7 | 0.0 | 64.3 | 0.0 | 0.0 | 35.7 | 0.0 | 64.3 | 0.0 | 0.0 | 47.2 | 0.0 | 52.8 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 38.4 | 0.0 | 61.6 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 43.7 | 0.0 | 56.3 |
| *Alpacas < 2 years* | 0.0 | 0.0 | 35.7 | 0.0 | 64.3 | 0.0 | 0.0 | 35.7 | 0.0 | 64.3 | 0.0 | 0.0 | 47.2 | 0.0 | 52.8 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 38.4 | 0.0 | 61.6 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 43.7 | 0.0 | 56.3 |
| *Alpacas > 2 years* | 0.0 | 0.0 | 35.7 | 0.0 | 64.3 | 0.0 | 0.0 | 35.7 | 0.0 | 64.3 | 0.0 | 0.0 | 47.2 | 0.0 | 52.8 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 38.4 | 0.0 | 61.6 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 43.7 | 0.0 | 56.3 |
| Deer (weighted average) | 0.0 | 0.0 | 35.7 | 0.0 | 64.3 | 0.0 | 0.0 | 35.7 | 0.0 | 64.3 | 0.0 | 0.0 | 47.2 | 0.0 | 52.8 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 38.4 | 0.0 | 61.6 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 43.7 | 0.0 | 56.3 |
| *Fallow Deer* | 0.0 | 0.0 | 35.7 | 0.0 | 64.3 | 0.0 | 0.0 | 35.7 | 0.0 | 64.3 | 0.0 | 0.0 | 47.2 | 0.0 | 52.8 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 38.4 | 0.0 | 61.6 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 43.7 | 0.0 | 56.3 |
| *Red Deer* | 0.0 | 0.0 | 35.7 | 0.0 | 64.3 | 0.0 | 0.0 | 35.7 | 0.0 | 64.3 | 0.0 | 0.0 | 47.2 | 0.0 | 52.8 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 38.4 | 0.0 | 61.6 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 43.7 | 0.0 | 56.3 |
| Goats | 0.0 | 0.0 | 13.6 | 0.0 | 86.4 | 0.0 | 0.0 | 13.6 | 0.0 | 86.4 | 0.0 | 0.0 | 28.5 | 0.0 | 71.5 | 0.0 | 0.0 | 27.3 | 0.0 | 72.7 | 0.0 | 0.0 | 28.1 | 0.0 | 71.9 | 0.0 | 0.0 | 28.3 | 0.0 | 71.7 | 0.0 | 0.0 | 33.7 | 0.0 | 66.3 |
| *Goat Places* | 0.0 | 0.0 | 13.6 | 0.0 | 86.4 | 0.0 | 0.0 | 13.6 | 0.0 | 86.4 | 0.0 | 0.0 | 28.5 | 0.0 | 71.5 | 0.0 | 0.0 | 27.3 | 0.0 | 72.7 | 0.0 | 0.0 | 28.1 | 0.0 | 71.9 | 0.0 | 0.0 | 28.3 | 0.0 | 71.7 | 0.0 | 0.0 | 33.7 | 0.0 | 66.3 |
| Horses (weighted average) | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 76.5 | 23.5 | 0.0 | 0.0 | 0.0 | 76.0 | 24.0 | 0.0 | 0.0 | 0.0 | 76.1 | 23.9 | 0.0 | 0.0 | 0.0 | 78.4 | 21.6 | 0.0 | 0.0 | 0.0 | 76.6 | 23.4 | 0.0 | 0.0 |
| *Horses <3 years* | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 69.0 | 31.0 | 0.0 | 0.0 | 0.0 | 70.5 | 29.5 | 0.0 | 0.0 | 0.0 | 70.0 | 30.0 | 0.0 | 0.0 | 0.0 | 71.5 | 28.5 | 0.0 | 0.0 | 0.0 | 64.9 | 35.1 | 0.0 | 0.0 |
| *Horses >3 years* | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 78.1 | 21.9 | 0.0 | 0.0 | 0.0 | 77.0 | 23.0 | 0.0 | 0.0 | 0.0 | 77.0 | 23.0 | 0.0 | 0.0 | 0.0 | 79.0 | 21.0 | 0.0 | 0.0 | 0.0 | 77.4 | 22.6 | 0.0 | 0.0 |
| Mules and Asses (weighted average) | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 84.0 | 16.0 | 0.0 | 0.0 | 0.0 | 76.7 | 23.3 | 0.0 | 0.0 | 0.0 | 76.9 | 23.1 | 0.0 | 0.0 | 0.0 | 77.9 | 22.1 | 0.0 | 0.0 | 0.0 | 80.4 | 19.6 | 0.0 | 0.0 |
| *Mules* | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 84.0 | 16.0 | 0.0 | 0.0 | 0.0 | 76.7 | 23.3 | 0.0 | 0.0 | 0.0 | 76.9 | 23.1 | 0.0 | 0.0 | 0.0 | 77.9 | 22.1 | 0.0 | 0.0 | 0.0 | 80.4 | 19.6 | 0.0 | 0.0 |
| *Asses* | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 84.0 | 16.0 | 0.0 | 0.0 | 0.0 | 76.7 | 23.3 | 0.0 | 0.0 | 0.0 | 76.9 | 23.1 | 0.0 | 0.0 | 0.0 | 77.9 | 22.1 | 0.0 | 0.0 | 0.0 | 80.4 | 19.6 | 0.0 | 0.0 |
| Poultry (weighted average) | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.5 | 0.0 | 99.5 | 0.0 | 0.0 | 2.8 | 0.0 | 97.2 | 0.0 | 0.0 | 3.2 | 0.0 | 96.8 | 0.0 | 0.0 | 2.9 | 0.0 | 97.1 | 0.0 | 0.0 | 2.9 | 0.0 | 97.1 | 0.0 | 0.0 | 3.2 | 0.0 | 96.8 |
| *Growers* | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.6 | 0.0 | 99.4 | 0.0 | 0.0 | 0.5 | 0.0 | 99.5 | 0.0 | 0.0 | 1.2 | 0.0 | 98.8 | 0.0 | 0.0 | 1.9 | 0.0 | 98.1 | 0.0 | 0.0 | 1.4 | 0.0 | 98.6 | 0.0 | 0.0 | 2.5 | 0.0 | 97.5 |
| *Layers* | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.6 | 0.0 | 99.4 | 0.0 | 0.0 | 5.3 | 0.0 | 94.7 | 0.0 | 0.0 | 6.8 | 0.0 | 93.2 | 0.0 | 0.0 | 6.9 | 0.0 | 93.1 | 0.0 | 0.0 | 7.0 | 0.0 | 93.0 | 0.0 | 0.0 | 7.1 | 0.0 | 92.9 |
| *Broilers* | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.4 | 0.0 | 99.6 | 0.0 | 0.0 | 0.7 | 0.0 | 99.3 | 0.0 | 0.0 | 1.1 | 0.0 | 98.9 | 0.0 | 0.0 | 0.4 | 0.0 | 99.6 | 0.0 | 0.0 | 0.3 | 0.0 | 99.7 | 0.0 | 0.0 | 0.5 | 0.0 | 99.5 |
| *Turkey* | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.4 | 0.0 | 99.6 | 0.0 | 0.0 | 3.0 | 0.0 | 97.0 | 0.0 | 0.0 | 2.0 | 0.0 | 98.0 | 0.0 | 0.0 | 1.9 | 0.0 | 98.1 | 0.0 | 0.0 | 3.1 | 0.0 | 96.9 | 0.0 | 0.0 | 3.1 | 0.0 | 96.9 |
| *Other Poultry* [a] | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 3.1 | 0.0 | 96.9 | 0.0 | 0.0 | 0.6 | 0.0 | 99.4 | 0.0 | 0.0 | 2.0 | 0.0 | 98.0 | 0.0 | 0.0 | 2.9 | 0.0 | 97.1 | 0.0 | 0.0 | 3.1 | 0.0 | 96.9 |
| Rabbits | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| Livestock NCAC (weighted average) | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 80.8 | 12.8 | 0.0 | 6.3 | 0.0 | 36.5 | 35.0 | 0.0 | 28.4 | 0.0 | 39.5 | 33.3 | 0.0 | 27.2 | 0.0 | 43.0 | 29.8 | 0.0 | 27.2 | 0.0 | 46.7 | 30.5 | 0.0 | 22.8 | 0.0 | 46.9 | 30.0 | 0.0 | 23.0 |
| *Fattening Sheep Non-Agr.* | 0.0 | 0.0 | 30.7 | 0.0 | 69.3 | 0.0 | 0.0 | 30.7 | 0.0 | 69.3 | 0.0 | 0.0 | 49.0 | 0.0 | 51.0 | 0.0 | 0.0 | 46.2 | 0.0 | 53.8 | 0.0 | 0.0 | 39.9 | 0.0 | 60.1 | 0.0 | 0.0 | 46.3 | 0.0 | 53.7 | 0.0 | 0.0 | 44.4 | 0.0 | 55.6 |
| *Milksheep Non-Agr.* | 0.0 | 0.0 | 11.4 | 0.0 | 88.6 | 0.0 | 0.0 | 11.4 | 0.0 | 88.6 | 0.0 | 0.0 | 43.0 | 0.0 | 57.0 | 0.0 | 0.0 | 33.4 | 0.0 | 66.6 | 0.0 | 0.0 | 24.6 | 0.0 | 75.4 | 0.0 | 0.0 | 33.2 | 0.0 | 66.8 | 0.0 | 0.0 | 27.2 | 0.0 | 72.8 |
| *Total Goats Non-Agr.* | NA | NA | NA | NA | NA | 0.0 | 0.0 | 13.6 | 0.0 | 86.4 | 0.0 | 0.0 | 28.5 | 0.0 | 71.5 | 0.0 | 0.0 | 27.3 | 0.0 | 72.7 | 0.0 | 0.0 | 28.1 | 0.0 | 71.9 | 0.0 | 0.0 | 28.3 | 0.0 | 71.7 | 0.0 | 0.0 | 33.7 | 0.0 | 66.3 |
| *Horses <3 years Non-Agr.* | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 69.0 | 31.0 | 0.0 | 0.0 | 0.0 | 70.5 | 29.5 | 0.0 | 0.0 | 0.0 | 70.0 | 30.0 | 0.0 | 0.0 | 0.0 | 71.5 | 28.5 | 0.0 | 0.0 | 0.0 | 64.9 | 35.1 | 0.0 | 0.0 |
| *Horses >3 years Non-Agr.* | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 78.1 | 21.9 | 0.0 | 0.0 | 0.0 | 77.0 | 23.0 | 0.0 | 0.0 | 0.0 | 77.0 | 23.0 | 0.0 | 0.0 | 0.0 | 79.0 | 21.0 | 0.0 | 0.0 | 0.0 | 77.4 | 22.6 | 0.0 | 0.0 |
| *Mules Non-Agr.* | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 84.0 | 16.0 | 0.0 | 0.0 | 0.0 | 76.7 | 23.3 | 0.0 | 0.0 | 0.0 | 76.9 | 23.1 | 0.0 | 0.0 | 0.0 | 77.9 | 22.1 | 0.0 | 0.0 | 0.0 | 80.4 | 19.6 | 0.0 | 0.0 |
| *Asses Non-Agr.* | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 84.0 | 16.0 | 0.0 | 0.0 | 0.0 | 76.7 | 23.3 | 0.0 | 0.0 | 0.0 | 76.9 | 23.1 | 0.0 | 0.0 | 0.0 | 77.9 | 22.1 | 0.0 | 0.0 | 0.0 | 80.4 | 19.6 | 0.0 | 0.0 |

[a] Other Poultry: Geese, Ducks, Ostriches, Quails

Table A – 22 Manure management system distribution for nitrogen in Switzerland.

| MS Distribution for nitrogen | 1990 | | | | | 1995 | | | | | 2002 | | | | | 2007 | | | | | 2010 | | | | | 2015 | | | | | 2019 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | | | | | % | | | | | % | | | | | % | | | | | % | | | | | % | | | | | % | | | | |
| | Liquid / Slurry | Solid manure | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) | Liquid / Slurry | Solid manure | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) | Liquid / Slurry | Solid manure | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) | Liquid / Slurry | Solid manure | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) | Liquid / Slurry | Solid manure | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) | Liquid / Slurry | Solid manure | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) | Liquid / Slurry | Solid manure | Pasture range and paddock | Digesters | Other (Deep litter, Poultry manure) |
| Mature Dairy Cattle | 65.7 | 25.6 | 8.3 | 0.5 | 0.0 | 67.5 | 22.5 | 9.6 | 0.4 | 0.0 | 65.4 | 17.1 | 16.9 | 0.5 | 0.0 | 68.1 | 13.1 | 17.3 | 1.4 | 0.0 | 68.7 | 12.1 | 17.2 | 2.0 | 0.0 | 69.7 | 9.9 | 16.5 | 3.8 | 0.0 | 68.2 | 9.0 | 16.7 | 6.0 | 0.0 |
| Other Mature Cattle | 41.1 | 28.9 | 29.6 | 0.5 | 0.0 | 38.6 | 31.4 | 29.6 | 0.4 | 0.0 | 43.3 | 19.5 | 36.7 | 0.5 | 0.0 | 53.8 | 17.0 | 27.8 | 1.4 | 0.0 | 53.8 | 14.8 | 29.3 | 2.0 | 0.0 | 54.6 | 12.4 | 29.2 | 3.8 | 0.0 | 49.8 | 13.2 | 31.0 | 6.0 | 0.0 |
| Growing Cattle (weighted average) | 49.5 | 29.9 | 15.8 | 0.5 | 4.4 | 50.0 | 29.3 | 15.9 | 0.4 | 4.4 | 45.3 | 22.3 | 27.1 | 0.5 | 4.8 | 48.7 | 20.3 | 25.2 | 1.4 | 4.4 | 48.6 | 19.5 | 24.8 | 2.0 | 5.1 | 50.9 | 16.7 | 24.1 | 3.8 | 4.5 | 49.6 | 15.7 | 24.3 | 6.0 | 4.4 |
| *Fattening Calves* | *15.9* | *0.0* | *0.0* | *0.5* | *83.6* | *15.6* | *0.0* | *0.0* | *0.4* | *84.0* | *14.9* | *0.0* | *0.7* | *0.5* | *83.9* | *25.2* | *0.0* | *0.4* | *1.4* | *73.0* | *25.5* | *0.0* | *1.0* | *2.0* | *71.5* | *33.5* | *0.0* | *1.2* | *3.8* | *61.4* | *37.5* | *0.0* | *1.7* | *6.0* | *54.8* |
| *Pre-Weaned Calves* | *41.1* | *28.9* | *29.6* | *0.5* | *0.0* | *38.6* | *31.4* | *29.6* | *0.4* | *0.0* | *40.2* | *23.8* | *35.5* | *0.5* | *0.0* | *52.7* | *16.7* | *29.2* | *1.4* | *0.0* | *44.6* | *20.9* | *32.5* | *2.0* | *0.0* | *43.3* | *20.4* | *32.4* | *3.8* | *0.0* | *40.3* | *20.9* | *32.7* | *6.0* | *0.0* |
| *Breeding Cattle 1st Year* | *39.2* | *46.3* | *14.1* | *0.5* | *0.0* | *40.1* | *45.3* | *14.2* | *0.4* | *0.0* | *37.3* | *34.7* | *27.4* | *0.5* | *0.0* | *44.9* | *28.9* | *24.8* | *1.4* | *0.0* | *48.0* | *25.8* | *24.2* | *2.0* | *0.0* | *48.6* | *24.2* | *23.4* | *3.8* | *0.0* | *49.5* | *21.2* | *23.3* | *6.0* | *0.0* |
| *Breeding Cattle 2nd Year* | *47.1* | *27.0* | *25.4* | *0.5* | *0.0* | *48.7* | *25.2* | *25.7* | *0.4* | *0.0* | *41.3* | *21.0* | *37.1* | *0.5* | *0.0* | *44.6* | *18.7* | *35.3* | *1.4* | *0.0* | *46.3* | *16.8* | *34.8* | *2.0* | *0.0* | *45.7* | *15.5* | *35.0* | *3.8* | *0.0* | *47.4* | *12.8* | *33.8* | *6.0* | *0.0* |
| *Breeding Cattle 3rd Year* | *52.4* | *27.1* | *20.0* | *0.5* | *0.0* | *52.9* | *26.3* | *20.4* | *0.4* | *0.0* | *45.7* | *19.6* | *34.2* | *0.5* | *0.0* | *48.9* | *17.2* | *32.6* | *1.4* | *0.0* | *50.8* | *15.4* | *31.8* | *2.0* | *0.0* | *52.7* | *13.3* | *30.2* | *3.8* | *0.0* | *50.5* | *12.8* | *30.7* | *6.0* | *0.0* |
| *Fattening Cattle* | *72.2* | *22.3* | *0.0* | *0.5* | *5.1* | *68.0* | *26.3* | *0.0* | *0.4* | *5.3* | *72.5* | *20.5* | *4.0* | *0.5* | *2.4* | *64.8* | *24.3* | *6.8* | *1.4* | *2.6* | *60.3* | *28.4* | *5.9* | *2.0* | *3.3* | *68.3* | *19.1* | *6.3* | *3.8* | *2.4* | *60.6* | *21.4* | *9.2* | *6.0* | *2.7* |
| Sheep (weighted average) | 0.0 | 0.0 | 30.1 | 0.0 | 69.9 | 0.0 | 0.0 | 30.3 | 0.0 | 69.7 | 0.0 | 0.0 | 48.7 | 0.0 | 51.3 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 38.8 | 0.0 | 61.2 | 0.0 | 0.0 | 45.3 | 0.0 | 54.7 | 0.0 | 0.0 | 42.9 | 0.0 | 57.1 |
| *Fattening Sheep* | *0.0* | *0.0* | *30.7* | *0.0* | *69.3* | *0.0* | *0.0* | *30.7* | *0.0* | *69.3* | *0.0* | *0.0* | *49.0* | *0.0* | *51.0* | *0.0* | *0.0* | *46.2* | *0.0* | *53.8* | *0.0* | *0.0* | *39.9* | *0.0* | *60.1* | *0.0* | *0.0* | *46.3* | *0.0* | *53.7* | *0.0* | *0.0* | *44.4* | *0.0* | *55.6* |
| *Milksheep* | *0.0* | *0.0* | *11.4* | *0.0* | *88.6* | *0.0* | *0.0* | *11.4* | *0.0* | *88.6* | *0.0* | *0.0* | *43.0* | *0.0* | *57.0* | *0.0* | *0.0* | *33.4* | *0.0* | *66.6* | *0.0* | *0.0* | *24.6* | *0.0* | *75.4* | *0.0* | *0.0* | *33.2* | *0.0* | *66.8* | *0.0* | *0.0* | *27.2* | *0.0* | *72.8* |
| Swine (weighted average) | 98.9 | 0.0 | 0.0 | 1.1 | 0.0 | 99.0 | 0.0 | 0.0 | 1.0 | 0.0 | 97.4 | 1.0 | 0.3 | 1.3 | 0.0 | 95.3 | 0.2 | 0.9 | 3.7 | 0.0 | 94.2 | 0.2 | 0.3 | 5.3 | 0.0 | 89.2 | 0.1 | 0.1 | 10.7 | 0.0 | 81.6 | 0.0 | 0.1 | 18.3 | 0.0 |
| *Piglets* | *98.9* | *0.0* | *0.0* | *1.1* | *0.0* | *99.0* | *0.0* | *0.0* | *1.0* | *0.0* | *96.5* | *2.2* | *0.0* | *1.3* | *0.0* | *95.0* | *0.8* | *0.6* | *3.7* | *0.0* | *92.7* | *1.9* | *0.0* | *5.3* | *0.0* | *89.2* | *0.1* | *0.0* | *10.7* | *0.0* | *81.3* | *0.4* | *0.0* | *18.3* | *0.0* |
| *Fattening Pig over 25 kg* | *98.9* | *0.0* | *0.0* | *1.1* | *0.0* | *99.0* | *0.0* | *0.0* | *1.0* | *0.0* | *97.6* | *0.7* | *0.4* | *1.3* | *0.0* | *95.4* | *0.0* | *0.9* | *3.7* | *0.0* | *94.3* | *0.0* | *0.4* | *5.3* | *0.0* | *89.1* | *0.1* | *0.1* | *10.7* | *0.0* | *81.7* | *0.0* | *0.0* | *18.3* | *0.0* |
| *Dry Sows* | *98.9* | *0.0* | *0.0* | *1.1* | *0.0* | *99.0* | *0.0* | *0.0* | *1.0* | *0.0* | *97.7* | *0.7* | *0.3* | *1.3* | *0.0* | *95.1* | *0.2* | *1.0* | *3.7* | *0.0* | *94.2* | *0.2* | *0.3* | *5.3* | *0.0* | *89.2* | *0.0* | *0.1* | *10.7* | *0.0* | *81.6* | *0.0* | *0.1* | *18.3* | *0.0* |
| *Nursing Sows* | *98.9* | *0.0* | *0.0* | *1.1* | *0.0* | *99.0* | *0.0* | *0.0* | *1.0* | *0.0* | *95.7* | *3.0* | *0.0* | *1.3* | *0.0* | *95.4* | *0.5* | *0.5* | *3.7* | *0.0* | *94.3* | *0.4* | *0.0* | *5.3* | *0.0* | *89.3* | *0.0* | *0.0* | *10.7* | *0.0* | *81.7* | *0.0* | *0.1* | *18.3* | *0.0* |
| *Boars* | *98.9* | *0.0* | *0.0* | *1.1* | *0.0* | *99.0* | *0.0* | *0.0* | *1.0* | *0.0* | *97.2* | *1.0* | *0.5* | *1.3* | *0.0* | *95.2* | *0.0* | *1.1* | *3.7* | *0.0* | *93.4* | *0.7* | *0.6* | *5.3* | *0.0* | *89.1* | *0.0* | *0.2* | *10.7* | *0.0* | *80.9* | *0.0* | *0.9* | *18.3* | *0.0* |
| Buffalo (weighted average) | NA | NA | NA | NA | NA | 0.0 | 70.8 | 29.2 | 0.0 | 0.0 | 0.0 | 64.2 | 35.8 | 0.0 | 0.0 | 0.0 | 63.8 | 36.2 | 0.0 | 0.0 | 0.0 | 65.0 | 35.0 | 0.0 | 0.0 | 0.0 | 64.4 | 35.6 | 0.0 | 0.0 | 0.0 | 65.6 | 34.4 | 0.0 | 0.0 |
| *Bisons < 3 years* | *0.0* | *70.8* | *29.2* | *0.0* | *0.0* | *0.0* | *70.8* | *29.2* | *0.0* | *0.0* | *0.0* | *64.2* | *35.8* | *0.0* | *0.0* | *0.0* | *63.8* | *36.2* | *0.0* | *0.0* | *0.0* | *65.0* | *35.0* | *0.0* | *0.0* | *0.0* | *64.4* | *35.6* | *0.0* | *0.0* | *0.0* | *65.6* | *34.4* | *0.0* | *0.0* |
| *Bisons > 3 years* | *0.0* | *70.8* | *29.2* | *0.0* | *0.0* | *0.0* | *70.8* | *29.2* | *0.0* | *0.0* | *0.0* | *64.2* | *35.8* | *0.0* | *0.0* | *0.0* | *63.8* | *36.2* | *0.0* | *0.0* | *0.0* | *65.0* | *35.0* | *0.0* | *0.0* | *0.0* | *64.4* | *35.6* | *0.0* | *0.0* | *0.0* | *65.6* | *34.4* | *0.0* | *0.0* |
| Camels (weighted average) | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.0 | 0.0 | 47.2 | 0.0 | 52.8 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 38.4 | 0.0 | 61.6 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 43.7 | 0.0 | 56.3 |
| *Llamas < 2 years* | *0.0* | *0.0* | *35.7* | *0.0* | *64.3* | *0.0* | *0.0* | *35.7* | *0.0* | *64.3* | *0.0* | *0.0* | *47.2* | *0.0* | *52.8* | *0.0* | *0.0* | *45.4* | *0.0* | *54.6* | *0.0* | *0.0* | *38.4* | *0.0* | *61.6* | *0.0* | *0.0* | *45.4* | *0.0* | *54.6* | *0.0* | *0.0* | *43.7* | *0.0* | *56.3* |
| *Llamas > 2 years* | *0.0* | *0.0* | *35.7* | *0.0* | *64.3* | *0.0* | *0.0* | *35.7* | *0.0* | *64.3* | *0.0* | *0.0* | *47.2* | *0.0* | *52.8* | *0.0* | *0.0* | *45.4* | *0.0* | *54.6* | *0.0* | *0.0* | *38.4* | *0.0* | *61.6* | *0.0* | *0.0* | *45.4* | *0.0* | *54.6* | *0.0* | *0.0* | *43.7* | *0.0* | *56.3* |
| *Alpacas < 2 years* | *0.0* | *0.0* | *35.7* | *0.0* | *64.3* | *0.0* | *0.0* | *35.7* | *0.0* | *64.3* | *0.0* | *0.0* | *47.2* | *0.0* | *52.8* | *0.0* | *0.0* | *45.4* | *0.0* | *54.6* | *0.0* | *0.0* | *38.4* | *0.0* | *61.6* | *0.0* | *0.0* | *45.4* | *0.0* | *54.6* | *0.0* | *0.0* | *43.7* | *0.0* | *56.3* |
| *Alpacas > 2 years* | *0.0* | *0.0* | *35.7* | *0.0* | *64.3* | *0.0* | *0.0* | *35.7* | *0.0* | *64.3* | *0.0* | *0.0* | *47.2* | *0.0* | *52.8* | *0.0* | *0.0* | *45.4* | *0.0* | *54.6* | *0.0* | *0.0* | *38.4* | *0.0* | *61.6* | *0.0* | *0.0* | *45.4* | *0.0* | *54.6* | *0.0* | *0.0* | *43.7* | *0.0* | *56.3* |
| Deer (weighted average) | 0.0 | 0.0 | 35.7 | 0.0 | 64.3 | 0.0 | 0.0 | 35.7 | 0.0 | 64.3 | 0.0 | 0.0 | 47.2 | 0.0 | 52.8 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 38.4 | 0.0 | 61.6 | 0.0 | 0.0 | 45.4 | 0.0 | 54.6 | 0.0 | 0.0 | 43.7 | 0.0 | 56.3 |
| *Fallow Deer* | *0.0* | *0.0* | *35.7* | *0.0* | *64.3* | *0.0* | *0.0* | *35.7* | *0.0* | *64.3* | *0.0* | *0.0* | *47.2* | *0.0* | *52.8* | *0.0* | *0.0* | *45.4* | *0.0* | *54.6* | *0.0* | *0.0* | *38.4* | *0.0* | *61.6* | *0.0* | *0.0* | *45.4* | *0.0* | *54.6* | *0.0* | *0.0* | *43.7* | *0.0* | *56.3* |
| *Red Deer* | *0.0* | *0.0* | *35.7* | *0.0* | *64.3* | *0.0* | *0.0* | *35.7* | *0.0* | *64.3* | *0.0* | *0.0* | *47.2* | *0.0* | *52.8* | *0.0* | *0.0* | *45.4* | *0.0* | *54.6* | *0.0* | *0.0* | *38.4* | *0.0* | *61.6* | *0.0* | *0.0* | *45.4* | *0.0* | *54.6* | *0.0* | *0.0* | *43.7* | *0.0* | *56.3* |
| Goats | 0.0 | 0.0 | 13.6 | 0.0 | 86.4 | 0.0 | 0.0 | 13.6 | 0.0 | 86.4 | 0.0 | 0.0 | 28.5 | 0.0 | 71.5 | 0.0 | 0.0 | 27.3 | 0.0 | 72.7 | 0.0 | 0.0 | 28.1 | 0.0 | 71.9 | 0.0 | 0.0 | 28.3 | 0.0 | 71.7 | 0.0 | 0.0 | 33.7 | 0.0 | 66.3 |
| *Goat Places* | *0.0* | *0.0* | *13.6* | *0.0* | *86.4* | *0.0* | *0.0* | *13.6* | *0.0* | *86.4* | *0.0* | *0.0* | *28.5* | *0.0* | *71.5* | *0.0* | *0.0* | *27.3* | *0.0* | *72.7* | *0.0* | *0.0* | *28.1* | *0.0* | *71.9* | *0.0* | *0.0* | *28.3* | *0.0* | *71.7* | *0.0* | *0.0* | *33.7* | *0.0* | *66.3* |
| Horses (weighted average) | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 76.5 | 23.5 | 0.0 | 0.0 | 0.0 | 76.0 | 24.0 | 0.0 | 0.0 | 0.0 | 76.1 | 23.9 | 0.0 | 0.0 | 0.0 | 78.4 | 21.6 | 0.0 | 0.0 | 0.0 | 76.6 | 23.4 | 0.0 | 0.0 |
| *Horses <3 years* | *0.0* | *87.2* | *12.8* | *0.0* | *0.0* | *0.0* | *87.2* | *12.8* | *0.0* | *0.0* | *0.0* | *69.0* | *31.0* | *0.0* | *0.0* | *0.0* | *70.5* | *29.5* | *0.0* | *0.0* | *0.0* | *70.0* | *30.0* | *0.0* | *0.0* | *0.0* | *71.5* | *28.5* | *0.0* | *0.0* | *0.0* | *64.9* | *35.1* | *0.0* | *0.0* |
| *Horses >3 years* | *0.0* | *87.2* | *12.8* | *0.0* | *0.0* | *0.0* | *87.2* | *12.8* | *0.0* | *0.0* | *0.0* | *78.1* | *21.9* | *0.0* | *0.0* | *0.0* | *77.0* | *23.0* | *0.0* | *0.0* | *0.0* | *77.0* | *23.0* | *0.0* | *0.0* | *0.0* | *79.0* | *21.0* | *0.0* | *0.0* | *0.0* | *77.4* | *22.6* | *0.0* | *0.0* |
| Mules and Asses (weighted average) | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 84.0 | 16.0 | 0.0 | 0.0 | 0.0 | 76.7 | 23.3 | 0.0 | 0.0 | 0.0 | 76.9 | 23.1 | 0.0 | 0.0 | 0.0 | 77.9 | 22.1 | 0.0 | 0.0 | 0.0 | 80.4 | 19.6 | 0.0 | 0.0 |
| *Mules* | *0.0* | *87.2* | *12.8* | *0.0* | *0.0* | *0.0* | *87.2* | *12.8* | *0.0* | *0.0* | *0.0* | *84.0* | *16.0* | *0.0* | *0.0* | *0.0* | *76.7* | *23.3* | *0.0* | *0.0* | *0.0* | *76.9* | *23.1* | *0.0* | *0.0* | *0.0* | *77.9* | *22.1* | *0.0* | *0.0* | *0.0* | *80.4* | *19.6* | *0.0* | *0.0* |
| *Asses* | *0.0* | *87.2* | *12.8* | *0.0* | *0.0* | *0.0* | *87.2* | *12.8* | *0.0* | *0.0* | *0.0* | *84.0* | *16.0* | *0.0* | *0.0* | *0.0* | *76.7* | *23.3* | *0.0* | *0.0* | *0.0* | *76.9* | *23.1* | *0.0* | *0.0* | *0.0* | *77.9* | *22.1* | *0.0* | *0.0* | *0.0* | *80.4* | *19.6* | *0.0* | *0.0* |
| Poultry (weighted average) | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.5 | 0.0 | 99.5 | 0.0 | 0.0 | 2.7 | 0.0 | 97.3 | 0.0 | 0.0 | 3.2 | 0.0 | 96.8 | 0.0 | 0.0 | 2.8 | 0.0 | 97.2 | 0.0 | 0.0 | 3.0 | 0.0 | 97.0 | 0.0 | 0.0 | 3.4 | 0.0 | 96.6 |
| *Growers* | *0.0* | *0.0* | *0.0* | *0.0* | *100.0* | *0.0* | *0.0* | *0.6* | *0.0* | *99.4* | *0.0* | *0.0* | *0.5* | *0.0* | *99.5* | *0.0* | *0.0* | *1.2* | *0.0* | *98.8* | *0.0* | *0.0* | *1.9* | *0.0* | *98.1* | *0.0* | *0.0* | *1.4* | *0.0* | *98.6* | *0.0* | *0.0* | *2.5* | *0.0* | *97.5* |
| *Layers* | *0.0* | *0.0* | *0.0* | *0.0* | *100.0* | *0.0* | *0.0* | *0.6* | *0.0* | *99.4* | *0.0* | *0.0* | *5.3* | *0.0* | *94.7* | *0.0* | *0.0* | *6.8* | *0.0* | *93.2* | *0.0* | *0.0* | *6.9* | *0.0* | *93.1* | *0.0* | *0.0* | *7.0* | *0.0* | *93.0* | *0.0* | *0.0* | *7.1* | *0.0* | *92.9* |
| *Broilers* | *0.0* | *0.0* | *0.0* | *0.0* | *100.0* | *0.0* | *0.0* | *0.4* | *0.0* | *99.6* | *0.0* | *0.0* | *0.7* | *0.0* | *99.3* | *0.0* | *0.0* | *1.1* | *0.0* | *98.9* | *0.0* | *0.0* | *0.4* | *0.0* | *99.6* | *0.0* | *0.0* | *0.3* | *0.0* | *99.7* | *0.0* | *0.0* | *0.5* | *0.0* | *99.5* |
| *Turkey* | *0.0* | *0.0* | *0.0* | *0.0* | *100.0* | *0.0* | *0.0* | *0.4* | *0.0* | *99.6* | *0.0* | *0.0* | *3.0* | *0.0* | *97.0* | *0.0* | *0.0* | *2.0* | *0.0* | *98.0* | *0.0* | *0.0* | *1.9* | *0.0* | *98.1* | *0.0* | *0.0* | *3.1* | *0.0* | *96.9* | *0.0* | *0.0* | *3.1* | *0.0* | *96.9* |
| *Other Poultry* [a] | *0.0* | *0.0* | *0.0* | *0.0* | *100.0* | *0.0* | *0.0* | *0.0* | *0.0* | *100.0* | *0.0* | *0.0* | *3.1* | *0.0* | *96.9* | *0.0* | *0.0* | *0.6* | *0.0* | *99.4* | *0.0* | *0.0* | *2.0* | *0.0* | *98.0* | *0.0* | *0.0* | *2.9* | *0.0* | *97.1* | *0.0* | *0.0* | *3.1* | *0.0* | *96.9* |
| Rabbits | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| Livestock NCAC (weighted average) | 0.0 | 87.2 | 12.8 | 0.0 | 0.0 | 0.0 | 80.8 | 12.8 | 0.0 | 6.3 | 0.0 | 36.5 | 35.0 | 0.0 | 28.4 | 0.0 | 39.5 | 33.3 | 0.0 | 27.2 | 0.0 | 43.0 | 29.8 | 0.0 | 27.2 | 0.0 | 46.7 | 30.5 | 0.0 | 22.8 | 0.0 | 46.4 | 30.2 | 0.0 | 23.4 |
| *Fattening Sheep Non-Agr.* | *0.0* | *0.0* | *30.7* | *0.0* | *69.3* | *0.0* | *0.0* | *30.7* | *0.0* | *69.3* | *0.0* | *0.0* | *49.0* | *0.0* | *51.0* | *0.0* | *0.0* | *46.2* | *0.0* | *53.8* | *0.0* | *0.0* | *39.9* | *0.0* | *60.1* | *0.0* | *0.0* | *46.3* | *0.0* | *53.7* | *0.0* | *0.0* | *44.4* | *0.0* | *55.6* |
| *Milksheep Non-Agr.* | *0.0* | *0.0* | *11.4* | *0.0* | *88.6* | *0.0* | *0.0* | *11.4* | *0.0* | *88.6* | *0.0* | *0.0* | *43.0* | *0.0* | *57.0* | *0.0* | *0.0* | *33.4* | *0.0* | *66.6* | *0.0* | *0.0* | *24.6* | *0.0* | *75.4* | *0.0* | *0.0* | *33.2* | *0.0* | *66.8* | *0.0* | *0.0* | *27.2* | *0.0* | *72.8* |
| *Total Goats Non-Agr.* | *NA* | *NA* | *NA* | *NA* | *NA* | *0.0* | *0.0* | *13.6* | *0.0* | *86.4* | *0.0* | *0.0* | *28.5* | *0.0* | *71.5* | *0.0* | *0.0* | *27.3* | *0.0* | *72.7* | *0.0* | *0.0* | *28.1* | *0.0* | *71.9* | *0.0* | *0.0* | *28.3* | *0.0* | *71.7* | *0.0* | *0.0* | *33.7* | *0.0* | *66.3* |
| *Horses <3 years Non-Agr.* | *0.0* | *87.2* | *12.8* | *0.0* | *0.0* | *0.0* | *87.2* | *12.8* | *0.0* | *0.0* | *0.0* | *69.0* | *31.0* | *0.0* | *0.0* | *0.0* | *70.5* | *29.5* | *0.0* | *0.0* | *0.0* | *70.0* | *30.0* | *0.0* | *0.0* | *0.0* | *71.5* | *28.5* | *0.0* | *0.0* | *0.0* | *64.9* | *35.1* | *0.0* | *0.0* |
| *Horses >3 years Non-Agr.* | *0.0* | *87.2* | *12.8* | *0.0* | *0.0* | *0.0* | *87.2* | *12.8* | *0.0* | *0.0* | *0.0* | *78.1* | *21.9* | *0.0* | *0.0* | *0.0* | *77.0* | *23.0* | *0.0* | *0.0* | *0.0* | *77.0* | *23.0* | *0.0* | *0.0* | *0.0* | *79.0* | *21.0* | *0.0* | *0.0* | *0.0* | *77.4* | *22.6* | *0.0* | *0.0* |
| *Mules Non-Agr.* | *0.0* | *87.2* | *12.8* | *0.0* | *0.0* | *0.0* | *87.2* | *12.8* | *0.0* | *0.0* | *0.0* | *84.0* | *16.0* | *0.0* | *0.0* | *0.0* | *76.7* | *23.3* | *0.0* | *0.0* | *0.0* | *76.9* | *23.1* | *0.0* | *0.0* | *0.0* | *77.9* | *22.1* | *0.0* | *0.0* | *0.0* | *80.4* | *19.6* | *0.0* | *0.0* |
| *Asses Non-Agr.* | *0.0* | *87.2* | *12.8* | *0.0* | *0.0* | *0.0* | *87.2* | *12.8* | *0.0* | *0.0* | *0.0* | *84.0* | *16.0* | *0.0* | *0.0* | *0.0* | *76.7* | *23.3* | *0.0* | *0.0* | *0.0* | *76.9* | *23.1* | *0.0* | *0.0* | *0.0* | *77.9* | *22.1* | *0.0* | *0.0* | *0.0* | *80.4* | *19.6* | *0.0* | *0.0* |

[a] Other Poultry: Geese, Ducks, Ostriches, Quails

Table A – 23 Nitrogen excretion of livestock in Switzerland.

| Nitrogen Excretion | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | kg N/head or place/year | | | | | | | | | | | | | | | |
| Mature Dairy Cattle | 100.4 | 100.7 | 100.9 | 101.1 | 101.3 | 101.5 | 102.1 | 102.6 | 103.1 | 103.6 | 104.1 | 104.6 | 105.1 | 105.8 | 106.6 | 107.4 |
| Other Mature Cattle | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 |
| Growing Cattle (weighted average) | 33.0 | 33.0 | 33.0 | 33.0 | 33.1 | 33.1 | 33.0 | 33.2 | 32.9 | 32.4 | 33.1 | 32.7 | 32.6 | 32.7 | 32.7 | 32.6 |
| *Fattening Calves* | *13.0* | *13.0* | *13.0* | *13.0* | *13.0* | *13.0* | *13.0* | *13.0* | *13.0* | *13.0* | *13.0* | *13.0* | *13.0* | *13.4* | *13.8* | *14.2* |
| *Pre-Weaned Calves* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* |
| *Breeding Cattle 1st Year* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* |
| *Breeding Cattle 2nd Year* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* |
| *Breeding Cattle 3rd Year* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* |
| *Fattening Cattle* | *33.0* | *33.0* | *33.0* | *33.0* | *33.0* | *33.0* | *33.0* | *33.0* | *33.0* | *33.0* | *33.0* | *33.0* | *33.0* | *33.4* | *33.8* | *34.2* |
| Sheep (weighted average) | 7.5 | 7.6 | 7.5 | 7.6 | 7.6 | 7.6 | 7.6 | 7.6 | 7.6 | 8.1 | 8.0 | 8.1 | 8.0 | 8.1 | 8.1 | 8.1 |
| *Fattening Sheep* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* |
| *Milksheep* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* |
| Swine (weighted average) | 14.3 | 14.3 | 14.3 | 14.1 | 14.0 | 14.0 | 13.6 | 13.0 | 12.5 | 11.6 | 11.0 | 10.5 | 10.1 | 9.9 | 9.7 | 9.6 |
| *Piglets* | *4.6* | *4.6* | *4.6* | *4.6* | *4.6* | *4.6* | *4.6* | *4.6* | *4.7* | *4.7* | *4.7* | *4.7* | *4.8* | *4.7* | *4.6* | *4.5* |
| *Fattening Pig over 25 kg* | *18.2* | *18.1* | *18.0* | *18.0* | *17.9* | *17.8* | *17.1* | *16.4* | *15.7* | *15.1* | *14.4* | *13.7* | *13.0* | *12.8* | *12.5* | *12.3* |
| *Dry Sows* | *22.6* | *22.6* | *22.6* | *22.6* | *22.6* | *22.6* | *22.2* | *21.9* | *21.5* | *21.1* | *20.7* | *20.4* | *20.0* | *20.1* | *20.1* | *20.2* |
| *Nursing Sows* | *49.3* | *49.3* | *49.3* | *49.3* | *49.3* | *49.3* | *47.6* | *45.8* | *44.1* | *42.4* | *40.7* | *38.9* | *37.2* | *37.3* | *37.4* | *37.6* |
| *Boars* | *18.9* | *18.9* | *18.9* | *18.9* | *18.9* | *18.9* | *18.2* | *17.6* | *16.9* | *16.2* | *15.6* | *14.9* | *14.3* | *14.3* | *14.3* | *14.3* |
| Buffalo (weighted average) | NA | NA | 36.5 | 37.8 | 37.5 | 37.2 | 37.3 | 37.1 | 37.3 | 34.9 | 41.1 | 37.5 | 38.8 | 37.4 | 38.5 | 38.7 |
| *Bisons < 3 years* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* |
| *Bisons > 3 years* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* |
| Camels (weighted average) | NA | NA | NA | NA | NA | NA | 15.3 | 15.3 | 15.3 | 14.0 | 14.1 | 13.0 | 13.3 | 13.7 | 13.3 | 12.8 |
| *Llamas < 2 years* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* |
| *Llamas > 2 years* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* |
| *Alpacas < 2 years* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* |
| *Alpacas > 2 years* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* |
| Deer (weighted average) | 20.0 | 20.4 | 21.2 | 21.6 | 21.8 | 21.9 | 23.6 | 21.9 | 21.7 | 22.0 | 22.3 | 22.1 | 22.4 | 21.8 | 22.0 | 21.9 |
| *Fallow Deer* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* |
| *Red Deer* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* |
| Goats | 11.2 | 11.2 | 11.2 | 11.2 | 11.1 | 11.1 | 11.1 | 11.1 | 11.2 | 11.3 | 11.3 | 11.4 | 11.1 | 11.3 | 11.1 | 11.1 |
| *Goat Places* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* |
| Horses (weighted average) | 43.6 | 43.6 | 43.6 | 43.6 | 43.5 | 43.5 | 43.5 | 43.6 | 43.6 | 43.5 | 43.6 | 43.6 | 43.6 | 43.6 | 43.7 | 43.7 |
| *Horses <3 years* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* |
| *Horses >3 years* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* |
| Mules and Asses (weighted average) | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 |
| *Mules* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* |
| *Asses* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* |
| Poultry (weighted average) | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| *Growers* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* |
| *Layers* | *0.7* | *0.7* | *0.7* | *0.7* | *0.7* | *0.7* | *0.7* | *0.7* | *0.7* | *0.7* | *0.7* | *0.7* | *0.7* | *0.7* | *0.7* | *0.8* |
| *Broilers* | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* |
| *Turkey* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* |
| *Other Poultry* [a] | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* |
| Rabbits | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Livestock NCAC (weighted average) | 36.5 | 36.2 | 36.0 | 35.4 | 36.8 | 29.4 | 14.0 | 12.2 | 12.2 | 12.4 | 12.5 | 12.2 | 12.8 | 13.0 | 13.0 | 13.0 |
| *Fattening Sheep Non-Agr.* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* |
| *Milksheep Non-Agr.* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* |
| *Total Goats Non-Agr.* | *NA* | *NA* | *NA* | *NA* | *NA* | *12.0* | *11.2* | *11.0* | *11.1* | *11.8* | *11.2* | *11.4* | *11.2* | *11.1* | *11.2* | *11.6* |
| *Horses <3 years Non-Agr.* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* |
| *Horses >3 years Non-Agr.* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* |
| *Mules Non-Agr.* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* |
| *Asses Non-Agr.* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* |

| Nitrogen Excretion | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | kg N/head or place/year | | | | | | | | | | | | | | |
| Mature Dairy Cattle | 108.2 | 108.9 | 109.3 | 109.7 | 110.1 | 110.3 | 110.5 | 110.7 | 110.9 | 111.1 | 111.1 | 111.2 | 111.3 | 111.4 | 111.4 |
| Other Mature Cattle | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 |
| Growing Cattle (weighted average) | 32.7 | 32.7 | 32.9 | 32.8 | 32.7 | 32.8 | 33.0 | 33.1 | 33.1 | 33.1 | 33.0 | 32.9 | 32.8 | 32.7 | 32.6 |
| *Fattening Calves* | *14.6* | *15.0* | *15.3* | *15.7* | *16.0* | *16.4* | *16.8* | *17.2* | *17.6* | *18.0* | *18.0* | *18.0* | *18.0* | *18.0* | *18.0* |
| *Pre-Weaned Calves* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* |
| *Breeding Cattle 1st Year* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* |
| *Breeding Cattle 2nd Year* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* |
| *Breeding Cattle 3rd Year* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* |
| *Fattening Cattle* | *34.6* | *35.0* | *35.3* | *35.7* | *36.0* | *36.4* | *36.8* | *37.2* | *37.6* | *38.0* | *38.0* | *38.0* | *38.0* | *38.0* | *38.0* |
| Sheep (weighted average) | 8.2 | 8.2 | 8.2 | 8.4 | 8.5 | 8.4 | 8.5 | 8.6 | 8.5 | 8.4 | 8.4 | 8.5 | 8.5 | 8.5 | 8.5 |
| *Fattening Sheep* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* |
| *Milksheep* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* |
| Swine (weighted average) | 9.4 | 9.2 | 9.2 | 9.3 | 9.2 | 9.2 | 9.1 | 9.1 | 9.1 | 9.1 | 9.1 | 9.1 | 9.1 | 9.1 | 9.1 |
| *Piglets* | *4.4* | *4.3* | *4.3* | *4.3* | *4.3* | *4.1* | *3.9* | *3.7* | *3.6* | *3.4* | *3.4* | *3.4* | *3.4* | *3.4* | *3.4* |
| *Fattening Pig over 25 kg* | *12.0* | *11.8* | *11.8* | *11.8* | *11.8* | *11.7* | *11.6* | *11.4* | *11.3* | *11.2* | *11.2* | *11.2* | *11.3* | *11.3* | *11.3* |
| *Dry Sows* | *20.3* | *20.3* | *20.2* | *20.1* | *20.0* | *21.0* | *22.0* | *22.9* | *23.9* | *24.9* | *24.9* | *24.9* | *24.8* | *24.8* | *24.8* |
| *Nursing Sows* | *37.7* | *37.8* | *37.9* | *37.9* | *38.0* | *38.5* | *39.1* | *39.6* | *40.1* | *40.7* | *40.7* | *40.7* | *40.8* | *40.8* | *40.8* |
| *Boars* | *14.3* | *14.3* | *14.3* | *14.3* | *14.3* | *14.3* | *14.3* | *14.3* | *14.3* | *14.3* | *14.3* | *14.3* | *14.3* | *14.3* | *14.3* |
| Buffalo (weighted average) | 38.0 | 34.9 | 34.4 | 36.5 | 37.3 | 38.4 | 36.9 | 36.9 | 36.4 | 36.4 | 36.4 | 35.9 | 47.1 | 45.9 | 45.7 |
| *Bisons < 3 years* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* |
| *Bisons > 3 years* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* | *60.0* |
| Camels (weighted average) | 12.8 | 12.8 | 12.8 | 12.8 | 12.6 | 12.7 | 12.8 | 12.9 | 12.8 | 12.7 | 12.6 | 12.6 | 12.5 | 12.6 | 12.6 |
| *Llamas < 2 years* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* |
| *Llamas > 2 years* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* |
| *Alpacas < 2 years* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* | *7.0* |
| *Alpacas > 2 years* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* | *11.0* |
| Deer (weighted average) | 22.1 | 22.1 | 22.4 | 22.5 | 22.4 | 22.4 | 22.5 | 23.0 | 23.0 | 23.0 | 23.1 | 23.3 | 23.4 | 23.6 | 23.6 |
| *Fallow Deer* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* |
| *Red Deer* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* |
| Goats | 11.3 | 11.2 | 11.2 | 11.4 | 11.2 | 11.4 | 11.5 | 11.6 | 11.6 | 11.4 | 11.4 | 11.4 | 11.4 | 11.4 | 11.4 |
| *Goat Places* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* | *17.0* |
| Horses (weighted average) | 43.7 | 43.7 | 43.7 | 43.7 | 43.7 | 43.7 | 43.7 | 43.8 | 43.8 | 43.8 | 43.8 | 43.9 | 43.9 | 43.9 | 43.9 |
| *Horses <3 years* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* |
| *Horses >3 years* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* |
| Mules and Asses (weighted average) | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 |
| *Mules* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* |
| *Asses* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* |
| Poultry (weighted average) | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| *Growers* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* | *0.3* |
| *Layers* | *0.8* | *0.8* | *0.8* | *0.8* | *0.8* | *0.8* | *0.8* | *0.8* | *0.8* | *0.8* | *0.8* | *0.8* | *0.8* | *0.8* | *0.8* |
| *Broilers* | *0.4* | *0.5* | *0.5* | *0.5* | *0.5* | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* | *0.4* |
| *Turkey* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* | *1.4* |
| *Other Poultry* [a] | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* | *0.6* |
| Rabbits | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Livestock NCAC (weighted average) | 13.0 | 13.6 | 13.8 | 14.0 | 14.7 | 15.2 | 15.4 | 15.9 | 15.7 | 15.8 | 16.1 | 16.1 | 14.7 | 14.9 | 15.0 |
| *Fattening Sheep Non-Agr.* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* | *15.0* |
| *Milksheep Non-Agr.* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* | *20.0* |
| *Total Goats Non-Agr.* | *11.2* | *10.9* | *11.1* | *10.8* | *10.7* | *11.8* | *11.9* | *11.9* | *12.0* | *11.5* | *11.4* | *11.4* | *11.5* | *11.4* | *11.4* |
| *Horses <3 years Non-Agr.* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* | *42.0* |
| *Horses >3 years Non-Agr.* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* | *44.0* |
| *Mules Non-Agr.* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* |
| *Asses Non-Agr.* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* | *16.0* |

[a] Other Poultry: Geese, Ducks, Ostriches, Quails

## A3.3.3 Additional data for estimating $N_2O$ emissions from 3D Agricultural soils

Table A – 24 Additional data for estimating $N_2O$ emission from crop residues.

| 2020 | | Total crop production<br>t DM | Nitrogen incorporated with crop residues $F_{(CR)}$<br>t N | $N_2O$ emissions from crop residues<br>t $N_2O$ |
|---|---|---|---|---|
| **1. Cereals** | Wheat | 425'838 | 1'784 | 28.03 |
| | Barley | 163'243 | 832 | 13.08 |
| | Maize | 186'738 | 1'758 | 27.62 |
| | Oats | 7'569 | 47 | 0.74 |
| | Rye | 8'783 | 37 | 0.58 |
| | | | | |
| | Other: | | | |
| | Triticale | 39'841 | 195 | 3.07 |
| | Spelt | 20'073 | 184 | 2.89 |
| | Mix of Fodder Cereals | 1'154 | 6 | 0.09 |
| | Mix of Bread Cereals | 174 | 1 | 0.01 |
| | Millet | 146 | 4 | 0.06 |
| **2. Pulse** | Dry Beans | 1'641 | 65 | 1.02 |
| | Peas (Eiweisserbsen) | 8'645 | 254 | 4.00 |
| | Soybeans | 4'460 | 184 | 2.89 |
| | Leguminous Vegetables | 2'829 | 295 | 4.63 |
| | Lupines | 440 | 18 | 0.28 |
| **3. Tuber and Root** | Potatoes | 104'764 | 383 | 6.01 |
| | Other: | | | |
| | Fodder Beet | 6'544 | 47 | 0.74 |
| | Sugar Beet | 286'989 | 2'048 | 32.18 |
| **5. Other** | Fruit | 50'594 | 472 | 7.42 |
| | Grass | 5'688'966'744 | 25'921 | 407.33 |
| | Green Corn | 139'255 | 132 | 2.08 |
| | Non-Leguminous Vegetables | 56'304 | 666 | 10.46 |
| | Rape | 79'275 | 1'359 | 21.36 |
| | Renewable Energy Crops | 711 | 12 | 0.19 |
| | Silage Corn | 819'145 | 483 | 7.58 |
| | Sunflowers | 10'449 | 221 | 3.48 |
| | Tobacco | 940 | 25 | 0.39 |
| | Berries | 3'202 | 56 | 0.88 |
| | Vine | 21'148 | 370 | 5.82 |
| | Oil Squash | 9 | 0 | 0.00 |
| | Oil Hemp | 23 | 1 | 0.02 |
| | Oil Flax | 258 | 2 | 0.03 |
| | Hops | 42 | 0 | 0.00 |
| | Medicinal Plants and Herbs | 386 | 32 | 0.50 |
| **Total Non-leguminous** | | 2'433'597 | 11'156 | 175.31 |
| **Total Leguminous** | | 18'014 | 815 | 12.81 |
| **Total excluding grass** | | 2'451'612 | 11'972 | 188.13 |
| **Total including grass** | | 5'691'418'356 | 37'893 | 595.46 |

Table A – 25 Additional data for estimating $N_2O$ emission from crop residues (fractions).

| 2020 | | Residue/ Crop ratio<br>kg/kg | Dry matter fraction of residue<br>kg/kg | Nitrogen content of residues<br>kg/kg |
|---|---|---|---|---|
| **1. Cereals** | Wheat | 1.15 | 0.85 | 0.0037 |
| | Barley | 1.00 | 0.85 | 0.0051 |
| | Maize | 1.10 | 0.85 | 0.0086 |
| | Oats | 1.27 | 0.85 | 0.0049 |
| | Rye | 1.17 | 0.85 | 0.0036 |
| | | | | |
| | Other : | | | |
| | Triticale | 1.25 | 0.85 | 0.0039 |
| | Spelt | 1.56 | 0.85 | 0.0059 |
| | Mix of Fodder Cereals | 1.00 | 0.85 | 0.0051 |
| | Mix of Bread Cereals | 1.15 | 0.85 | 0.0037 |
| | Millet | 1.29 | 0.85 | 0.0196 |
| **2. Pulse** | Dry Beans | 1.13 | 0.85 | 0.0353 |
| | Peas (Eiweisserbsen) | 1.25 | 0.85 | 0.0235 |
| | Soybeans | 1.00 | 0.85 | 0.0412 |
| | Other: | | | |
| | Leguminous Vegetables | 3.87 | 0.16 | 0.0328 |
| | Lupines | 1.00 | 0.85 | 0.0412 |
| **3. Tuber and Root** | Potatoes | 0.47 | 0.13 | 0.0127 |
| | Other : | | | |
| | Fodder Beet | 0.37 | 0.15 | 0.0233 |
| | Sugar Beet | 0.53 | 0.15 | 0.0220 |
| **5. Other** | Fruit | NA | 0.17 | 0.0040 |
| | Grass | 0.24 | NA | 0.0205 |
| | Green Corn | 0.05 | 0.32 | 0.0190 |
| | Non-Leguminous Vegetables | 0.46 | 0.13 | 0.0230 |
| | Rape | 2.57 | 0.85 | 0.0071 |
| | Renewable Energy Crops | 2.57 | 0.85 | 0.0071 |
| | Silage Corn | 0.05 | 0.32 | 0.0118 |
| | Sunflowers | 2.00 | 0.60 | 0.0150 |
| | Tobacco | 1.18 | NA | 0.0221 |
| | Berries | NA | 0.20 | 0.0060 |
| | Vine | NA | 0.20 | 0.0060 |
| | Oil Squash | 0.46 | 0.13 | 0.0230 |
| | Oil Hemp | 4.62 | 0.85 | 0.0106 |
| | Oil Flax | 1.25 | 0.85 | 0.0071 |
| | Hops | NA | 1.00 | NA |
| | Medicinal Plants and Herbs | 2.50 | NA | 0.0330 |

Table A – 26 $NH_3$ and $NO_x$ emission factors for 3Db Indirect $N_2O$ emissions from managed soils.

| Emission Factors Volatilisation | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | % | | | | | | | | | | | | | | | |
| $NH_3$ from application of animal manure N ($Frac_{GASMT}$) | 24.72 | 24.70 | 24.65 | 24.59 | 24.59 | 24.54 | 24.32 | 24.12 | 23.92 | 23.67 | 23.47 | 23.27 | 23.02 | 23.12 | 23.22 | 23.32 | 23.50 | 23.60 | 23.10 | 22.51 | 21.95 | 21.72 | 21.46 | 21.21 | 20.96 | 20.70 | 20.69 | 20.69 | 20.71 | 20.69 | 20.64 |
| Mature Dairy Cattle | 26.85 | 26.83 | 26.82 | 26.81 | 26.79 | 26.78 | 26.64 | 26.50 | 26.35 | 26.20 | 26.04 | 25.88 | 25.71 | 25.88 | 26.05 | 26.21 | 26.37 | 26.53 | 25.99 | 25.46 | 24.94 | 24.61 | 24.28 | 23.96 | 23.63 | 23.31 | 23.32 | 23.33 | 23.34 | 23.36 | 23.36 |
| Other Mature Cattle | 22.86 | 22.70 | 22.55 | 22.38 | 22.22 | 22.06 | 22.12 | 22.18 | 22.24 | 22.31 | 22.38 | 22.46 | 22.53 | 22.60 | 22.66 | 22.72 | 22.78 | 22.83 | 22.71 | 22.59 | 22.47 | 22.30 | 22.12 | 21.94 | 21.77 | 21.59 | 21.53 | 21.46 | 21.40 | 21.34 | 21.33 |
| Growing Cattle (weighted average) | 23.68 | 23.63 | 23.59 | 23.55 | 23.54 | 23.51 | 23.42 | 23.38 | 23.27 | 23.14 | 23.14 | 23.00 | 22.90 | 23.11 | 23.30 | 23.48 | 23.68 | 23.86 | 23.48 | 23.09 | 22.71 | 22.41 | 22.13 | 21.82 | 21.52 | 21.22 | 21.28 | 21.37 | 21.42 | 21.48 | 21.46 |
| Sheep (weighted average) | 4.89 | 4.89 | 4.89 | 4.89 | 4.89 | 4.89 | 4.86 | 4.84 | 4.82 | 4.79 | 4.75 | 4.71 | 4.67 | 4.90 | 5.12 | 5.33 | 5.54 | 5.75 | 5.64 | 5.54 | 5.45 | 5.36 | 5.26 | 5.16 | 5.05 | 4.93 | 4.98 | 5.03 | 5.07 | 5.11 | 5.12 |
| Swine (weighted average) | 24.20 | 24.15 | 24.10 | 24.05 | 24.00 | 23.95 | 23.63 | 23.28 | 22.88 | 22.44 | 21.93 | 21.35 | 20.67 | 20.87 | 21.07 | 21.28 | 21.49 | 21.74 | 20.81 | 19.94 | 19.09 | 18.92 | 18.76 | 18.57 | 18.40 | 18.22 | 18.24 | 18.27 | 18.30 | 18.32 | 18.34 |
| Buffalo (weighted average) | NA | NA | 3.49 | 3.49 | 3.49 | 3.49 | 3.47 | 3.44 | 3.41 | 3.39 | 3.36 | 3.33 | 3.30 | 3.30 | 3.30 | 3.30 | 3.30 | 3.30 | 3.30 | 3.30 | 3.30 | 3.30 | 3.29 | 3.29 | 3.29 | 3.29 | 3.29 | 3.29 | 3.28 | 3.28 | 3.28 |
| Camels (weighted average) | NA | NA | NA | NA | NA | NA | 3.37 | 3.35 | 3.34 | 3.33 | 3.31 | 3.30 | 3.28 | 3.27 | 3.26 | 3.25 | 3.24 | 3.23 | 3.28 | 3.32 | 3.35 | 3.34 | 3.34 | 3.33 | 3.32 | 3.31 | 3.28 | 3.24 | 3.21 | 3.17 | 3.17 |
| Deer (weighted average) | 3.38 | 3.38 | 3.38 | 3.38 | 3.38 | 3.38 | 3.37 | 3.35 | 3.34 | 3.33 | 3.31 | 3.30 | 3.28 | 3.27 | 3.26 | 3.25 | 3.24 | 3.23 | 3.28 | 3.32 | 3.35 | 3.34 | 3.34 | 3.33 | 3.32 | 3.31 | 3.28 | 3.24 | 3.21 | 3.17 | 3.17 |
| Goats | 5.19 | 5.19 | 5.19 | 5.19 | 5.19 | 5.19 | 5.05 | 4.91 | 4.77 | 4.61 | 4.44 | 4.27 | 4.08 | 5.04 | 5.97 | 6.89 | 7.79 | 8.67 | 7.69 | 6.69 | 5.67 | 5.70 | 5.74 | 5.77 | 5.81 | 5.85 | 6.00 | 6.16 | 6.33 | 6.51 | 6.51 |
| Horses (weighted average) | 4.98 | 4.98 | 4.98 | 4.98 | 4.98 | 4.98 | 4.96 | 4.94 | 4.91 | 4.89 | 4.85 | 4.82 | 4.79 | 4.82 | 4.85 | 4.89 | 4.92 | 4.96 | 4.89 | 4.82 | 4.76 | 4.80 | 4.84 | 4.89 | 4.93 | 5.00 | 4.96 | 4.93 | 4.88 | 4.84 | 4.84 |
| Mules and Asses (weighted average) | 4.98 | 4.98 | 4.98 | 4.98 | 4.98 | 4.98 | 4.96 | 4.94 | 4.92 | 4.90 | 4.88 | 4.86 | 4.84 | 4.93 | 5.02 | 5.12 | 5.21 | 5.32 | 5.43 | 5.54 | 5.65 | 5.56 | 5.47 | 5.38 | 5.29 | 5.20 | 5.30 | 5.39 | 5.47 | 5.56 | 5.56 |
| Poultry (weighted average) | 13.61 | 13.90 | 14.11 | 14.15 | 14.25 | 14.46 | 14.08 | 13.88 | 13.65 | 13.45 | 13.24 | 12.95 | 12.69 | 12.76 | 12.84 | 12.92 | 12.98 | 13.10 | 13.29 | 13.46 | 13.64 | 13.64 | 13.65 | 13.65 | 13.65 | 13.65 | 13.59 | 13.52 | 13.46 | 13.38 | 13.40 |
| Rabbits | 4.11 | 4.11 | 4.11 | 4.11 | 4.11 | 4.11 | 4.08 | 4.06 | 4.03 | 4.01 | 3.98 | 3.96 | 3.93 | 3.94 | 3.95 | 3.95 | 3.96 | 3.97 | 3.96 | 3.95 | 3.94 | 3.94 | 3.94 | 3.95 | 3.95 | 3.95 | 3.94 | 3.94 | 3.94 | 3.93 | 3.93 |
| Livestock NCAC (weighted average) | 4.98 | 4.98 | 4.98 | 4.98 | 4.98 | 5.01 | 4.93 | 4.89 | 4.85 | 4.81 | 4.76 | 4.72 | 4.67 | 4.85 | 5.04 | 5.26 | 5.42 | 5.54 | 5.43 | 5.27 | 5.13 | 5.14 | 5.13 | 5.12 | 5.13 | 5.13 | 5.13 | 5.13 | 5.21 | 5.23 | 5.22 |
| $NH_3$ from urine and dung N deposited on PR&P ($Frac_{GASPT}$) | 4.65 | 4.66 | 4.67 | 4.68 | 4.69 | 4.69 | 4.72 | 4.75 | 4.77 | 4.80 | 4.80 | 4.80 | 4.82 | 4.84 | 4.86 | 4.89 | 4.90 | 4.93 | 4.91 | 4.90 | 4.89 | 4.89 | 4.90 | 4.90 | 4.90 | 4.91 | 4.94 | 4.96 | 4.98 | 5.00 | 5.03 |
| Mature Dairy Cattle | 4.67 | 4.67 | 4.66 | 4.66 | 4.66 | 4.65 | 4.65 | 4.64 | 4.64 | 4.64 | 4.63 | 4.63 | 4.63 | 4.62 | 4.62 | 4.61 | 4.61 | 4.60 | 4.60 | 4.60 | 4.60 | 4.60 | 4.60 | 4.59 | 4.59 | 4.59 | 4.59 | 4.59 | 4.59 | 4.59 | 4.59 |
| Other Mature Cattle | 4.56 | 4.56 | 4.56 | 4.56 | 4.57 | 4.57 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 |
| Growing Cattle (weighted average) | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.56 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 |
| Sheep (weighted average) | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Swine (weighted average) | NA | NA | NA | NA | NA | NA | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 |
| Buffalo (weighted average) | NA | NA | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Camels (weighted average) | NA | NA | NA | NA | NA | NA | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Deer (weighted average) | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Goats | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Horses (weighted average) | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Mules and Asses (weighted average) | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Poultry (weighted average) | NA | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 |
| Rabbits | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Livestock NCAC (weighted average) | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| $NH_3$ from commercial fertiliser N ($Frac_{GASFi}$) | 6.19 | 5.61 | 5.63 | 5.85 | 6.04 | 6.05 | 6.04 | 5.80 | 5.37 | 5.39 | 5.42 | 4.97 | 4.99 | 4.67 | 4.81 | 4.66 | 4.44 | 4.81 | 4.67 | 4.55 | 4.69 | 4.77 | 4.81 | 5.02 | 5.20 | 5.57 | 5.47 | 5.56 | 5.65 | 5.95 | 5.93 |
| Urea | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 | 13.11 |
| Other Mineral Fertilisers | 2.72 | 2.72 | 2.72 | 2.72 | 2.72 | 2.72 | 2.72 | 2.59 | 2.44 | 2.62 | 2.51 | 2.44 | 2.66 | 2.58 | 2.62 | 2.76 | 2.65 | 2.74 | 2.94 | 3.11 | 3.07 | 2.98 | 3.10 | 3.11 | 3.03 | 3.29 | 2.80 | 2.99 | 3.05 | 3.12 | 3.20 |
| Recycling Fertilisers (weighted average) | 17.60 | 18.12 | 18.63 | 19.17 | 19.60 | 19.97 | 19.78 | 19.70 | 19.61 | 19.20 | 18.80 | 17.64 | 15.92 | 15.00 | 14.10 | 13.40 | 12.78 | 11.78 | 10.48 | 9.03 | 9.37 | 9.80 | 10.41 | 10.73 | 11.24 | 11.74 | 11.64 | 11.83 | 12.07 | 12.04 | 12.21 |
| Sewage Sludge | 20.00 | 20.81 | 21.60 | 22.39 | 23.17 | 23.94 | 24.25 | 24.61 | 25.02 | 25.50 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 | 26.07 |
| Compost | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 |
| Digestate Liquid | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 29.55 | 29.10 | 28.09 | 27.08 | 26.06 | 25.05 | 24.04 | 23.03 | 22.01 | 21.00 | 21.00 | 21.00 | 21.00 | 21.00 | 21.00 | 21.00 | 21.00 | 21.00 | 21.00 | 21.00 |
| Digestate Solid | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 |
| $NO_x$ from applied fertilisers ($Frac_{NOXA}$) | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |
| $NO_x$ from urine and dung N deposited on PR&P ($Frac_{NOXP}$) | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |

Table A – 27 Overview of N pools and flows for calculating 3Db Indirect $N_2O$ emission from managed soils.

| Nitrogen pools and flows | | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1990-2005 | | | | | | | | | | | | | | | |
| | | t N/yr | | | | | | | | | | | | | | | |
| | Animals manure N applied to soils | 115'221 | 113'408 | 111'030 | 108'761 | 107'751 | 106'496 | 102'273 | 96'986 | 94'238 | 90'657 | 87'264 | 85'823 | 82'765 | 81'757 | 80'984 | 82'437 |
| | Commercial fertiliser | 75'085 | 75'390 | 75'318 | 70'487 | 66'846 | 67'018 | 64'629 | 56'401 | 56'432 | 58'641 | 57'969 | 61'410 | 59'339 | 56'498 | 56'716 | 55'393 |
| Deposition | Sum volatised N ($NH_3$ and $NO_x$) | 34'883 | 34'004 | 33'368 | 32'572 | 32'230 | 31'897 | 30'547 | 28'426 | 27'385 | 26'465 | 25'558 | 25'061 | 24'098 | 23'597 | 23'580 | 23'870 |
| | $NH_3$ emissions from commercial fertilisers | 4'644 | 4'229 | 4'243 | 4'120 | 4'037 | 4'058 | 3'906 | 3'271 | 3'031 | 3'158 | 3'142 | 3'054 | 2'959 | 2'636 | 2'728 | 2'582 |
| | $NH_3$ emissions from applied animal manure | 28'487 | 28'017 | 27'374 | 26'742 | 26'493 | 26'136 | 24'870 | 23'393 | 22'540 | 21'456 | 20'479 | 19'972 | 19'051 | 18'900 | 18'809 | 19'226 |
| | $NH_3$ emissions from pasture, range and paddock | 630 | 644 | 650 | 648 | 662 | 670 | 764 | 823 | 883 | 924 | 1'021 | 1'100 | 1'172 | 1'167 | 1'155 | 1'172 |
| | $NO_x$ emissions from commercial fertilisers | 413 | 415 | 414 | 388 | 368 | 369 | 355 | 310 | 310 | 323 | 319 | 338 | 326 | 311 | 312 | 305 |
| | $NO_x$ emissions from applied animal manure | 634 | 624 | 611 | 598 | 593 | 586 | 563 | 533 | 518 | 499 | 480 | 472 | 455 | 450 | 445 | 453 |
| | $NO_x$ emissions from PR&P | 75 | 76 | 77 | 76 | 78 | 79 | 89 | 95 | 102 | 106 | 117 | 126 | 134 | 133 | 131 | 132 |
| Leaching and run-off | Sum leaching and run-off | 50'634 | 50'241 | 50'098 | 49'093 | 48'348 | 48'418 | 46'777 | 43'378 | 42'878 | 42'840 | 42'691 | 41'981 | 40'970 | 39'346 | 38'649 | 38'290 |
| | Leaching and run-off from commercial fertilisers | 15'474 | 15'536 | 15'522 | 14'526 | 13'776 | 13'811 | 13'200 | 11'415 | 11'317 | 11'652 | 11'411 | 11'975 | 11'462 | 10'809 | 10'746 | 10'393 |
| | Leaching and run-off from applied animal manure | 23'745 | 23'371 | 22'881 | 22'414 | 22'206 | 21'947 | 20'888 | 19'629 | 18'899 | 18'013 | 17'178 | 16'736 | 15'987 | 15'641 | 15'344 | 15'467 |
| | Leaching and run-off from pasture, range and paddock | 2'791 | 2'845 | 2'867 | 2'851 | 2'910 | 2'943 | 3'302 | 3'506 | 3'712 | 3'827 | 4'187 | 4'466 | 4'696 | 4'615 | 4'500 | 4'495 |
| | Leaching and run-off from crop residues | 8'052 | 7'949 | 7'959 | 7'910 | 7'742 | 7'751 | 7'987 | 7'829 | 7'889 | 7'536 | 7'778 | 7'393 | 7'504 | 7'115 | 7'441 | 7'254 |
| | Leaching and run-off from mineralisation of SOM | 572 | 539 | 869 | 1'392 | 1'715 | 1'966 | 1'400 | 998 | 1'061 | 1'811 | 2'136 | 1'410 | 1'321 | 1'166 | 618 | 682 |

| Nitrogen pools and flows | | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2006-2020 | | | | | | | | | | | | | | |
| | | t N/yr | | | | | | | | | | | | | | |
| | Animals manure N applied to soils | 83'196 | 83'882 | 85'866 | 85'284 | 85'963 | 85'488 | 85'359 | 84'754 | 85'071 | 84'570 | 84'077 | 83'390 | 82'822 | 81'713 | 81'436 |
| | Commercial fertiliser | 54'472 | 56'875 | 53'590 | 50'603 | 58'580 | 52'353 | 51'374 | 50'208 | 56'100 | 50'475 | 53'771 | 56'962 | 53'348 | 48'040 | 49'207 |
| Deposition | Sum volatised N ($NH_3$ and $NO_x$) | 24'046 | 24'634 | 24'455 | 23'579 | 23'729 | 23'134 | 22'853 | 22'540 | 22'828 | 22'358 | 22'394 | 22'499 | 22'223 | 21'788 | 21'755 |
| | $NH_3$ emissions from commercial fertilisers | 2'420 | 2'737 | 2'500 | 2'302 | 2'747 | 2'499 | 2'471 | 2'521 | 2'919 | 2'812 | 2'940 | 3'167 | 3'012 | 2'859 | 2'918 |
| | $NH_3$ emissions from applied animal manure | 19'550 | 19'792 | 19'838 | 19'198 | 18'868 | 18'570 | 18'318 | 17'973 | 17'831 | 17'509 | 17'394 | 17'252 | 17'150 | 16'905 | 16'808 |
| | $NH_3$ emissions from pasture, range and paddock | 1'186 | 1'197 | 1'214 | 1'197 | 1'185 | 1'175 | 1'179 | 1'172 | 1'170 | 1'163 | 1'172 | 1'178 | 1'182 | 1'180 | 1'181 |
| | $NO_x$ emissions from commercial fertilisers | 300 | 313 | 295 | 278 | 322 | 288 | 283 | 276 | 309 | 278 | 296 | 313 | 293 | 264 | 271 |
| | $NO_x$ emissions from applied animal manure | 458 | 461 | 472 | 469 | 473 | 470 | 469 | 466 | 468 | 465 | 462 | 459 | 456 | 449 | 448 |
| | $NO_x$ emissions from PR&P | 133 | 133 | 136 | 134 | 133 | 132 | 133 | 132 | 131 | 130 | 130 | 131 | 131 | 130 | 129 |
| Leaching and run-off | Sum leaching and run-off | 37'768 | 38'276 | 37'606 | 36'792 | 37'850 | 37'023 | 37'082 | 36'791 | 39'443 | 37'657 | 37'355 | 37'996 | 36'985 | 36'179 | 36'300 |
| | Leaching and run-off from commercial fertilisers | 10'120 | 10'432 | 9'721 | 9'105 | 10'429 | 9'313 | 9'137 | 8'929 | 9'983 | 8'977 | 9'558 | 10'077 | 9'404 | 8'411 | 8'622 |
| | Leaching and run-off from applied animal manure | 15'456 | 15'428 | 15'635 | 15'371 | 15'335 | 15'250 | 15'227 | 15'119 | 15'176 | 15'087 | 14'999 | 14'876 | 14'775 | 14'577 | 14'528 |
| | Leaching and run-off from pasture, range and paddock | 4'492 | 4'463 | 4'502 | 4'403 | 4'323 | 4'287 | 4'298 | 4'268 | 4'258 | 4'223 | 4'231 | 4'240 | 4'234 | 4'213 | 4'186 |
| | Leaching and run-off from crop residues | 6'976 | 7'035 | 6'906 | 6'912 | 6'619 | 6'800 | 6'697 | 6'437 | 7'065 | 6'629 | 6'556 | 6'774 | 6'492 | 6'768 | 6'760 |
| | Leaching and run-off from mineralisation of SOM | 725 | 917 | 843 | 1'000 | 1'143 | 1'372 | 1'722 | 2'038 | 2'961 | 2'742 | 2'011 | 2'029 | 2'079 | 2'210 | 2'205 |

### A3.3.4 Estimation of the distribution of nitrogen and volatile solids to manure management systems for cattle animals

The fraction of animal manure handled using different manure management systems (MS) as well as the percentages of urine and dung deposited on pasture, range and paddock was separately assessed for each cattle category.

In a first step the share of manure deposited on pasture, range and paddock is calculated assuming that the amount of deposited manure is proportional to the time spent grazing. The estimated grazing time is based on expert judgement and values from the literature (1990, 1995) and on extensive farm surveys (2002, 2007, 2010, 2015 and 2019) (Kupper et al. 2022). The approach is consistent for nitrogen and volatile solids.

Subsequently, the remaining manure is distributed to the different manure management systems. Data for manure management system distribution for cattle are different for VS and nitrogen. This is because cattle stables often have simultaneously both liquid and solid manure storage systems. As volatile solids are excreted mainly in dung and nitrogen mainly in urine, the proportion of VS stored as solid manure is higher compared to the proportion of N.

Estimation of the distribution of nitrogen is conducted within the Swiss ammonium model AGRAMMON and follows a nitrogen mass balance approach. Further details are provided in Kupper et al. (2022).

The distribution of VS was estimated using data on stable systems, manure accumulation and manure properties from Richner et al. (2017; chapter 4, table 4 and 6). For this purpose five different stable systems are distinguished. For tie stall and loose housing systems with slurry production only (“Vollgülle”) it is assumed that all manure goes to liquid systems. For loose housing systems with deep litter 100% of the manure is allocated to “deep litter”. For tie stall and loose housing systems with simultaneous production of liquid slurry and solid manure (dung) the distribution to the respective storage systems is conducted as exemplified for mature dairy cattle in Table A – 28. The final shares of volatile solids in the different manure management systems is then calculated based on the frequency of the 5 different stable systems as assessed based on expert judgement and values from the literature (1990, 1995) and on extensive farm surveys (2002, 2007, 2010, 2015 and 2019) (Kupper et al. 2022) (Table A – 29).

Table A – 28 Production of slurry and dung and manure management system distribution for nitrogen and volatile solids for mature dairy cattle in stable systems with simultaneous production of slurry and dung (according to Richner et al., 2017).

| | slurry* | dung | Richner et al. 2017, chapter 4 |
|---|---|---|---|
| Production per year | 11 $m^3$*$year^{-1}$ | 8.9 t*$year^{-1}$ | table 4 |
| Content of nitrogen | 4.5 kg*$m^{-3}$ | 4.5 kg*$t^{-1}$ | table 6 |
| Total amount of nitrogen produced | 49.5 kg*$year^{-1}$ | 40.1 kg*$year^{-1}$ | |
| **Distribution of nitrogen** | **55.3%** | **44.7%** | |
| Content of volatile solids | 40 kg*$m^{-3}$ | 150 kg*$t^{-1}$ | table 6 |
| Total amount of volatile solids produced | 440 kg*$year^{-1}$ | 1335 kg*$year^{-1}$ | |
| **Distribution of volatile solids** | **24.8%** | **75.2%** | |

* all values are for undiluted slurry

Table A – 29 Distribution of nitrogen and volatile solids to different storage systems in different stable systems for mature dairy cattle.

| | Distribution of nitrogen* | | Distribution of volatile solids | | Frequency of stable system 2019 | Distribution of nitrogen* | | Distribution of volatile solids | |
|---|---|---|---|---|---|---|---|---|---|
| | Liquid Slurry / Digesters | Solid manure / Deep litter | Liquid Slurry / Digesters | Solid manure / Deep litter | | Liquid Slurry / Digesters | Solid manure / Deep litter | Liquid Slurry / Digesters | Solid manure / Deep litter |
| Tie stall with slurry ("Vollgülle") | 100.0 | 0.0 | 100.0 | 0.0 | 12.8% | 80.4% | 19.6% | 67.7% | 32.3% |
| Tie stall with liquid slurry and solid manure | 55.3 | 44.7 | 24.8 | 75.2 | 29.5% | | | | |
| Loose housing system with slurry ("Vollgülle") | 100.0 | 0.0 | 100.0 | 0.0 | 44.6% | | | | |
| Loose housing system with liquid slurry and solid manure | 55.3 | 44.7 | 24.8 | 75.2 | 12.0% | | | | |
| Loose housing system with deep litter | 0.0 | 100.0 | 0.0 | 100.0 | 1.1% | | | | |

* all values for nitrogen are only indicative here as the exact distribution is assessed in a more detailed mass balance approach within the AGRAMMON-model

In order to assess the quality of the final result the distribution of volatile solids was calculated alternatively by multiplying the distribution of nitrogen from the AGRAMMON-model with average VS/N ratios for slurry and solid manure. The resulting values differ only slightly from the estimated distribution of volatile solids.

# Annex 4 National energy balance and reference approach

## A4.1 Swiss energy balance: energy flows

The diagram shows a summary of the Swiss energy flow 2020 as published by the Swiss Federal Office of Energy (SFOE 2021). Diagram languages are German and French. The energy balance is also provided in tabular form in Table A – 30.

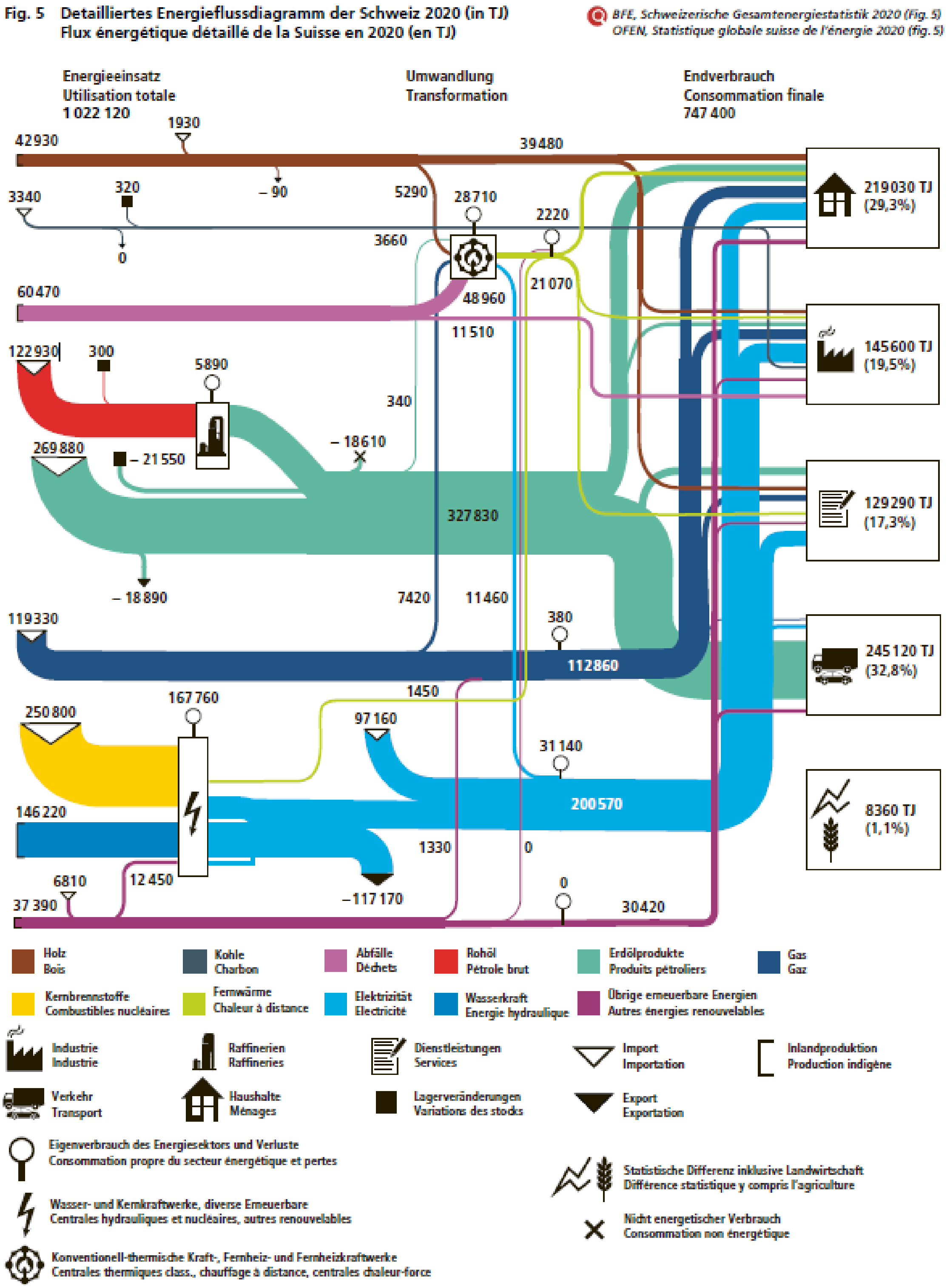



Figure A – 2 Energy flow in Switzerland 2020 in TJ (SFOE 2021)

Table A – 30 Switzerland's energy balance 2020 (SFOE 2021) in TJ. Liechtenstein's consumption of liquid fuels is included in the numbers (see general remarks in annex A4.2 below on final Swiss energy consumption).

**Tab. 4 Energiebilanz der Schweiz für das Jahr 2020 (in TJ)**
**Bilan énergétique de la Suisse pour 2020 (en TJ)**

| | | Holzenergie | Kohle | Müll und Industrie-abfälle | Rohöl | Erdöl-produkte | Gas | Wasserkraft | Kernbrenn-stoffe | Übrige erneuerbare Energien | Elektrizität | Fernwärme | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Energie du bois | Charbon | Ord. mén. et déchets ind. | Pétrole brut | Produits pétroliers | Gaz | Energie hydraulique | Combustibles nucléaires | Autres énergies renouvelables | Electricité | Chaleur à distance | | |
| | | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | |
| Inlandproduktion | (a) | 42930 | – | 60470 | – | – | – | 146220 | – | 37390 | – | – | 287010 | Production indigène |
| + Import | (b) | 1930 | 3340 | – | 122930 | 269880 | 119330 | – | 250800 | 6810 | 97160 | – | 872180 | + Importation |
| + Export | (c) | −90 | 0 | – | – | −18890 | – | – | – | – | −117170 | – | −136150 | + Exportation |
| + Lagerveränderung[1] | (d) | – | 320 | – | 300 | −21550 | – | – | – | – | – | – | −20930 | + Variation de stock[1] |
| = Bruttoverbrauch | (e) | 44770 | 3660 | 60470 | 123230 | 229440 | 119330 | 146220 | 250800 | 44200 | −20010 | 0 | 1002110 | = Consommation brute |
| + Energieumwandlung: | | | | | | | | | | | | | | + Transformation d'énergie: |
| · Wasserkraftwerke | (f) | – | – | – | – | – | – | −146220 | – | – | 146220 | – | 0 | · Centrales hydrauliques |
| · Kernkraftwerke | (g) | – | – | – | – | – | – | – | −250800 | – | 82760 | 1450 | −166590 | · Centrales nucléaires |
| · konventionell-thermische Kraft-, Fernheiz- und Fernheizkraftwerke | (h) | −3300 | – | −48960 | – | −340 | −7420 | – | – | – | 10040 | 21840 | −28140 | · Centrales thermiques class., chauffage à distance, centrales chaleur-force |
| · Gaswerke | (i) | – | – | – | – | – | – | – | – | – | – | – | 0 | · Usines à gaz |
| · Raffinerien | (j) | – | – | – | −123230 | 123230 | – | – | – | – | – | – | 0 | · Raffineries |
| · Diverse Erneuerbare | (k) | −1990 | – | – | – | – | 1330 | – | – | −13780 | 12700 | – | −1740 | · Renouvelables div. |
| + Eigenverbrauch des Energiesektors, Netzverluste, Verbrauch der Speicherungen | (l) | – | – | – | – | −5890 | −380 | – | – | – | −31140 | −2220 | −39630 | + Consommation propre du secteur énergétique, pertes de réseau, pompage d'accumulation |
| + Nichtenergetischer Verbrauch | (m) | – | – | – | – | −18610 | – | – | – | – | – | – | −18610 | + Consommation non énergétique |
| = Endverbrauch | (n) | 39480 | 3660 | 11510 | 0 | 327830 | 112860 | 0 | 0 | 30420 | 200570 | 21070 | 747400 | = Consommation finale |
| Haushalte | (o) | 17100 | 100 | – | – | 59470 | 47350 | – | – | 17200 | 69470 | 8340 | 219030 | Ménages |
| Industrie | (p) | 11720 | 3560 | 11510 | – | 11680 | 38090 | – | – | 1850 | 60070 | 7120 | 145600 | Industrie |
| Dienstleistungen | (q) | 9700 | 0 | – | – | 27600 | 25090 | – | – | 3660 | 57630 | 5610 | 129290 | Services |
| Verkehr | (r) | – | – | – | – | 226720 | 1060 | – | – | 7260 | 10080 | 0 | 245120 | Transport |
| Statistische Differenz inkl. Landwirtschaft | (s) | 960 | 0 | – | – | 2360 | 1270 | – | – | 450 | 3320 | 0 | 8360 | Différence statistique, y compris l'agriculture |

[1] + Lagerabnahme
− Lagerzunahme

[1] + diminution de stock
− augmentation de stock

*BFE, Schweizerische Gesamtenergiestatistik 2020 (Tab. 4)*
*OFEN, Statistique globale suisse de l'énergie 2020 (tabl. 4)*

## A4.2 Differences between International Energy Agency (IEA) data and the reference approach

Reviewers have repeatedly asked for explanations of the apparent differences between the energy data held by the International Energy Agency (IEA) and the data reported in the Reference Approach. In order to clarify the pertaining issues, the reasons for the major differences are given below. Data for the year 2010 are used to illustrate the description, however, a recent comparison with data for 2016 produced similar results.

### General remarks

The net calorific values used by IEA differ from those used in the greenhouse gas inventory. In order to avoid differences caused by the conversion with different NCV, the comparison between IEA and the Reference Approach is made in kt.

Stock changes as reported by IEA are only including primary stocks (IEA 2005), while the reporting in the Reference Approach includes secondary and tertiary stocks. This results in a particularly large difference for gas oil, as retailers and end-consumers hold considerable amounts of heating fuel on stock. The IEA subsumes secondary and tertiary stock changes under statistical differences.

All data regarding liquid fuel consumption reported by the IEA includes fuel consumption in Liechtenstein (geographical coverage in IEA 2012). For reporting purposes under the UNFCCC, consumption of Liechtenstein is subtracted.

Data sources used for the comparison shown in Table A – 31 below are:

- Switzerland's greenhouse gas inventory 1990–2011, submission of 15. April 2013, CRF Table1.A(b), (FOEN 2013).
- Energy statistics of OECD countries (2012 Edition), (IEA 2012).

### Liquid fuels

The total amount of liquid fuel consumption as reported in the greenhouse gas inventory is 11'052 kt. There is a difference of 13 kt (0.1%) between CRF and IEA. This difference is primarily caused by the different methodology used for aviation bunkers (see below).

### Crude oil

Crude oil in the reference approach contains additives, while IEA lists them separately (data in italics in Table A – 31. The difference between CRF and IEA is smaller than 0.1% if the sum of additives, refinery feedstocks and crude oil is considered.

### Gasoline

The comparison is made for motor gasoline only. Aviation gasoline is included under aviation fuels. Gasoline reported by IEA includes gasoline used in Liechtenstein (LIE), which is subtracted for reporting under the UNFCCC. The difference between CRF and IEA is approximately 0.1%, if the consumption of LIE is taken into account.

**Aviation fuels**

The different aviation fuels are aggregated in the greenhouse gas inventory. For comparison of IEA and reference approach, all aviation fuels are summed up. The difference between IEA and reference approach if considering the apparent final consumption is 12 kt (approximately 1% of imports). This difference is largely due to a different methodology used to estimate international bunker. Aviation bunkers have to be reported monthly to the IEA. As the tier 3 approach used for the greenhouse gas inventory is not available on a monthly basis, the international bunker fuel estimate of IEA consists of the total consumption at the two international airports in Zurich and Geneva, while all remaining fuel use is considered domestic. The reporting in the national greenhouse gas inventory is based on a much more detailed approach, where information on single flights is taken into account. Due to the different approach, the numbers are somewhat different. However, the order of magnitude is the same, and the information in the inventory is based on a higher-tier method and presumably more accurate.

**Diesel oil and gas oil**

The IEA numbers include diesel oil and gas oil used in Liechtenstein. Furthermore, stock changes are reported differently in the CRF and by the IEA. Secondary and tertiary stock changes are subsumed under statistical differences by the IEA, while they are included in the stock change reported in the reference approach. If the statistical differences are taken into account, the difference in the apparent consumption is less than 0.1%.

**Residual fuel oil**

Data agree between IEA and greenhouse gas inventory. It seems as if there is a rounding error in the imported amounts, leading to an apparent difference of 1 kt. According to the foreign trade statistics, 33'693 t of residual fuel oil had been imported in 2010.

**Bitumen**

Bitumen is a main feedstock in the greenhouse gas inventory. Data between IEA and the reference approach compare well. Again, small differences are likely due to the use of rounded values, leading to apparent differences of the order of 1–2 kt.

**Petroleum coke**

There are considerable differences (26 kt) in the reported numbers for petroleum coke import. The reason for this apparent difference is that for IEA, all petroleum coke is reported together. In the greenhouse gas inventory submitted in 2013, however, only the petroleum coke used as a fuel was reported under petroleum coke, while calcined petroleum coke was reported together with “other oil” as feedstocks. This is largely a consequence of the treatment of fuels and feedstocks in the Swiss overall energy statistics (SFOE 2012).

### Lubricants

There are small differences between IEA and the reference approach, as the data reported to the IEA comprises a slightly different set of customs tariff headings for lubricants to the one used for the Swiss overall energy statistics. The substances not reported under lubricants in the reference approach are reported under other oil.

### Liquefied petroleum gas

The reporting of liquefied petroleum gas in the greenhouse gas inventory includes white spirit and lamp oil. As for petroleum coke, IEA numbers include fuels that are used as feedstocks, while in the reference approach, only liquefied petroleum gas, white spirit and lamp oil used as fuels are reported under liquefied petroleum gas. The difference in apparent consumption between IEA and the reference approach is 3 kt (0.03% of total liquid fuel consumption).

### Other oil products

In the greenhouse gas inventory, all other oil products are reported together, while IEA has a finer degree of disaggregation. As already mentioned above, the share of petroleum coke that is used as a feedstock is reported under other oil in the greenhouse gas inventory. Therefore, the difference between IEA and the reference approach corresponds largely to the difference in apparent consumption of petroleum coke.

### Solid fuels

Solid fuels, mainly other bituminous coal and lignite, play only a minor role in Switzerland (246 kt) and are reported in good agreement.

### Gaseous fuels

In the greenhouse gas inventory, the amount of gas reported under 1B2b Fugitive emissions is subtracted from the total gas import as reported by IEA, as this gas is not used for energy purposes. Taking this into account the difference is of the order of 2 TJ.

Table A – 31 Comparison of the IEA energy statistic with the Reference Approach for the year 2010. Numbers in italics are fuels that are reported in a finer disaggregation in the IEA energy statistic than in the Reference Approach. Numbers in bold aggregate the data to the level of disaggregation used in the Reference Approach.

| **CRF vs. IEA (2010)** | **Import** | | **Export** | | **Bunker** | | **Stock change** | | **Stat. Diff.** | **LIE** | **Consumption** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Gg** | **IEA** | **CRF** | **IEA** | **CRF** | **IEA** | **CRF** | **IEA** | **CRF** | **IEA** | **CRF** | **IEA** | **CRF** |
| **Liquid Fuels** | | | | | | | | | | | **11'039** | **11'052** |
| **Sum** | | | | | | | | | | | **4'546** | **4'547** |
| Crude oil | 4'488 | 4'546 | | | | | | 1.0 | | | 4'488 | 4'547 |
| Refinery feedstokcs | 3.0 | | | | | | 1.0 | | 2.0 | | 6.0 | |
| Additives/blending components | 51 | | | | | | -1.0 | | 2.0 | | 52 | |
| **Motor gasoline** | 1'850 | 1'838 | | | | | -9.0 | -6.0 | 4.0 | 15 | **1'830** | **1'832** |
| **Sum** | | | | | | | | | | | **0.0** | **12** |
| Aviation gasoline | 7.0 | | | | | | -2.0 | | -1.0 | | 4.0 | |
| Kerosene type jet fuel | 1'354 | 1'362 | | | -1'367 | -1'352 | | 2.0 | 6.0 | | -7.0 | 12 |
| Other kerosene | 3.0 | | | | | | | | | | 3.0 | |
| **Gas/diesel oil** | 3'510 | 3'485 | -21 | -39 | -10 | -11 | 38 | 1'072 | 1'020 | 27 | **4'510** | **4'507** |
| **Fuel oil** | 33 | 34 | -323 | -316 | | | -17 | -17 | 7.0 | | **-300** | **-299** |
| **White spirit & SBP** | 7.0 | | | | | | | | -1.0 | | **6.0** | |
| **Bitumen** | 317 | 318 | -2.0 | -2.0 | | | | | | | **315** | **316** |
| **Lubricants** | 86 | 72 | -38 | -16 | | | | | 7.0 | | **55** | **56** |
| **Petroleum coke** | 73 | 47 | | | | | | | | | **73** | **47** |
| **Sum** | | | | | | | | | | | **10** | **34** |
| Naptha | 1.0 | | | | | | 5.0 | | -1.0 | | 5.0 | |
| Paraffin waxes | 1.0 | | | | | | | | | | 1.0 | |
| Non-specified oil products / other oil | 4.0 | 63 | | -23 | | | | -6.0 | | | 4.0 | 34 |
| **Solid fuels** | | | | | | | | | | | **246** | **246** |
| Anthracite | 7.0 | | | | | | | | | | 7.0 | |
| Other bitominous coal | 123 | 152 | | | | | *36* | *32* | | | 159 | 184 |
| Lignite | 66 | 62 | | | | | *-4.0* | | | | 62 | 62 |
| Coke oven coke | 18 | | | | | | | | | | 18 | |
| **Gaseous Fuels** | | | | | | | | | | | **126'014** | **126'016** |
| Natural gas (TJ, NCV) | 126'014 | 125'627 | | | | | | | | | 126'014 | 125'627 |
| Fugitive emissions (TJ, NCV) | | 389 | | | | | | | | | | 389 |

### Additional information regarding reporting of waste-derived fuels

During the in-country review in 2016, the ERT identified that the apparent consumption of non-biomass fraction of waste in the CRF Table1.A(b) was systematically smaller than the consumption reported to IEA. The difference stems from the assumptions made with regard to the fossil and renewable fractions. The SFOE, which is responsible for reporting to the IEA, allocates total wastes to 50% fossil and 50% renewable. For the greenhouse gas inventory, a more sophisticated method based on a detailed analysis of waste composition and measurements in the flue gas of waste incineration plants is used to estimate fossil and renewable fractions (see chp. 3.2.5.2.1).

# Annex 5 Additional information on verification activities

## A5.1 Independent verification of the Swiss National Inventory for F-gases

***Introduction***

Since 2000, the Swiss Federal Laboratories for Materials Science and Technology (Empa) performs continuous measurements of halogenated greenhouse gases at the high-Alpine site of Jungfraujoch (3580 m a.s.l.). These measurements are used for estimating emissions of fluorinated greenhouse gases (HFCs, $SF_6$) from Switzerland and neighbouring countries. The information can be used for an independent assessment of Swiss inventory data of these greenhouse gases. The independent emission estimate is not used directly for deriving data for the inventory. Data is used, however, to identify either consistency in support of the inventory or discrepancies, which could lead to a reassessment for identifying sources for disagreement and options for improvements.

For the independent assessment of fluorinated greenhouse gas emissions from Switzerland the so-called tracer-ratio method is applied, where Swiss pollution events of HFCs and $SF_6$, arriving at Jungfraujoch, are scaled to concurrent pollution events of carbon monoxide (CO) and then multiplied by the Swiss CO emission inventory (see Figure A – 3 for a graphical illustration of the method). Similar approaches are also used for the independent verification of greenhouse gas emissions in the United Kingdom (UK MetOffice – using atmospheric observations from Mace Head (Ireland) combined with atmospheric transport models) and in Australia (CSIRO – using the tracer-ratio method with measurements from Cape Grim, Tasmania).

***Method description***

For estimates of annual Swiss HFC and $SF_6$ emissions, only observations at the high-Alpine station Jungfraujoch are taken from air masses that are predominantly influenced by emissions from Switzerland. The number of events which can be used each year depends on the meteorological conditions and lies between 7-15 days per year (mostly in the summer). The process to select these periods is shown in Figure A – 3 and is shortly described here. First, the footprints from the COSMO-model are screened for periods when the Jungfraujoch site is under the influence of air masses which were within the Swiss boundary layer for the last 48 hours. Second, for these periods, mixing ratios of halogenated greenhouse gases are compared with those of CO. Periods which show a concurrent increase are selected for the independent assessment of Swiss emissions, as this is taken as an indication of thorough mixing of Swiss emissions during the transport to Jungfraujoch. Third, the emissions are calculated for each case/day using the formula given in Figure A – 3. The resulting emissions are only used for the annual emission estimate if they are within three standard deviations of the average (Grubbs test). This criterion is met by approximately 90% of the selected data. Finally, annual emissions are estimated as the median of these individual cases. These annual estimates are merged to a 3-year annual average centred over a 3-year period (e.g. the estimate for the 2015 emissions is calculated by using data from 2014–2016). Since 2009, the uncertainty of the estimates for HFCs has been assessed by using the range of the 25%–75% percentiles of the estimates from single pollution events. For estimates between 2001–2008 the average of the 2009–2011 uncertainties has been taken. For $SF_6$, with comparably low emissions and a higher degree of uncertainty, an overall uncertainty of 50% is estimated, based on the long-term average of the 25%–75% percentiles. An additional systematic error could occur if the Swiss emissions of CO are over/underestimated by the inventory. This would linearly impact the emissions of the fluorinated greenhouse gases. Uncertainties may vary from year to year due to the limited amount of data for performing the analysis. Therefore, even subsequent years of lower or higher uncertainty do not signify a change towards lower or higher uncertainty but are just a result of this.

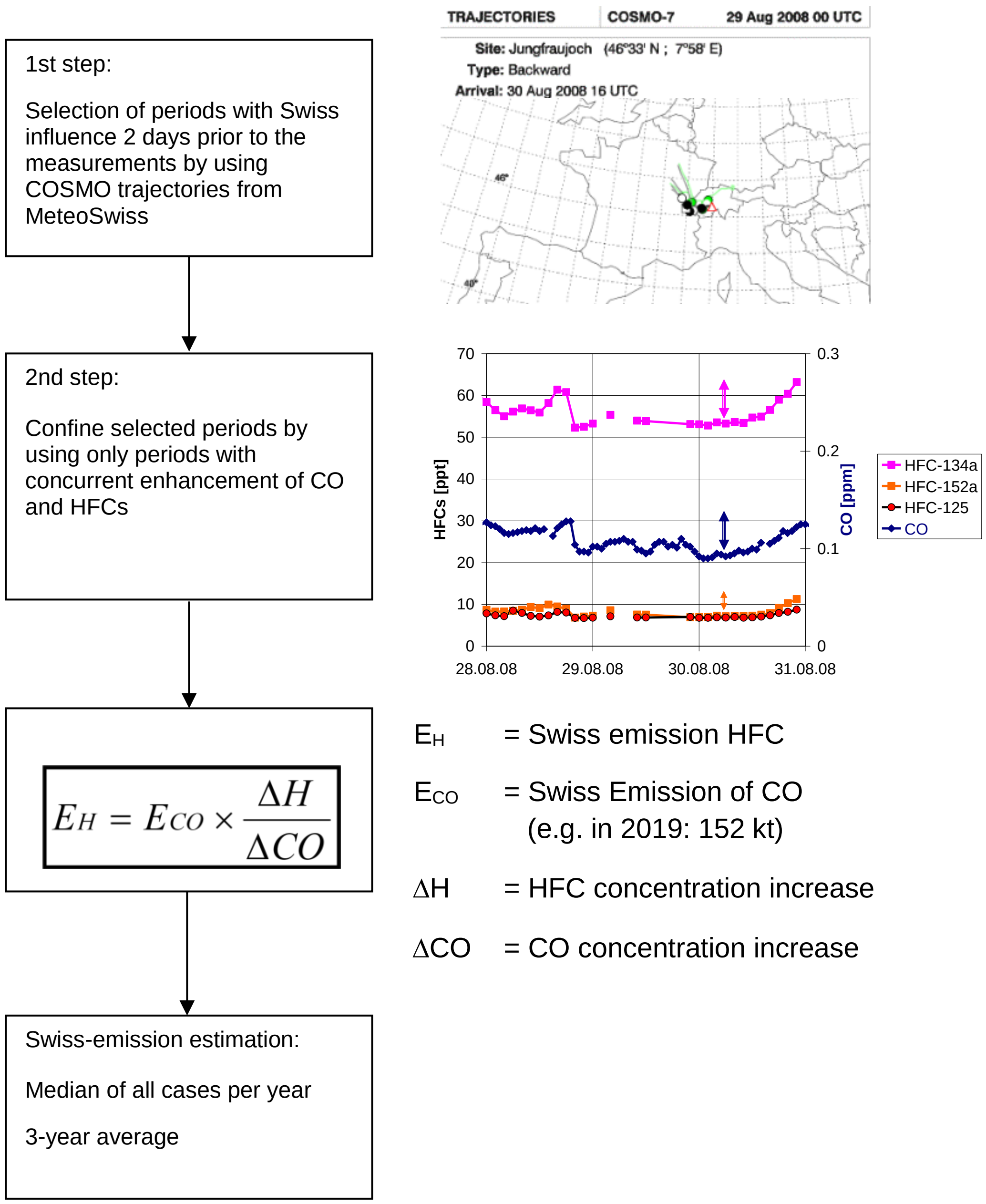



Figure A – 3 Description of the procedure to estimate annual emissions of halogenated greenhouse gases from Switzerland by using continuous measurements of HFCs at Jungfraujoch (Switzerland). Swiss emission of CO ($E_{CO}$) values are taken from FOEN (2021b), see chp. 3.2.4.1 concerning system boundaries.

### *Results and discussion*

In the following, Swiss emissions of five HFCs (HFC-134a, HFC-125, HFC-152a, HFC-143a, HFC-32) and of $SF_6$ are estimated based on data from Jungfraujoch and are compared to the emission estimate of the Swiss greenhouse gas inventory. Further emission estimates of other fluorinated greenhouse gases will be added in future National Inventory Reports (NIR) upon availability.

***HFC-134a***

HFC-134a is the most important anthropogenic HFC. One of its main sources is the diffuse emission from its usage as cooling agent in mobile air conditioners (MACs). Further relevant applications are the usage in cooling mixtures in the industrial and commercial refrigeration as well as in stationary air conditioners and heat pumps and as propellant. The stock of HFC-134a in MACs and the related emissions have been steadily increasing until 2016 but are declining in most recent years due to the replacement of HFC-134a in this application by HFO-1234yf.

After a common increase of estimated emissions from 2001 until 2007 both the estimate from Jungfraujoch and the inventory showed a stabilization of the emissions. This could be related to the decreasing HFCs used in propellants and to optimizations in the industrial and commercial refrigeration. In the inventory increasing tendencies are found again from 2008 until 2018, whereas the measurement-based estimate shows no clear trend and fluctuates around 300 tonnes/year. Overall, the agreement between the two methods was excellent from 2001 – 2006; while a discrepancy of ca. 25%–40% is observed between 2012 and 2018 (Figure A – 4). Interestingly, also emission estimates for HFC-134a for the United Kingdom of Great Britain and Northern Ireland show a similar discrepancy in the comparison between measurement-based emission estimates (comparable to those performed here) and the UK inventory (Brown et al. 2019). Since 2019 the inventory-based emissions show a decline, whereas the measurement-based estimate remains stable at the lower level.

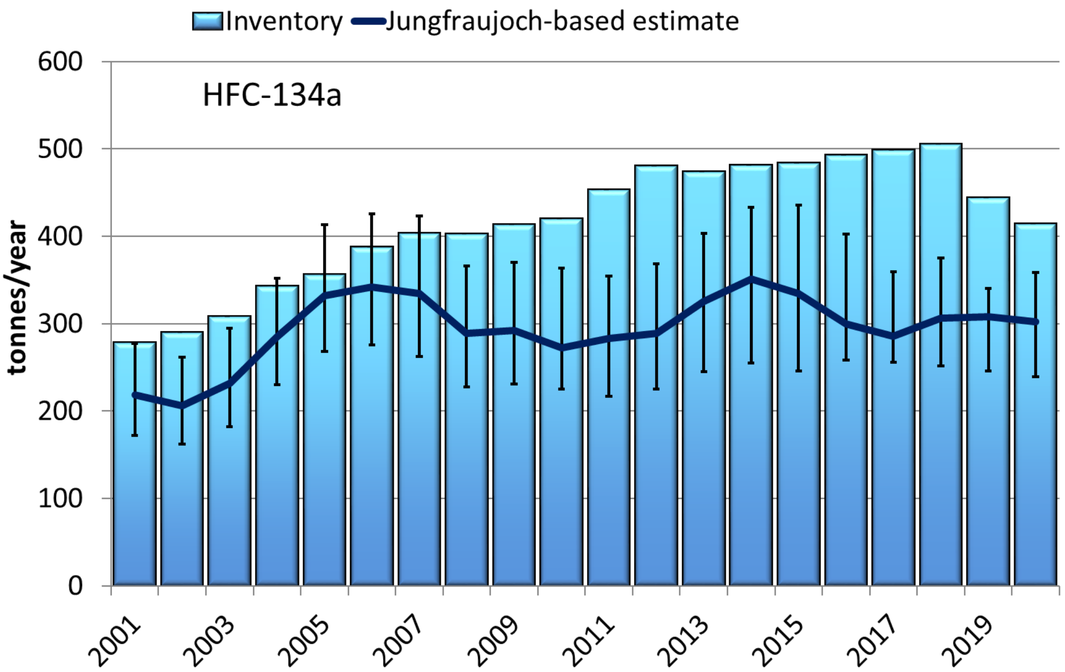



Figure A – 4 Comparison of HFC-134a emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

***HFC-125***

HFC-125 is mainly used in cooling mixtures in air conditioners and commercial refrigeration equipment. Estimated emissions from Jungfraujoch measurement data tend to be slightly but consistently lower than in the inventory (Figure A – 5). Emission estimates from Jungfraujoch show a decrease of emissions in 2017 and a stabilization thereafter. Due to efforts to eliminate high-GWP HFCs from refrigeration applications and the related elimination of HFC-125 containing blends, the emissions based on the inventory became stable in recent years and are expected to decrease in the near future. Potentially the timing between the two approaches is different due to differences in the real-world usage of HFC-125 and the model approach in the inventory.

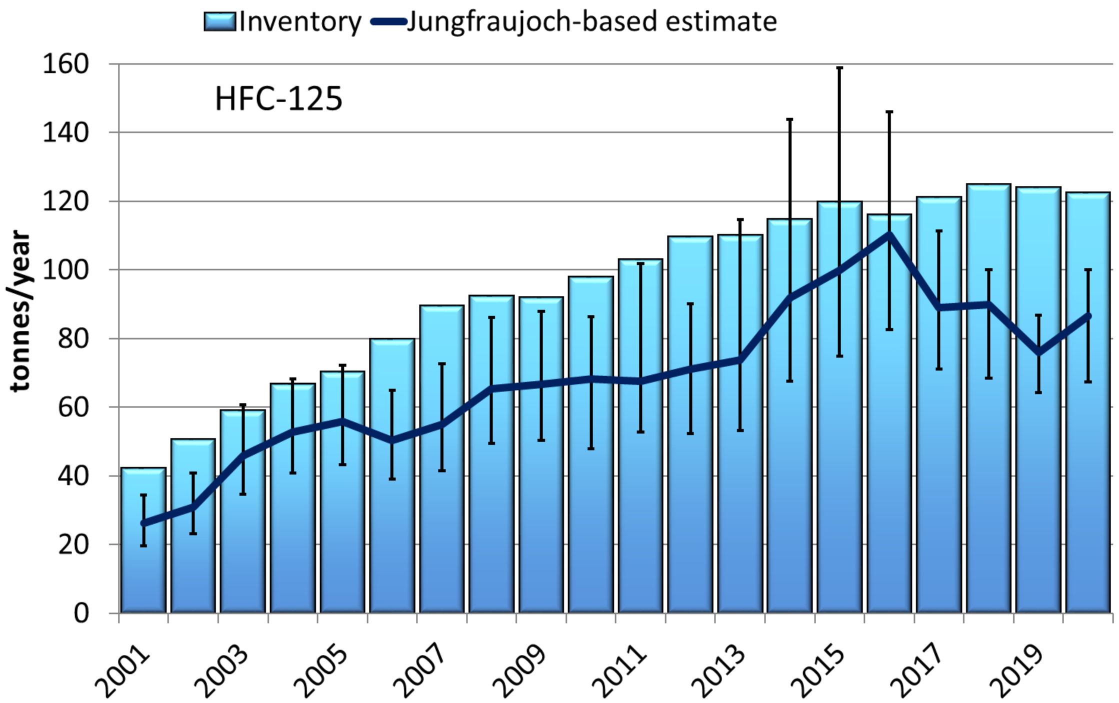



Figure A – 5 Comparison of HFC-125 emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

***HFC-152a***

HFC-152a is mainly used as a blowing agent in open-cell polyurethane (PU) foams, in closed cell PU sprays and closed-cell extruded polystyrene (XPS) foams. In open cell foams, 100% of emissions are related to the blowing process. In closed cell foams, part of the blowing agent remains in the product and emissions occur over its lifetime, with a rate depending on the cell- and molecular-structure of the blowing agent. Unlike for other blowing agents, experts assume that within the first year of the lifetime of the foam 95%–100% of HFC-152a is emitted. The emissions of the first year are commonly allocated to the country of production (according to UNFCCC good practice guidance). These assumptions and allocation are also applied for the model used in the Swiss inventory for estimating HFC-152a emissions under the source category 2F2 (Foam Blowing).

HFC-152a emissions from foams in the inventory are mainly related to the production and consumption of PU spray. Most of other foam products are imported, and consequently these emissions are allocated to the country of origin. The reported decrease in the inventory since 2003 reflects the replacement of HFC-152a in PU spray.

Up to the year 2002, estimated emissions from Jungfraujoch measurement data are lower than reported in the inventory and from then onwards they are higher. This can be explained by the UNFCCC practice to allocate HFC-152a emissions of the first year to the country of production of foams (which is except for PU spray mainly outside Switzerland). However, in reality a fraction of these first-year emissions occur during the usage of the products (e.g. for insulation) in Switzerland and are, therefore, reflected in the measurements but, by definition, not in the inventory. Nonetheless, it is important to apply the UNFCCC approach in the inventory as otherwise double counting may occur when allocating the total emissions to the country of origin and the country of product use. Emissions estimated from Jungfraujoch show a consistent decrease related to the partial phase-out of HFC-152a from the foam-blowing applications (Figure A – 6).

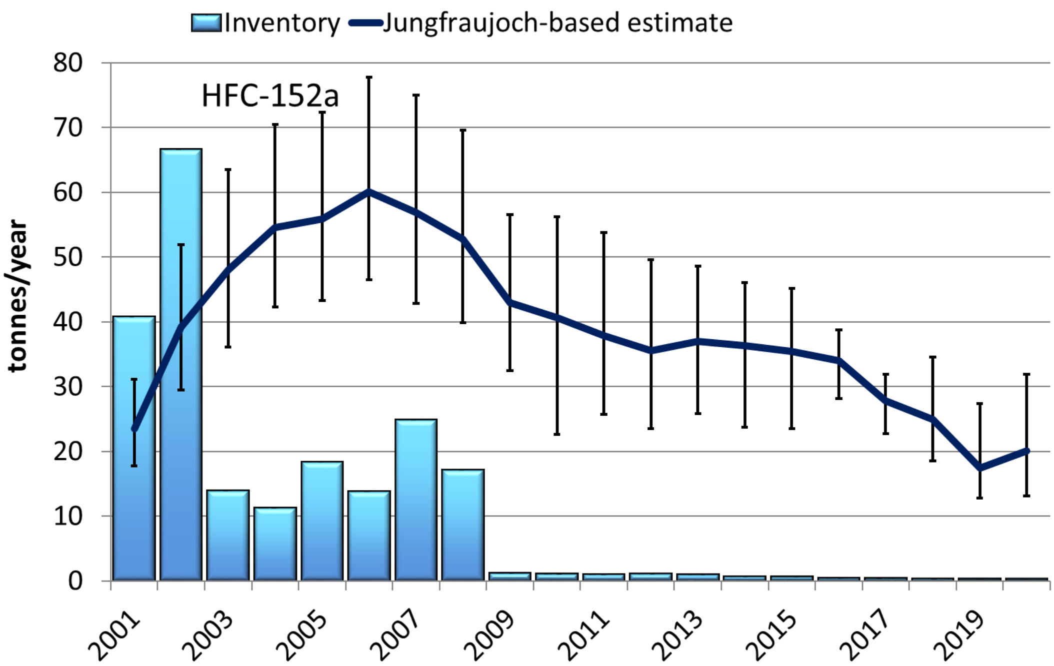



Figure A – 6 Comparison of HFC-152a emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

***HFC-143a and HFC-32***

HFC-143a (Figure A – 7) and HFC-32 (Figure A – 8) are mainly used in cooling agent mixtures in commercial refrigeration and stationary air conditioners (together with HFC-134a and/or HFC-125). Until 2013, HFC-143a emissions estimated from Jungfraujoch measurement data were slightly lower than those from the inventory. From 2014–2016, there was a very good agreement between the two methods and a slight decrease in emissions in most recent years, which is seen by both methods. Since 2017 a downward trend is seen by both methods, with a more pronounced tendency by the measurement-based method. Emissions estimated from Jungfraujoch have stabilized in the most recent years. A similar trend can also be seen in measurement-based estimated HFC-125 emissions (see Figure A – 5). A further decline is expected in the future because of regulations of GWP for refrigeration applications and the related elimination of HFC-143a containing blends.

The measurement-based estimates of HFC-32 are consistently lower (by about 40%) than the data from the inventory. In contrast to HFC-125 and HFC-143a, emissions of HFC-32 increased until 2018. This could be due to the fact that HFC-32 has a lower GWP than the other two compounds and is therefore preferably used in new air-conditioner applications. Since 2016, however, the measurement-based method estimates stable emissions, whereas the inventory-based method sees an unhindered increase of emissions. It has to be seen if this recent gap between the methods becomes a long-term feature.

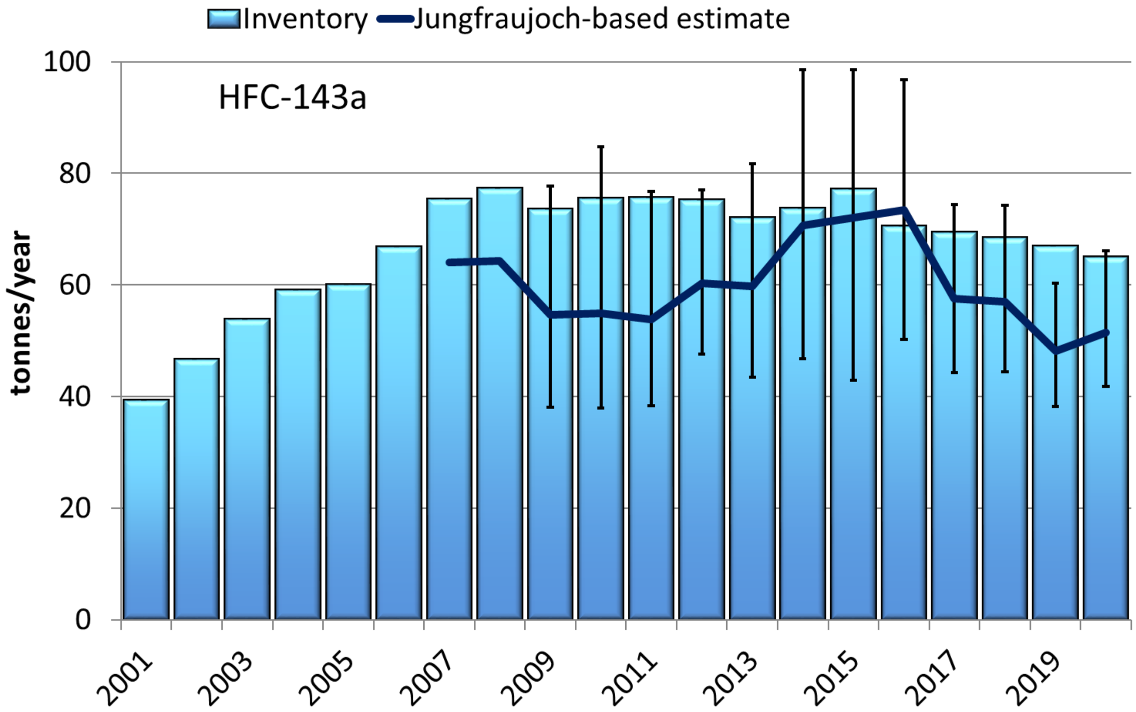



Figure A – 7 Comparison of HFC-143a emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

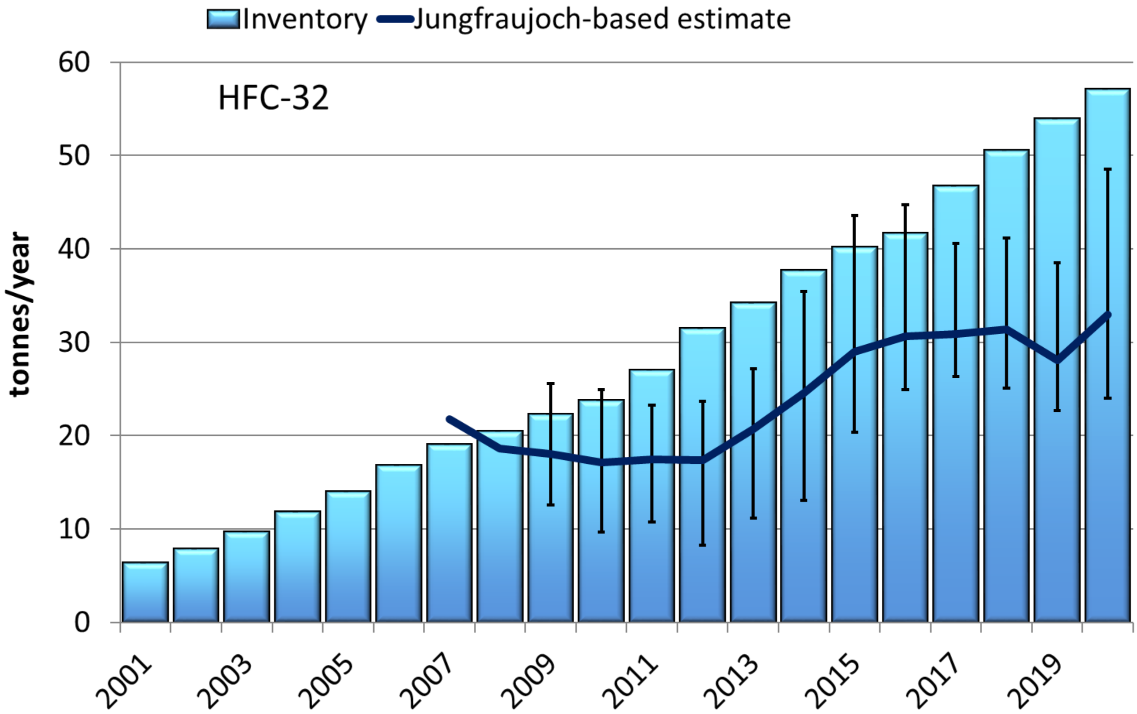



Figure A – 8 Comparison of HFC-32 emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

***Sulfur hexafluoride ($SF_6$)***

Until 2010, emissions of $SF_6$ in Switzerland were mainly due to its use as an insulator of electrical equipment, as for example in gas insulated switchgears and in gas circuit breakers. Since then, emissions from decommissioning of insulating windows are dominant. Additional minor emissions arise from magnesium smelters, industrial particle accelerators and various other applications. Generally, emission estimates for both methods show a remarkable similarity in the trend, except for the early comparison period of 2001–2003, when slightly higher emissions were estimated from the measurement-based method. This could be due to the mass balance approach based on industry data, which has been introduced since 2003. Increasing $SF_6$ emissions were estimated between 2010 and 2015 and could be the result of the increased disposal of insulating windows (all $SF_6$ released) during this period. Since then, emissions from both methods were consistently decreasing until 2019 (Figure A – 9). For the measurement-based emissions this decrease was less stringent and could be due to uncertainties. In fact, when uncertainties are included, no clear downward trend in emissions can be derived yet from the Jungfraujoch-based emission estimate.

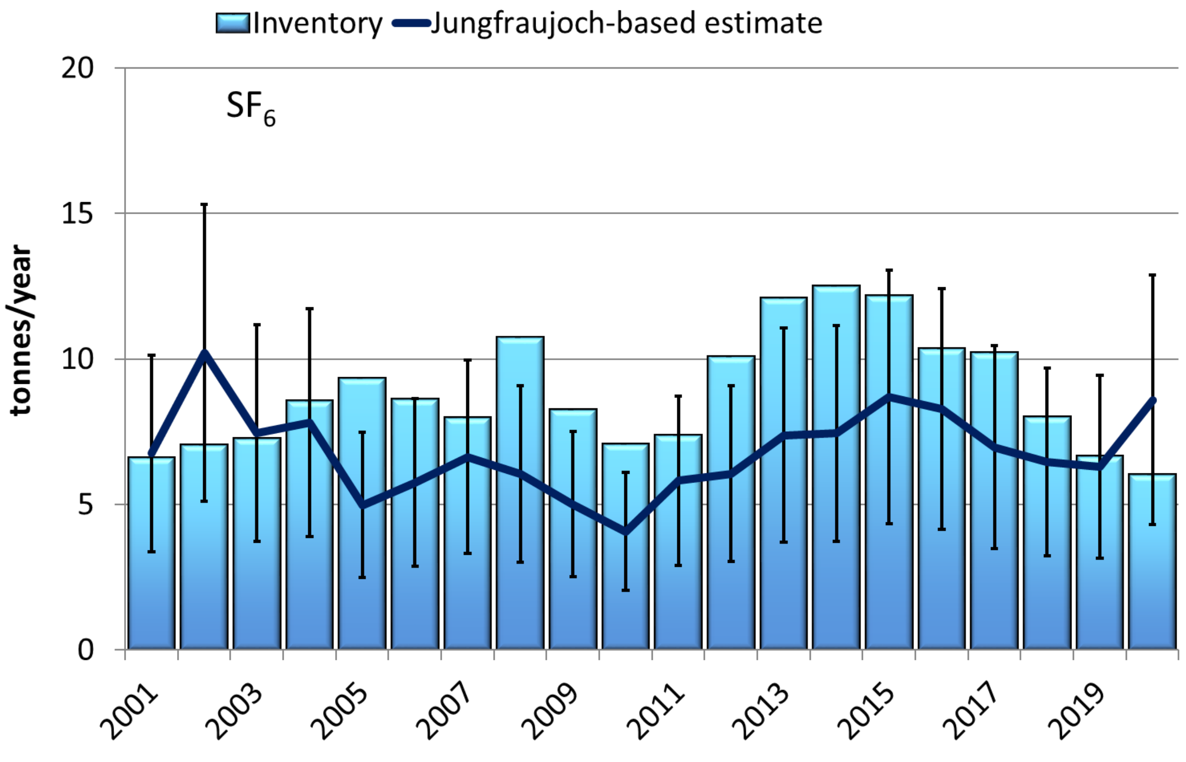



Figure A – 9 Comparison of $SF_6$ emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

## A5.2 Independent verification of methane and nitrous oxide emissions by inverse modelling

***Introduction***

In 2013 the Swiss Federal Laboratories for Material Science and Technology (Empa), ETH Zurich and the University of Bern established a greenhouse gas (GHG) observing network in Switzerland as part of the CarboCount-CH SNF-Sinergia project (www.carbocount.ch). The network consisted of four sites that continuously measure the atmospheric concentration of carbon dioxide ($CO_2$) and methane ($CH_4$). The sites were chosen to cover most of the densely populated and agriculturally used Swiss Plateau (see Figure A – 10). Atmospheric transport simulations confirm that the measurements at these sites are sensitive to emissions from a large part of Switzerland (Oney et al. 2015). The aim of CarboCount-CH was to better understand and quantify the anthropogenic emissions and biosphere-atmosphere exchange of the abovementioned GHGs by inverse modelling. Currently (March 2022), 3 of the 4 sites (Beromünster, Lägern-Hochwacht, Gimmiz) are still operational, whereas the measurements at Früebüel were closed down in 2016. Additional GHG measurements were carried out in the summer of 2017 in north-eastern Switzerland (Gäbris, GBR, Appenzell) as part of a FOEN-funded validation study to analyse the sensitivity of inverse modelling results to additional measurements in an area poorly covered by the network. Further continuous GHG observations with sensitivity to emissions over Switzerland are available from the high altitude site Jungfraujoch (Empa) and Schauinsland (Germany, UBA, mountain top). High precision measurements of $N_2O$ commenced in March 2017 at the tall tower site Beromünster and additional $N_2O$ observations are available from Jungfraujoch and Schauinsland.

Here, the results of inverse modelling to validate total Swiss $CH_4$ and $N_2O$ emissions are reported. A previous analysis for $CH_4$ had been carried out for the measurement period March 2013 to February 2014, the first year with data available from all four CarboCount-CH sites, which showed good agreement between the NIR reporting and the top-down inverse modelling (Henne et al. 2016). That study also raised further questions regarding the spatial and temporal distribution of the emissions and the sensitivity to boundary conditions (i.e., $CH_4$ baseline concentrations) required for the regional inversion. Additional sensitivity tests concerning the use of additional measurements in north-eastern Switzerland and the use of baseline concentrations from global scale models were reported in a previous NIR (FOEN 2018). Here, results for $CH_4$ are given for the period 2013 to 2021, whereas for $N_2O$ inverse modelling results are given for 2017 onwards. The results presented for 2021 are preliminary, since quality-controlled observational data (both $CH_4$ and $N_2O$) from Schauinsland were not available at the time of analysis.

***Methods***

The inversion approach applied here was described in detail in Henne et al. (2016). It is based on source sensitivities that were calculated for each of the mentioned measurement sites with the Lagrangian atmospheric transport model FLEXPART. Source sensitivities give the sensitivity of an atmospheric concentration observation to the emissions released at a distant source and as such can be given as concentration units divided by a mass flux (e.g. ppb $kg^{-1}$ s). FLEXPART was driven with high resolution meteorological input data from the numerical weather prediction model COSMO (7 km by 7 km horizontal resolution) provided by the Swiss national weather service (MeteoSwiss) until 2020-10-29 (decommission of COSMO-7 forecasts and respective compute hardware). For FLEXPART simulations after 2020-10-29, COSOM-7 analysis fields were calculated by Empa following the previous

MeteoSwiss setup as closely as possible. For each site, 3-hourly source sensitivities were calculated by running the model in time-inverted mode, releasing in each 3-hour time interval 50'000 air parcels and following them 4 days backward in time.

When convoluting source sensitivities with gridded surface emission fluxes, atmospheric concentrations at the location of the observations can be obtained. These simulated concentrations can be compared with the measurements, and through “inverse modelling” an optimized (*a posteriori*) emission distribution can be estimated that minimizes the differences between simulated and observed concentrations while also considering the uncertainties of the initial (*a priori*) emission distribution. In addition to the emission distribution, the applied inversion system also optimizes a baseline concentration for each site, which is required to subtract the non-regional contribution from the total observed concentration

In contrast to the previously reported approach (Henne et al. 2016), which contained a large number of sensitivity inversions to investigate the structural uncertainty of the inversion system, only a reduced set of sensitivity inversions was used here, varying some key aspects of the transport model and the inversion system (particle release height, absolute *a priori* emissions, and seasonality).

As *a priori* emissions for Switzerland, the MAIOLICA $CH_4$ inventory was used (Hiller et al. 2014), which disaggregates the emissions reported by the Swiss National Inventory Report (NIR) onto a regular spatial grid. For emissions outside of Switzerland the European TNO/MACC-2 inventory was employed (Kuenen et al. 2014). The total anthropogenic emissions of the MAIOLICA inventory was 176 kt $yr^{-1}$, which corresponds to the Swiss $CH_4$ emissions in 2012 as reported by the NIR in 2014 (FOEN 2014). The MAIOLICA inventory also includes a small contribution from natural sources of 3 kt $yr^{-1}$ (<2%). For the application to more recent years the Swiss national total emissions were scaled to those included in the NIR in 2016 (FOEN 2016).

The same inversion technique as for $CH_4$ was also applied to $N_2O$ for the period March 2017 to December 2021. In addition to the grid-resolved inversion used for $CH_4$, an additional sector-based inversion system was set-up for $N_2O$, allowing for the distinction between emissions from different source sectors, but at a reduced spatial resolution (Henne et al. 2019). *A priori* emissions for the $N_2O$ inversion were developed with a spatial resolution of 500 m by 500 m and for 26 emission sectors based on EMIS/NIR total national emission estimates and an evaluation of indirect emissions from (semi-)natural ecosystems (Bühlmann et al. 2015).

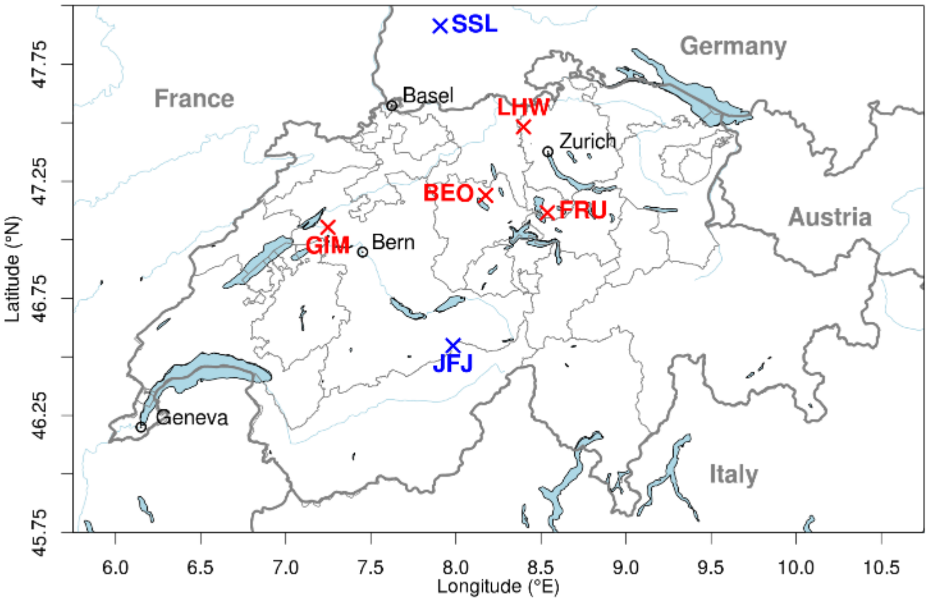



Figure A – 10 Map of Switzerland illustrating the location of CarboCount-CH sites (red), supplementary sites (blue), cantonal and national borders (grey) as well as major cities (black). The sites are: Beromünster (tall tower, BEO), Lägern Hochwacht (mountain top, tower, LHW), Gimmiz (flat, tower, GIM), Früehbüehl (mountain, near surface, FRU), Schauinsland (mountain top, SSL), and Jungfraujoch (high Alpine, JFJ).

***Methane emissions***

The inversion results are presented in the following in terms of national total emissions and spatial distribution. The inversion system was not set-up to optimize emissions by category separately, but to estimate the spatial distribution of total emissions. Nevertheless, through the spatial and temporal information the results can provide qualitative insights into the contribution from specific source categories that dominate in a given region or period. Further details and discussion on the inversion performance and results can be found in Henne et al. (2017).

The overall mean inverse estimate of total Swiss $CH_4$ emissions for the period 2013 to 2020 was 199±15 kt $yr^{-1}$ (1-σ confidence interval around the mean). This number represents the average and standard deviation over the reference and all sensitivity inversions for all years. It is slightly larger than NIR values (incl. emissions from LULUCF) reported in the latest submission (2022) for the same period of 191 kt $yr^{-1}$ (CRF Table10s3) but well within the 1-σ uncertainty range of ~±15 kt $yr^{-1}$ for the reporting year 2020. Since inverse modelling estimates integrate all fluxes (sources and sinks) between the land surface and the atmosphere, they need to be compared to inventory emissions including those from LULUCF.

For the period 2013 to 2020, the NIR suggests a $CH_4$ emission (incl. LULUCF) reduction of 11.5 kt (from 195 to 184 kt $yr^{-1}$ between 2013 and 2020), whereas the inversion estimates showed large inter-annual variability (range: 175 to 220 kt $yr^{-1}$; standard deviation of 15.5 kt $yr^{-1}$ for individual years) with considerable downward tendencies in the last years (2018, 2019, 2021) (Figure A – 11). This variability may mostly reflect the uncertainty of the inverse modelling system itself rather than a real temporal variability in the emissions. Due to this variability it is currently not possible to determine or validate the reported tendency. Additional years of observations and inverse modelling are required for this purpose.

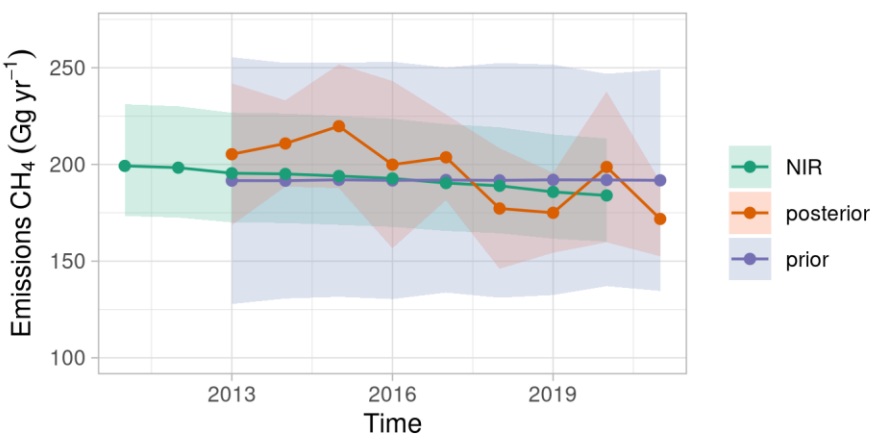



Figure A – 11 Time series of total Swiss $CH_4$ emissions as reported in the latest NIR (green), used as *a priori* information in the inverse modelling (purple), and as estimated by the inverse modelling (*a posteriori*, orange). The uncertainty ribbons give the 95% confidence (2σ) level of each estimate.

In Figure A – 12 the spatial distribution of the *a priori* emissions is shown, whereas the absolute differences between *a posteriori* minus *a priori* emissions for individual years are shown in Figure A – 13. An irregular inversion grid was used that exhibits high spatial resolution close to the observations and gets coarser with distance to these. In the *a priori* emissions the dominating role of agricultural emissions in the rural areas of the Cantons Lucerne and Thurgau/Appenzell is clearly seen. In contrast, the densely populated areas of Zurich, Basel and Geneva do not show up as emission hot-spots, consistent with the small contribution of emissions from natural gas distribution and wastewater treatment reported in the NIR.

The *a posteriori* results for the seven analysed years (2013 to 2021) in terms of annual totals and spatial distribution were rather similar providing evidence for the robustness of the method. The *a posteriori* emissions were smaller than *a priori* emissions in the agricultural areas of Canton Lucerne, but were increased in the north-eastern part of Switzerland (Cantons Appenzell and Saint Gallen). Smaller differences were seen in other parts of the country.

Previously, an alternative sensitivity inversion was performed that used *a priori* emissions from the EDGAR inventory (v4.2 FT2010, EC JRC 2009). In EDGAR, the Swiss country total amounts to 228 kt $yr^{-1}$, mostly due to about 25 kt $yr^{-1}$ larger emissions from the natural gas distribution network (IPCC category 1B2: fugitive emissions from oil and gas). *A posteriori* emissions in this sensitivity inversion were very similar to those of the reference inversion, which in turn required large reductions from the *a priori* distribution especially in densely populated areas. From this Henne et al. (2016) concluded that the natural gas emissions as given in the NIR (8 kt $yr^{-1}$) are in much better agreement with the atmospheric observations than the emissions in the EDGAR inventory (32 kt $yr^{-1}$).

When allowing the inversion to derive seasonal mean instead of annual mean emissions, a clear seasonal cycle with reduced winter time and increased spring to summer emissions was detected for all years (Figure A – 14). This is in line with the temperature-dependent seasonality expected from manure handling and storage (fewer emissions at lower temperatures) and the productivity-dependent seasonality of milk cows (spring maximum in productivity and calving date). However, considerable variability in the seasonality was observed for different years, sometimes showing a secondary summer minimum (2018) and in other years a summer maximum (2019). In 2021 unprecedentedly low emissions were observed in spring (preliminary result). In how far these variations could be traced to climate variability needs yet to be analysed.

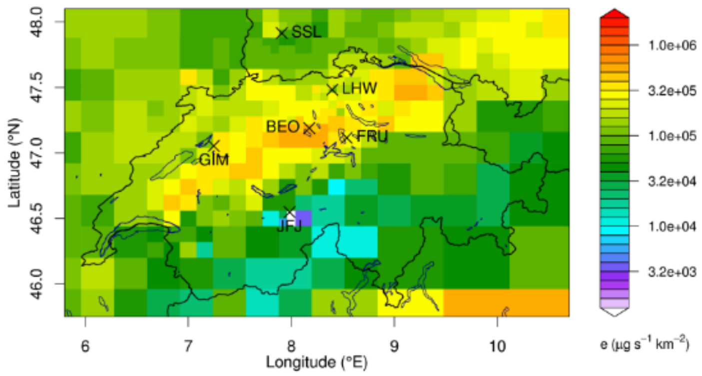



Figure A – 12 Spatial distribution of *a priori* $CH_4$ emissions. Within Switzerland the distribution follows that derived by Hiller et al. (2014), scaled to the bottom-up estimates of the NIR 2016 (FOEN 2016), outside Switzerland the bottom-up inventory of TNO/MACC (Kuenen et al. 2014) was used.

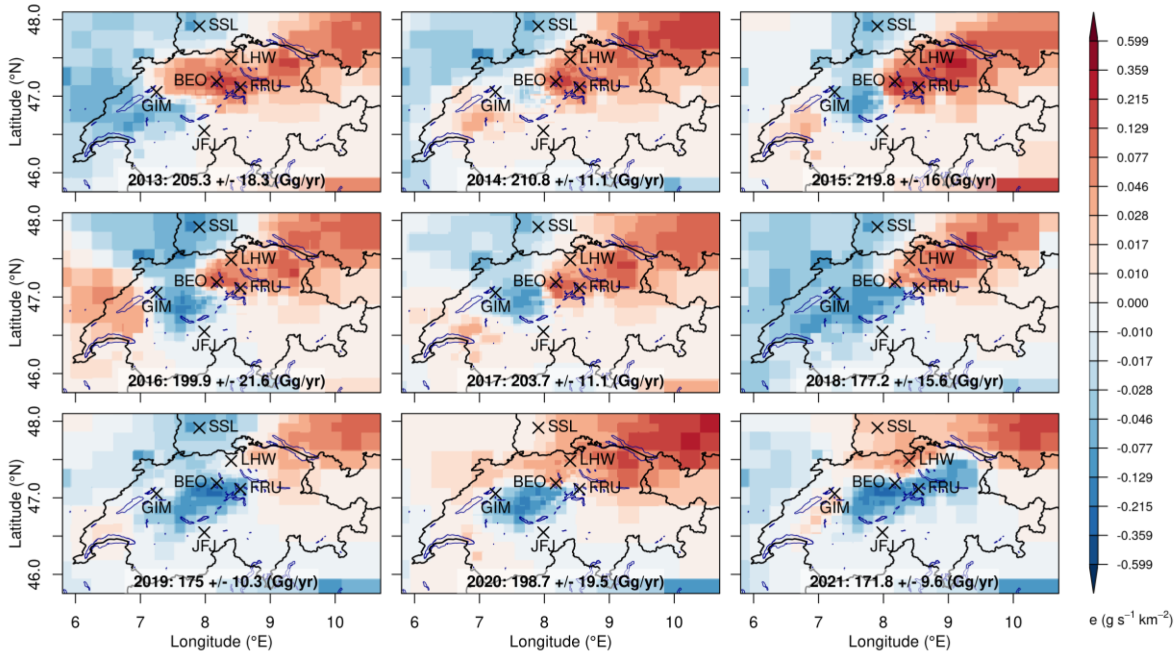



Figure A – 13 Absolute difference between *a posteriori* and *a priori* mean annual $CH_4$ emissions (each being the mean over 8 sensitivity runs). The numbers given in the plots refer to the total *a posteriori* Swiss emissions and their uncertainty (1σ level) for the given year.

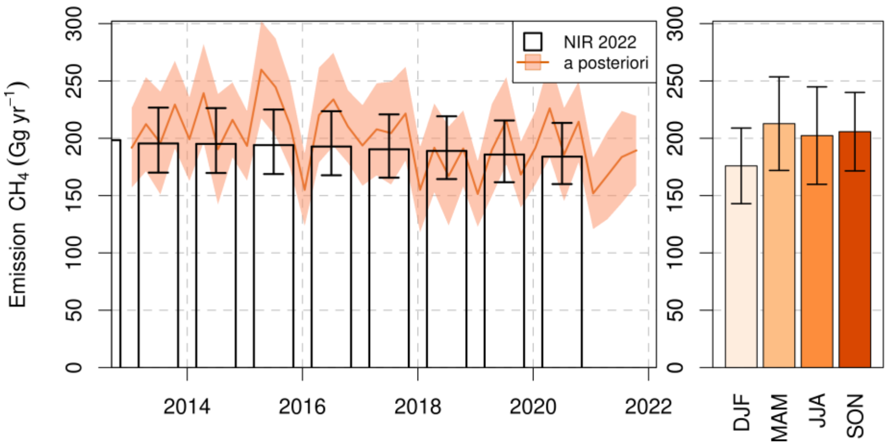



Figure A – 14 Seasonality of Swiss $CH_4$ emissions. Left panel: NIR values and their uncertainties are given as black bars and error bars. *A posteriori* emissions are given as orange line and uncertainty ribbons. Average *a posteriori* emissions by season are given on the right panel (DJF: December, January, February; MAM: March, April, May; JJA: June, July, August; SON: September, October, November). All uncertainties refer to 2-σ confidence intervals.

***Nitrous oxide emissions***

With the $N_2O$ observations established at the Beromünster tall tower site in 2017, it was possible to estimate Swiss $N_2O$ emissions by inverse methods at the country scale for the period March 2017 to April 2018 (Henne et al. 2019). Inversely estimated Swiss $N_2O$ emissions were slightly larger than reported $N_2O$ emission. However, due to the large uncertainties connected to these numbers, the inverse estimates are not significantly different from the NIR estimates. The relative uncertainty of the inverse modelling estimate was smaller than that of the NIR estimate. The uncertainty range of the inverse method was calculated from the spread across 14 sensitivity inversions. These comprised the application of two different inversion approaches: one focussing on the spatial distribution (grid inversion), the other on the temporal evolution and emissions by sector (sector inversion). The largest contributors to the *a posteriori* spread were the definition and uncertainty of a baseline of the atmospheric concentrations required by the model approach and systematic differences between grid and sector inversions.

The inverse modelling methodology described in Henne et al. (2019) was extended to the period 2017 to 2021. A slightly different set of 14 sensitivity inversions (per year) was selected, using both inversion approaches and varying important factors of the inversion setup: baseline, a priori emissions, receptor height above model ground.

The best inverse estimate of Swiss annual $N_2O$ emissions for the years 2017 to 2020 was 10.9±3.1 Gg yr$^{-1}$. This compares to 10.1 (4.1 to 18.3) Gg yr$^{-1}$ given for the same period in this NIR (incl. emissions from LULUCF; 2-σ confidence range). For the year 2021, the inverse estimate is considerably lower than in previous years (Figure A-15), whereas the NIR only suggests a very moderate downward trend in the emissions. As some of the observational data, on which the inverse estimates are based, are still preliminary, the 2021 result may still be subject to change.

Most of the slightly larger emission estimates of the inversion model as compared with the *a priori* estimates were assigned to direct emissions from agricultural soils (central and eastern Swiss Plateau) and to a smaller degree to indirect emissions from (semi-)natural ecosystems (southern Switzerland) and agricultural soils (northern Switzerland) (compare spatial distribution Figure A – 16 and sectorial emissions Figure A-17). The general increase from agricultural lands and (semi)natural ecosystems may partly be explained by solely natural $N_2O$ emissions, which were not taken into account in the applied *a priori* inventory, since they are not part of the NIR (only indirect emissions from (semi)natural ecosystems were considered). Reductions in the uncertainty of these estimates were largest for the sectors 'direct agriculture', 'industry and use', and 'indirect (semi-)natural'. Lower than *a priori* emissions were assigned to other types of anthropogenic emission sectors, mainly industry and use. However, the changes in this and other smaller sectors were associated with larger uncertainties and considerable negative covariance towards the major emission sectors. Hence, it cannot be concluded that they are significant. However, some further support for reduced industry and use emissions is provided by the grid inversions, which also estimated that emissions in urban areas are potentially overestimated in the NIR.

All inversions suggested a pronounced seasonality in the emissions with a mean amplitude over all inversions of around ±40% of the annual total (Figure A- 17). Largest emissions were estimated in summer, smallest in winter. However, there was considerable spread in the seasonal amplitude as well, with the tendency of inversions with smaller annual total emissions to predict smaller summertime emissions and correspondingly smaller seasonal amplitudes. Seasonality was dominated by emissions from soils. Emissions in summer and fall 2021 were considerably lower than in other years.

The tendency to larger than reported $N_2O$ emissions and strong seasonality obtained here for Switzerland compares well with other recent inverse estimates of $N_2O$ emissions in Europe. Some of these studies also highlight a similarly pronounced seasonality (Ganesan et al. 2015, Brown et al. 2019).

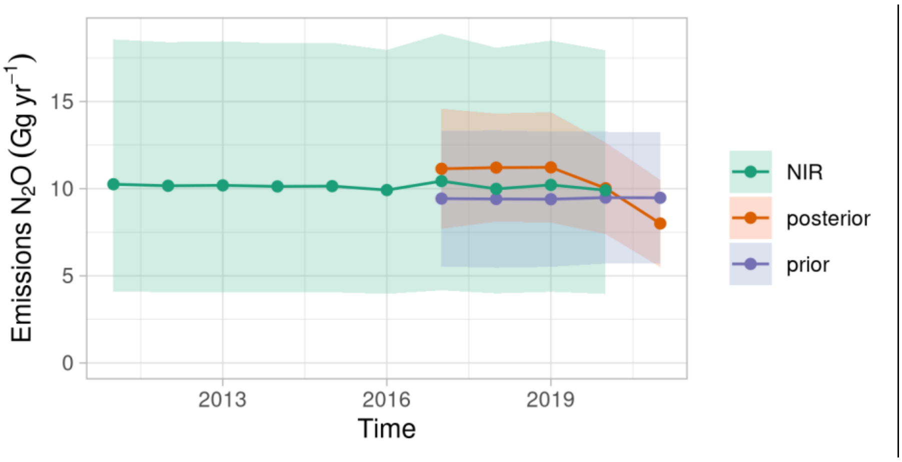



Figure A – 15 Time series of inversely estimated and NIR reported Swiss $N_2O$ emissions. (NIR reported and inversely estimated annual values and their uncertainties are given by lines, symbols and uncertainty ribbons. All uncertainty indicators refer to 2-σ levels.

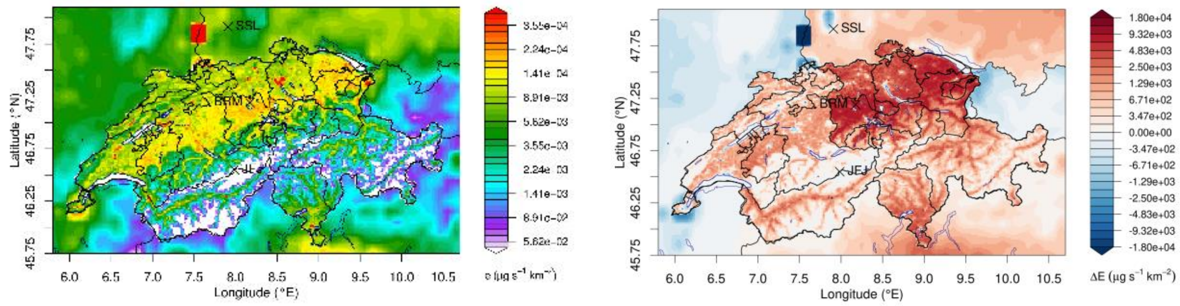



Figure A – 16 (Left) mean *a priori* and (right) *a posteriori* minus *a priori* $N_2O$ emission distribution over all sensitivity inversions (sector inversion only) for the period 2017 March to 2021 November.

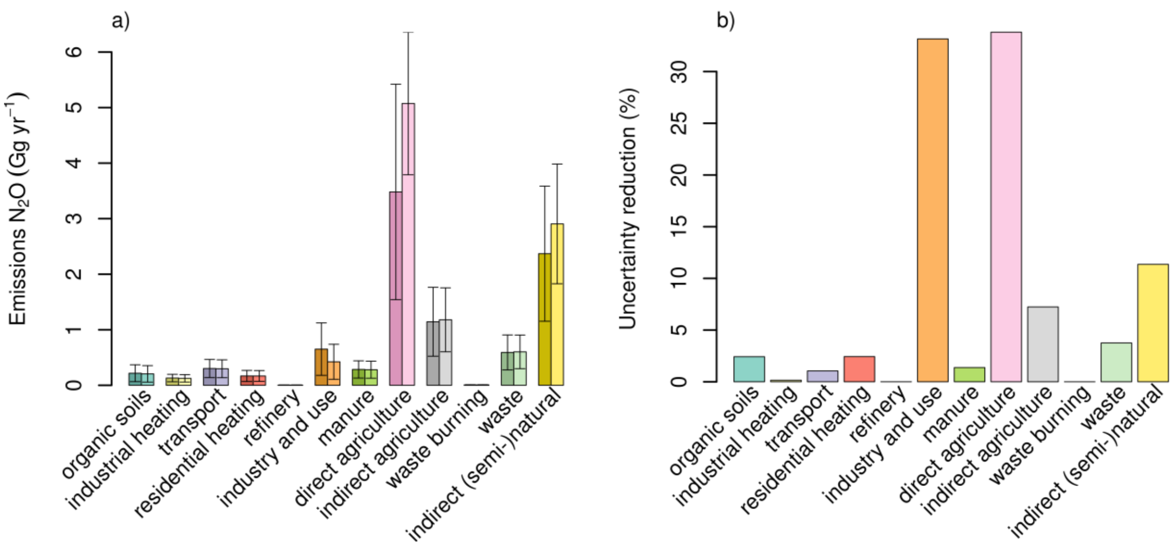



Figure A –17 (Left) contributions to Swiss $N_2O$ emissions: *a priori* darker colours, *a posteriori* lighter colours. (right) reduction of uncertainty estimate from *a priori* assumption to inverse *a posteriori* estimate. Results present the average for the period 2017 March to 2021 November. Uncertainty bars represent 2-σ confidence intervals.

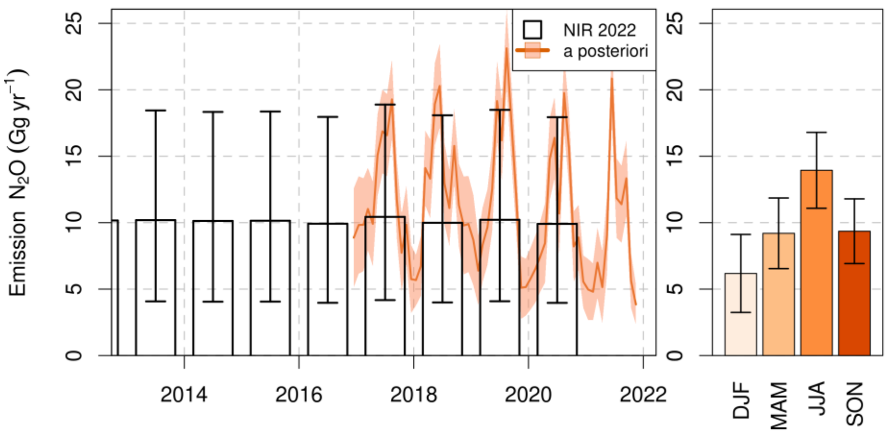



Figure A –18 Seasonality of Swiss $N_2O$ emissions. Left panel: NIR values and their uncertainties are given as black bars and error bars. Monthly a *posteriori* emissions are given as orange line and uncertainty ribbons. Average a posteriori emissions by season are given on the right panel (DJF: December, January, February; MAM: March, April, May; JJA: June, July, August; SON: September, October, November). All uncertainties refer to 2-σ confidence intervals.

# Annex 6 Information on the CRF reporter

The CRF reporter still seems to generate errors in the numerical output of some reporting tables. A non-exhaustive list of issues and errors identified so far is provided in Table A – 32. In some instances where numbers are not identical in the reporting tables (CRF) and in the NIR, a remark was added in the NIR. This aspect should be taken into consideration when comparing information in the NIR with the reporting tables.

Table A – 32 Identified errors in the output of some reporting tables (CRF).

| **Reporting table CRF** | **Problem** | **Solution** |
|---|---|---|
| Table1A(d) | The column "Reported under..." should include the NFR code in the Text. | Actually, there is no possibility to change it, because a drop-down-menu determines the text. |
| Table2(I)s1-s2 | In all empty cells should be written „NO", but the effort would be very big to generate in the navigation tree of the CRF web application for every cell a new node and then to adapt all the import files to these changes. | Because the effort would be quite big, and there is no real benefit, we passed on it. |
| Table2(II) | In all empty cells should be written „NO", but the effort would be very big to generate in the navigation tree of the CRF web application for every cell a new nod and then to adapt all the import files to these changes. | Because the effort would be quite big, and there is no real benefit, we indicate in the documentation box: „2.B.9, 2.C, 2.E, 2.F.1-2.F6, 2.G: "NO" for all empty cells". |
| Table2(II)B-Hs1 | In Line 49 of the reporting table the emissions are indicated as kt $CO_2$ eq instead of t. | Problem in the CRF web application. |
| Table3.B(a)s2 | NFR codes 3B4g and 3B4hi: cells I55 and L103 are still empty despite of correctly imported values. | Problem in the CRF web application. |
| Table3.B(b) | The IEF for "indirect emissions from atmospheric deposition" (cell R37): Wrong molecular weight. The IEF is displayed in kg $N_2O$ per kg N handled instead of kg $N_2O$-N per kg N handled. | Problem in the CRF web application. |
| Table3s1;<br>Table3.As1;<br>Table3.As2;<br>Table3.B(a)s1;<br>Table3.B(a)s2;<br>Table3.B(b) | All cells for "Cattle, Option A" should be filled with "IE" but this Option A cannot be selected together with Option B. | Problem in the CRF web application.<br>Solved with comment in documentation boxes of tables Table3.As1, Table3.B(a)s1, Table3.B(b) |
| Table4 | $N_2O$ from 4(IV) (indirect emissions) are included in the total sum in Table 4 without being displayed in any subcategory in Table 4. The sum is correct (with indirect emissions). | Inaccuracy in the CRF web application. The total is not equal to the sum of the subcategories. |
| Table4 | There are several empty cells in the $CH_4$ and $N_2O$ columns, where numbers and/or notation keys are not inserted. | Problem in the CRF web application. |
| Tables 4A-4F | In these LULUCF categories, the value "0" can represent a Tier 1 estimate for changes in carbon stock (and implied CSC | Inaccuracy in the CRF web application. Inappropriate display of |

| | | |
|---|---|---|
| | factors) (cf. IPCC 2006, Vol. 4, chp. 2.2.1). However, the CRF web application does not accept "0". Instead, notation keys (NO or NE) must be inserted, which are not really appropriate. | notation keys. |
| Table4(V) | "Values" and "IEF" in lines 8 to 10 are missing. | Problem in the CRF web application. |
| Summary3s1 Summary3s2 | Empty cells in "Method applied" and "Emission factor" for several sectors and gases: There should be indicated "NO" instead of empty cells. | Inaccuracy in the CRF web application. „NO" is not imported and there is no possibility to change it, because „NO" or „NA" are not in the drop-down menu. |
| Summary3s1 Summary3s2 | Some method and emission factor information are not imported into the web application. | Problem in the CRF web application. |
| Table8s4 | PFC emissions from 2G2 are also displayed under 2G4. | Problem in the CRF web application. |
| Table9 | For some entries "no gas" is documented for the first column "GHG". | Problem in the CRF web application. |
| Table10s1 | For $CO_2$ eq in sector 4 LULUCF, the total is not equal to the sum of the displayed $CO_2$ eq emissions in the categories 4A+4B+4C+4D+4E+4F (rows 40 to 47) but includes also indirect $N_2O$ from 4(IV) in $CO_2$ eq. The sum is correct (with indirect emissions). | Inaccuracy in the CRF web application. |
| Table10s2 | Empty cell for $CO_2$ captured in the year 2005 | Problem in the CRF web application. |
| Table10s4 | For $N_2O$ in sector 4 LULUCF, the total is not equal to the sum of the displayed $N_2O$ emissions in the categories 4A+4B+4C+4D+4E+4F (rows 39 to 46) but includes also indirect $N_2O$ from 4(IV). The sum is correct (with indirect emissions). | Inaccuracy in the CRF web application. |
| 4(KP-I)B.1 | Description of category and sub-category is shown twice under „identification code" and „subdivision". This is not wrong but not necessary. | Problem in the CRF web application. |
| All | Documentation box entries are not consistent. Sometimes all entries are in a single cell, sometimes there are several lines with entries, some of them empty. | Inaccuracy in the CRF web application. |

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# References to EMIS database comments

Table A – 33 Assignments of NFR Codes to titles of EMIS (Swiss Emission Information System) database comments. These internal documents will be made available to reviewers on request.

| NFR Code CRF [UNECE] | EMIS Title | NFR Code CRF [UNECE] | EMIS Title |
|---|---|---|---|
| 1 A | Energiemodell*** | 2 D 3 a [2 D 3 g] | Gummi-Verarbeitung** |
| 1 A | Holzfeuerungen | 2 D 3 a [2 D 3 g] | Klebband-Produktion |
| 1 A 2 | Sektorgliederung Industrie | 2 D 3 a [2 D 3 g] | Klebstoff-Produktion** |
| 1 A 1 a | Kehrichtverbrennungsanlagen | 2 D 3 a [2 D 3 g] | Lösungsmittel-Umschlag und -Lager |
| 1 A 1 a | Sondermüllverbrennungsanlagen | 2 D 3 a [2 D 3 g] | Pharmazeutische Produktion** |
| 1 A 1 a & 5 A | Kehrichtdeponien | 2 D 3 a [2 D 3 g] | Polyester-Verarbeitung |
| 1 A 1 b | Heizkessel Raffinerien* (ab 2016) | 2 D 3 a [2 D 3 g] | Polystyrol-Verarbeitung** |
| 1 A 1 c | Holzkohle Produktion | 2 D 3 a [2 D 3 g] | Polyurethan-Verarbeitung |
| 1 A 2 a & 2 C 1 | Eisengiessereien Kupolöfen | 2 D 3 a [2 D 3 g] | PVC-Verarbeitung |
| 1 A 2 a | Stahl-Produktion Wärmeöfen** | 2 D 3 a [2 D 3 g] | Gerben von Ledermaterialien |
| 1 A 2 b | Buntmetallgiessereien übriger Betrieb** | 2 D 3 b | Strassenbelagsarbeiten** |
| 1 A 2 b & 2 C 3 | Aluminium Produktion | 2 D 3 c | Dachpappe** |
| 1 A 2 c & 2 B 8 b [2 B 10 a] | Ethen-Produktion* | 2 D 3 d | Urea (AdBlue) Einsatz Strassenverkehr |
| 1 A 2 d & 2 A 4 d | Zellulose-Produktion Feuerung* | 2 G 3 a | Lachgasanwendung Spitäler** |
| 1 A 2 f | Kalkproduktion, Feuerung* | 2 G 3 b | Lachgasanwendung Haushalt** |
| 1 A 2 f | Mischgut Produktion | 2 G 4 [2 D 3 a ] | Pharma-Produkte im Haushalt |
| 1 A 2 f | Zementwerke Feuerung | 2 G 4 [2 D 3 a ] | Reinigungs- und Lösemittel; Haushalte |
| 1 A 2 f & 2 A 3 | Glas übrige Produktion* | 2 G 4 [2 D 3 a] | Spraydosen Haushalte** |
| 1 A 2 f & 2 A 3 | Glaswolle Produktion Rohprodukt* | 2 G 4 [2 D 3 h ] | Verpackungsdruckereien** |
| 1 A 2 f & 2 A 3 | Hohlglas Produktion* | 2 G 4 [2 D 3 h ] | Druckereien uebrige** |
| 1 A 2 f & 2 A 4 a | Feinkeramik Produktion* | 2 G 4 [2 D 3 i ] | Entfernung von Farben und Lacken** |
| 1 A 2 f & 2 A 4 a | Ziegeleien** | 2 G 4 [2 D 3 i ] | Entwachsung von Fahrzeugen |
| 1 A 2 f & 2 A 4 d | Steinwolle Produktion* | 2 G 4 [2 D 3 i ] | Kosmetika-Produktion** |
| 1 A 2 g iv | Faserplatten Produktion** | 2 G 4 [2 D 3 i ] | Lösungsmittel-Emissionen IG nicht zugeordnet |
| 1A2gvii, 1A3c, 1A3e, 1A4aii/bii/cii, 1A5b (without military aviation) | Non-Road | 2 G 4 [2 D 3 i ] | Öl- und Fettgewinnung |
| 1 A 2 g viii & 5 B 2 | Vergärung IG (industriell-gewerblich) | 2 G 4 [2 D 3 i ] | Papier- und Karton-Produktion** |
| 1 A 3 a & 1 A 5 | Flugverkehr | 2 G 4 [2 D 3 i ] | Parfum- und Aromen-Produktion** |
| 1 A 3 b i-viii | Strassenverkehr | 2 G 4 [2 D 3 i ] | Tabakwaren Produktion** |
| 1 A 3 c | Schienenverkehr | 2 G 4 [2 D 3 i ] | Textilien-Produktion |
| 1 A 3 e | Gastransport Kompressorstation | 2 G 4 [2 D 3 i ] | Wissenschaftliche Laboratorien |
| 1 A 4 b i | Holzkohle-Verbrauch | 2 G 4 [2 G] | Korrosionsschutz im Freien |
| 1 A 4 b i | Lagerfeuer | 2 G 4 [2 G] | Betonzusatzmittel-Anwendung |
| 1 A 4 c i | Gewächshäuser** | 2 G 4 [2 G] | Coiffeursalons |
| 1 A 4 c i | Grastrocknung** | 2 G 4 [2 G] | Fahrzeug-Unterbodenschutz** |
| 1 A 4 c i & 5 B 2 | Vergärung LW (landwirtschaftlich) | 2 G 4 [2 G] | Feuerwerke |
| 1 B 2 a iii | Raffinerie, Pipelinetransport | 2 G 4 [2 G] | Flaechenenteisung Flughaefen |
| 1 B 2 a iv | Raffinerie, Leckverluste* | 2 G 4 [2 G] | Flugzeug-Enteisung |
| 1 B 2 a iv | H2-Produktion* | 2 G 4 [2 G] | Frostschutzmittel Automobil |
| 1 B 2 a iv | Raffinerie, Clausanlage* | 2 G 4 [2 G] | Gas-Anwendung |
| 1 B 2 a v | Benzinumschlag Tanklager | 2 G 4 [2 G] | Gesundheitswesen, übrige** |
| 1 B 2 a v | Benzinumschlag Tankstellen | 2 G 4 [2 G] | Glaswolle Imprägnierung* |
| 1 B 2 b ii & 1 B 2 c ii | Gasproduktion und Flaring | 2 G 4 [2 G] | Holzschutzmittel-Anwendung |
| 1 B 2 b iv-vi | Netzverluste Erdgas | 2 G 4 [2 G] | Klebstoff-Anwendung** |
| 1 B 2 c | Raffinerie, Abfackelung | 2 G 4 [2 G] | Kosmetik-Institute |
| 2 A 1 | Zementwerke Rohmaterial | 2 G 4 [2 G] | Kühlschmiermittel-Verwendung |
| 2 A 1 | Zementwerke übriger Betrieb | 2 G 4 [2 G] | Medizinische Praxen** |
| 2 A 2 | Kalkproduktion, Rohmaterial* | 2 G 4 [2 G] | Pflanzenschutzmittel-Verwendung |
| 2 A 2 | Kalkproduktion, übriger Betrieb* | 2 G 4 [2 G] | Reinigung Gebäude IGD** |
| 2 A 4 d | Kehrichtverbrennungsanlagen Karbonat** | 2 G 4 [2 G] | Schmierstoff-Verwendung |
| 2 A 4 d | Karbonatanwendung weitere | 2 G 4 [2 G] | Spraydosen IndustrieGewerbe |
| 2 A 5 a | Gips-Produktion übriger Betrieb** | 2 G 4 [2 G] | Tabakwaren Konsum |
| 2 A 5 a | Kieswerke | 2 G 4 [2 G] | Steinwolle-Imprägnierung* |
| 2 B 1 | Ammoniak-Produktion* | 2 H 1 | Faserplatten Produktion** |
| 2 B 10 [2 B 10 a] | Ammoniumnitrat-Produktion* | 2 H 1 | Zellulose Produktion übriger Betrieb* |
| 2 B 10 [2 B 10 a] | Chlorgas-Produktion* | 2 H 1 | Spanplatten Produktion* |
| 2 B 10 [2 B 10 a] | Essigsäure-Produktion* | 2 H 2 | Bierbrauereien |
| *2 B 10 [2 B 10 a]* | *Formaldehyd-Produktion* | 2 H 2 | Branntwein Produktion |
| 2 B 10 [2 B 10 a] | PVC-Produktion | 2 H 2 | Brot Produktion |
| *2 B 10 [2 B 10 a]* | *Salzsäure-Produktion** | 2 H 2 | Fleischräuchereien |
| 2 B 10 [2 B 10 a] | Schwefelsäure-Produktion* | 2 H 2 | Kaffeeröstereien |
| 2 B 10 | Kalksteingrube* | 2 H 2 | Müllereien |
| 2 B 10 | Niacin-Produktion* | 2 H 2 | Wein Produktion |
| 2 B 2 | Salpetersäure Produktion* | 2 H 2 | Zucker Produktion |
| 2 B 5 | Graphit und Siliziumkarbid Produktion* | 2 H 3 | Sprengen und Schiessen |
| 2 C - 2 G | Synthetische Gase | 2 I | Holzbearbeitung |
| 2 C 1 | Eisengiessereien Elektroschmelzöfen | 2K, 1A1a, 2C1, 5A, 5C1, 5E & 6Ad | Emissions due to former PCB usage |
| 2 C 1 | Eisengiessereien übriger Betrieb | 2 L | NH3 aus Kühlanlagen |
| 2 C 1 & 1 A 2 a | Stahl-Produktion Elektroschmelzöfen** | 3 | Landwirtschaft |
| 2 C 1 | Stahl-Produktion übriger Betrieb** | 3 B | Tierhaltung |
| 2 C 1 | Stahl-Produktion Walzwerke** | 3 C | Reisanbau |
| 2 C 7 a | Buntmetallgiessereien Elektroöfen** | 3 D e | Landwirtschaftsflächen |
| 2 C 7 c | Verzinkereien | 4 V A 1 [11 B] | Waldbrände |
| 2 C 7 c | Batterie-Recycling* | 5 B 1 | Kompostierung |
| 2 D 1 | Schmiermittel-Anwendung | 5 B 2 | Biogasaufbereitung (Methanverlust) |
| 2 D 1 | Schmiermittel-Verbrauch B2T | 5 C 1 [5 C 1 a] | Abfallverbrennung illegal |
| 2 D 2 | Paraffinwachs-Anwendung | 5 C 1 [5 C 1 b i] | Kabelabbrand |
| 2 D 3 a [2 D 3 d] | Farben-Anwendung Bau | 5 C 1 [5 C 1 b iii] | Spitalabfallverbrennung |
| 2 D 3 a [2 D 3 d] | Farben-Anwendung andere | 5 C 1 [5 C 1 b iv] | Klärschlammverbrennung |
| 2 D 3 a [2 D 3 d] | Farben-Anwendung Haushalte** | 5 C 1 [5 C 1 b v] | Krematorien |
| 2 D 3 a [2 D 3 d] | Farben-Anwendung Holz | 5 C 2 / 4 V A 1 (Forstwirtschaft) | Abfallverbrennung Land- und Forstwirtschaft und Private |
| 2 D 3 a [2 D 3 d] | Farben-Anwendung Autoreparatur** | 5 D 1 [5 D] | Kläranlagen kommunal (Luftschadstoffe) |
| 2 D 3 a [2 D 3 e] | Elektronik-Reinigung** | 5 D 2 [5 D] | Kläranlagen industriell (Luftschadstoffe) |
| 2 D 3 a [2 D 3 e] | Metallreinigung** | 5 D 1 / 5 D 2 [5 D] | Kläranlagen GHG |
| 2 D 3 a [2 D 3 e] | Reinigung Industrie übrige** | 5 E | Shredder Anlagen |
| 2 D 3 a [2 D 3 f] | Chemische Reinigung** | 6 A d | Brand- und Feuerschäden Immobilien |
| 2 D 3 a [2 D 3 g] | Druckfarben Produktion** | 6 A d | Brand- und Feuerschäden Motorfahrzeuge |
| 2 D 3 a [2 D 3 g] | Farben-Produktion** | [11 C] | NMVOC Emissionen Wald |
| 2 D 3 a [2 D 3 g] | Feinchemikalien-Produktion** | 1, 2, 5, 6 - indirect | Indirekte Emissionen |

* confidential process
** confidential EMIS comment
*** work in progress
*Cursive: process not relevant for the years after 1990.*