

Switzerland's Greenhouse Gas Inventory 1990–2017

National Inventory Report

Including reporting elements under the Kyoto Protocol

Submission of April 2019
under the United Nations Framework Convention on Climate Change
and under the Kyoto Protocol



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Bern, April 2019

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Glossary

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, forth survey 2013/18
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
AAU	Assigned Amount Unit (under the Kyoto Protocol)
BAFU	German for FOEN
BCEF, BEF	Biomass conversion and expansion factor, biomass expansion factor
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
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
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
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 Material Testing and Research
ERT	Expert review team (under the UNFCCC and the Kyoto Protocol)
ERU	Emission Reduction Unit (under the Kyoto Protocol)
ETS	Emission Trading System
EV	Erdöl-Vereinigung (Swiss Petroleum Association)
FAL	Swiss Federal Research Station for Agroecology and Agriculture (since 2006: ART; since 2014 Agroscope)
FCA	Federal Customs Administration
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
FOD	First order decay (model)
FOEN	Federal Office for the Environment (former name SAEFL until 2005)
FOITT	Federal Office of Information Technology, Systems and Telecommunication
GHG	Greenhouse gas
GL	Guidelines
g	Gramme/gram
GVS	Swiss Foundry Association
GWP	Global Warming Potential
ha	hectare
HFC	Hydrofluorocarbons (e.g. HFC-32 difluoromethane)
HWP	Harvested wood products
ICAO	International Civil Aviation Organization
IDM	FOEN Internal Document Management System
IDP	Inventory Development Plan
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial processes and product use
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
MSW	Municipal solid waste
NABO	Swiss Soil Monitoring Network
NCV	Net calorific value
NEU	Non-energy use of fuels
NF ₃	Nitrogen trifluoride 2006 IPCC GWP: 17'200 (UNFCCC 2014a, Annex III)
NFI1, NFI2	First (1983–1985), Second (1993–1995), Third (2004–2006)
NFI3, NFI4	and Fourth (2009–2017) 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 ₂ O	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)
SAEFL	Swiss Agency for the Environment, Forests and Landscape (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
SF ₆	Sulphur hexafluoride, 2006 IPCC GWP: 22'800 (UNFCCC 2014a, Annex III)
SGWA	Swiss Gas and Water Industry Association
SECO	State Secretariat for Economic Affairs
SFOE	Swiss Federal Office of Energy
SFSO	Swiss Federal Statistical Office
SGWA	Swiss Gas and Water Industry Association (see SVGW/SSIGE)
SKW	Schweizerischer Kosmetik- und Waschmittelverband (Swiss Association of cosmetics and detergents)
SO ₂	Sulphur dioxide
SOC	Soil organic carbon
SOLV	Swiss Organisation for the Solvent Recovery of Industrial Enterprises in the Packaging Sector
SVGW/SSIGE	Schweizerischer Verein des Gas- und Wasserfaches / Société Suisse de l'Industrie du Gaz et des Eaux (Swiss Gas and Water Industry Association)
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)
QA/QC	Quality assurance/Quality control
QMS	Quality management system
UBA	Umweltbundesamt (Federal Environment Agency in Germany)
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
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 degrees Celsius compared to +0.9 degrees Celsius 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 per cent 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. Recently, 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 2017k).

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.

The 2019 inventory submission under the UNFCCC and under the Kyoto Protocol includes the NIR, the greenhouse gas inventory 1990–2017 including also the Kyoto Protocol LULUCF tables 2008–2017 in the Common Reporting Format as well as the Standard Electronic Format (SEF) tables and the standard independent assessment report (SIAR) from the National Registry.

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.

The structure of Switzerland's NIR corresponds to the UNFCCC annotated outline (UNFCCC 2014a) and it contains three parts:

PART 1 reports the obligations under the UNFCCC,

PART 2 shows the additional obligations under the Kyoto Protocol and several

Annexes provide detailed information on selected issues of Part 1 and Part 2.

Chapter 1 provides information on the impacts of climate change in Switzerland, on institutional, legal and procedural arrangements, QA/QC activities, inventory preparation, methodologies of emissions modelling, key categories, uncertainties and completeness of the inventory.

Chapter 2 contains an analysis of trends in Switzerland's greenhouse gas emissions by sources and removals by sinks for all sectors.

Chapters 3 to 9 provide principal source and sink category estimates.

Chapter 10 justifies, explains and summarises major recalculations and improvements. It also contains an overview of the planned improvements.

In **PART 2, Chapter 11** reports KP LULUCF data, **Chapter 12** presents information on accounting of Kyoto Units, **Chapter 13** lists changes in the National Registry, and **Chapter 14** includes information on minimization of adverse impacts in accordance with Article 3, paragraph 14.

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 2013–2017, data for the whole time series since 1990 are available and shown in Switzerland's NIR 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 2017, Switzerland emitted 47'159 kt CO₂ eq (kilo tonnes of CO₂ equivalent), corresponding to 5.6 t CO₂ eq per capita (CO₂: 4.5 t per capita), to the atmosphere, excluding emissions from international bunkers (aviation and marine), excluding indirect greenhouse gas emissions and excluding emissions and removals from Land use, land-use change, and forestry (LULUCF). For emissions that are relevant under the Kyoto Protocol see chapter ES.3.3.

Key category analysis (KCA)

Several key category analyses are carried out by level (years 1990 and 2017) and trend assessment (period 1990–2017), both including LULUCF categories (see details in chp. 1.5.1.2 and IPCC (2006)).

- Approach 1: For 2017, 30 categories among a total of 163 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 2017, 21 categories among a total of 163 are identified as level key categories. Under Approach 2, the most important categories stem 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 2017. Total emissions excluding LULUCF reach a minimum in 2017 with 11.4% below 1990.

Table E- 1 Greenhouse gas emissions in CO₂ equivalent (kt) by gas. HFC emissions increased by more than 5 million per cent when compared to 1990 levels (1990 = 0.025 kt CO₂ equivalent).

Greenhouse Gas Emissions	1990	1995	2000	2005
	CO ₂ equivalent (kt)			
CO ₂ emissions including net CO ₂ from LULUCF	41'592	39'509	49'119	43'229
CO ₂ emissions excluding net CO ₂ from LULUCF	44'162	43'414	43'612	45'780
CH ₄ emissions including CH ₄ from LULUCF	6'034	5'708	5'301	5'196
CH ₄ emissions excluding CH ₄ from LULUCF	6'005	5'688	5'286	5'182
N ₂ O emissions including N ₂ O from LULUCF	2'887	2'784	2'674	2'502
N ₂ O emissions excluding N ₂ O from LULUCF	2'831	2'734	2'626	2'456
HFCs	0.02	242	634	1'049
PFCs	117	17	50	44
SF ₆	137	93	144	203
NF ₃	0	0	0	0
Total (including LULUCF)	50'767	48'354	57'921	52'223
Total (excluding LULUCF)	53'252	52'189	52'352	54'714

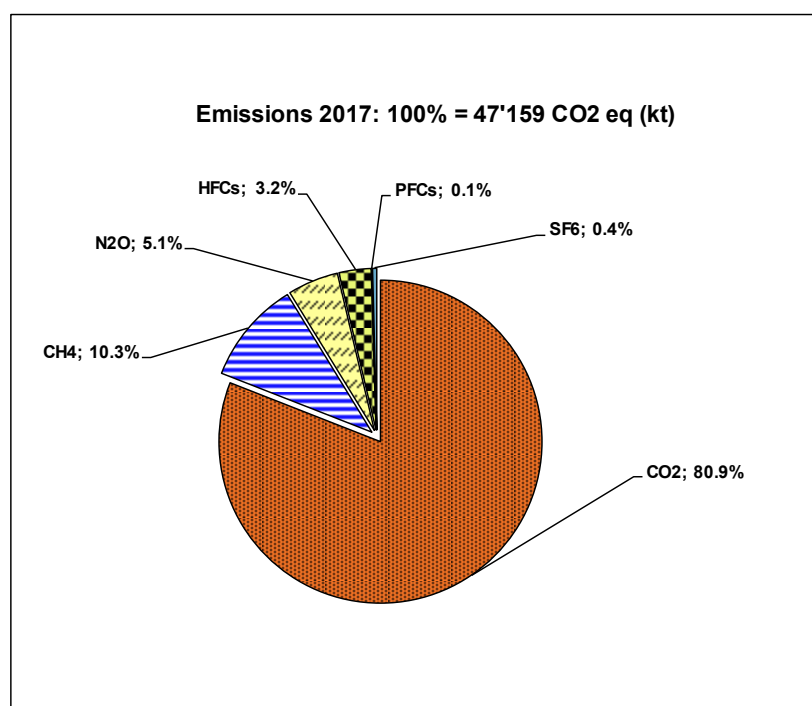
Greenhouse Gas Emissions	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2017 vs.1990
	CO ₂ equivalent (kt)										%
CO ₂ emissions including net CO ₂ from LULUCF	42'326	40'347	42'365	39'496	40'323	41'049	38'509	36'482	37'007	36'514	-12.2%
CO ₂ emissions excluding net CO ₂ from LULUCF	44'707	43'529	45'043	40'979	42'248	43'179	39'229	38'728	39'187	38'172	-13.6%
CH ₄ emissions including CH ₄ from LULUCF	5'263	5'171	5'140	5'090	5'062	5'000	5'000	4'976	4'933	4'868	-19.3%
CH ₄ emissions excluding CH ₄ from LULUCF	5'250	5'157	5'127	5'075	5'050	4'987	4'987	4'963	4'917	4'854	-19.2%
N ₂ O emissions including N ₂ O from LULUCF	2'469	2'434	2'495	2'443	2'504	2'398	2'443	2'377	2'411	2'440	-15.5%
N ₂ O emissions excluding N ₂ O from LULUCF	2'422	2'387	2'449	2'396	2'458	2'350	2'395	2'330	2'362	2'394	-15.4%
HFCs	1'274	1'271	1'308	1'381	1'455	1'436	1'472	1'514	1'491	1'512	see caption
PFCs	39	34	34	32	36	24	21	25	18	31	-73.6%
SF ₆	222	180	148	160	209	252	259	256	207	197	43.5%
NF ₃	0.1	5.1	8	6	0	0.1	0.4	0.5	0.5	0.5	-
Total (including LULUCF)	51'593	49'441	51'498	48'608	49'589	50'161	47'705	45'630	46'067	45'561	-10.3%
Total (excluding LULUCF)	53'914	52'562	54'117	50'029	51'456	52'229	48'364	47'816	48'183	47'159	-11.4%

With regard to the distribution of emissions by individual greenhouse gases, CO₂ is the largest single contributor accounting for over 80% of total GHG emissions (excluding LULUCF) in 2017. The shares of CH₄ and N₂O are about 10% and 5%, respectively. The shares of the three gases show slightly decreasing trends in the period 1990–2017, whereas aggregated F-gases, which contributed only 0.5% in 1990, increased to a share of almost 4% in 2017 (Table E- 2).

Table E- 2 Contribution of individual gases to total emissions (excluding LULUCF, excluding indirect CO₂) in CO₂ equivalent (kt) and (%).

Greenhouse Gas Emissions (excluding LULUCF)	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	%
CO ₂	44'162	82.9%	43'414	83.2%	43'612	83.3%	45'780	83.7%	45'043	83.2%
CH ₄	6'005	11.3%	5'688	10.9%	5'286	10.1%	5'182	9.5%	5'127	9.5%
N ₂ O	2'831	5.3%	2'734	5.2%	2'626	5.0%	2'456	4.5%	2'449	4.5%
HFCs	0	0.0%	242	0.5%	634	1.2%	1'049	1.9%	1'308	2.4%
PFCs	117	0.2%	17	0.0%	50	0.1%	44	0.1%	34	0.1%
SF ₆	137	0.3%	93	0.2%	144	0.3%	203	0.4%	148	0.3%
NF ₃	0	0.0%	0	0.0%	0	0.0%	0	0.0%	8	0.0%
Total (excluding LULUCF)	53'252	100%	52'189	100%	52'352	100%	54'714	100%	54'117	100%

Greenhouse Gas Emissions (excluding LULUCF)	2013		2014		2015		2016		2017	
	kt CO ₂ eq	%	kt CO ₂ eq	%	kt CO ₂ eq	%	kt CO ₂ eq	%	kt CO ₂ eq	%
CO ₂	43'179	82.7%	39'229	81.1%	38'728	81.0%	39'187	81.3%	38'172	80.9%
CH ₄	4'987	9.5%	4'987	10.3%	4'963	10.4%	4'917	10.2%	4'854	10.3%
N ₂ O	2'350	4.5%	2'395	5.0%	2'330	4.9%	2'362	4.9%	2'394	5.1%
HFCs	1'436	2.7%	1'472	3.0%	1'514	3.2%	1'491	3.1%	1'512	3.2%
PFCs	24	0.0%	21	0.0%	25	0.1%	18	0.0%	31	0.1%
SF ₆	252	0.5%	259	0.5%	256	0.5%	207	0.4%	197	0.4%
NF ₃	0.1	0.0%	0.4	0.0%	0.5	0.0%	0.5	0.0%	0.5	0.0%
Total (excluding LULUCF)	52'229	100%	48'364	100%	47'816	100%	48'183	100%	47'159	100%

Figure E- 1 Contribution of individual gases to total greenhouse gas emissions (excluding LULUCF, excluding indirect CO₂) in 2017.

Uncertainty Analysis

Uncertainties were assessed with Approach 1, including and excluding LULUCF categories for the years 1990 and 2017 (level) and for the period 1990–2017 (trend) (see details in chp. 1.6 and IPCC (2006)). The uncertainty results for Approach 1 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 for national total GHG emissions excluding and including the LULUCF sector – Approach 1: Level uncertainties 2017 and trend uncertainties 1990–2017.

Approach 1 Uncertainty Analysis		
Inventory	Level uncertainty 2017	Trend uncertainty 1990-2017
excl. LULUCF	3.85%	1.39%
incl. LULUCF	7.14%	5.37%

Recalculations

For the latest recalculated year (2016), the total national emissions (excluding LULUCF) decreased from 48'199 kt CO₂ eq in the previous submission (FOEN 2018) to 48'183 kt CO₂ 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 total contribution of these activities is shown in Table E- 4 and corresponds to the values of the KP reporting tables. All activities include emissions and removals of all GHG (i.e. CO₂, CH₄, N₂O) from Harvested wood products (HWP), biomass burning, drainage and N mineralisation, where appropriate (see chp. 11.3).

Table E- 4 Net CO₂ 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 in kt CO₂ eq.

	1990	1995	2000	2005
	kt CO ₂ equivalent			
A. Article 3.3 activities	88.29	110.45	126.08	131.79
B. Article 3.4 Forest management	-2'464.60	-4'614.09	4'224.64	-3'439.90

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	kt CO ₂ equivalent									
A. Article 3.3 activities	115.15	128.76	139.40	142.04	143.51	143.40	134.09	121.56	127.98	146.23
B. Article 3.4 Forest management	-2'257.42	-3'230.73	-3'155.17	-1'849.62	-3'109.88	-2'877.37	-1'611.08	-3'096.04	-2'975.10	-2'902.22

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), 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 are a net GHG sink.

Overall, Switzerland's GHG emissions decreased in 2017 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 CO₂) in CO₂ equivalent (kt) by individual source (positive numbers) and sink (negative numbers) categories.

Source and Sink Categories	1990	1995	2000	2005
	CO ₂ equivalent (kt)			
1. Energy	41'826	41'869	42'181	43'991
1A1 Energy industries	2'519	2'643	3'172	3'816
1A2 Manufacturing industries and construction	6'443	6'192	5'925	5'974
1A3 Transport	14'639	14'257	15'927	15'855
1A4 Other sectors	17'641	18'184	16'648	17'895
1A5 Other	220	163	151	139
1B Fugitive emissions from fuels	363	431	360	313
2. Industrial processes and product use	3'576	2'911	3'143	3'771
3. Agriculture	6'766	6'523	6'185	6'094
5. Waste	1'071	874	830	845
6. Other	12	12	13	14
Total (excluding LULUCF)	53'252	52'189	52'352	54'714
4. Land use, land-use change and forestry	-2'484	-3'835	5'569	-2'491
Total (including LULUCF)	50'767	48'354	57'921	52'223

Source and Sink Categories	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2017 vs. 1990
	CO ₂ equivalent (kt)										%
1. Energy	42'945	41'835	43'203	39'140	40'531	41'451	37'405	37'071	37'461	36'468	-12.8%
1A1 Energy industries	3'837	3'674	3'846	3'598	3'641	3'736	3'607	3'292	3'380	3'299	30.9%
1A2 Manufacturing industries and construction	6'018	5'701	5'814	5'376	5'387	5'478	5'079	4'962	4'965	4'918	-23.7%
1A3 Transport	16'644	16'438	16'326	16'144	16'259	16'167	16'059	15'321	15'151	14'884	1.7%
1A4 Other sectors	16'040	15'622	16'800	13'614	14'853	15'700	12'295	13'142	13'606	13'017	-26.2%
1A5 Other	131	133	137	125	132	133	139	135	139	128	-41.9%
1B Fugitive emissions from fuels	275	268	279	283	259	236	226	218	219	223	-38.6%
2. Industrial processes and product use	3'933	3'796	3'968	3'995	3'990	3'975	4'046	3'919	3'914	3'910	9.3%
3. Agriculture	6'213	6'131	6'159	6'120	6'182	6'057	6'178	6'097	6'093	6'077	-10.2%
5. Waste	810	788	775	760	738	732	723	716	703	691	-35.5%
6. Other	13	13	12	13	14	14	12	12	12	13	3.5%
Total (excluding LULUCF)	53'914	52'562	54'117	50'029	51'456	52'229	48'364	47'816	48'183	47'159	-11.4%
4. Land use, land-use change and forestry	-2'321	-3'122	-2'619	-1'420	-1'866	-2'069	-659	-2'186	-2'115	-1'598	-35.7%
Total (including LULUCF)	51'593	49'441	51'498	48'608	49'589	50'161	47'705	45'630	46'067	45'561	-10.3%

As shown in Figure E- 2 GHG emissions in the period 1990–2017 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.

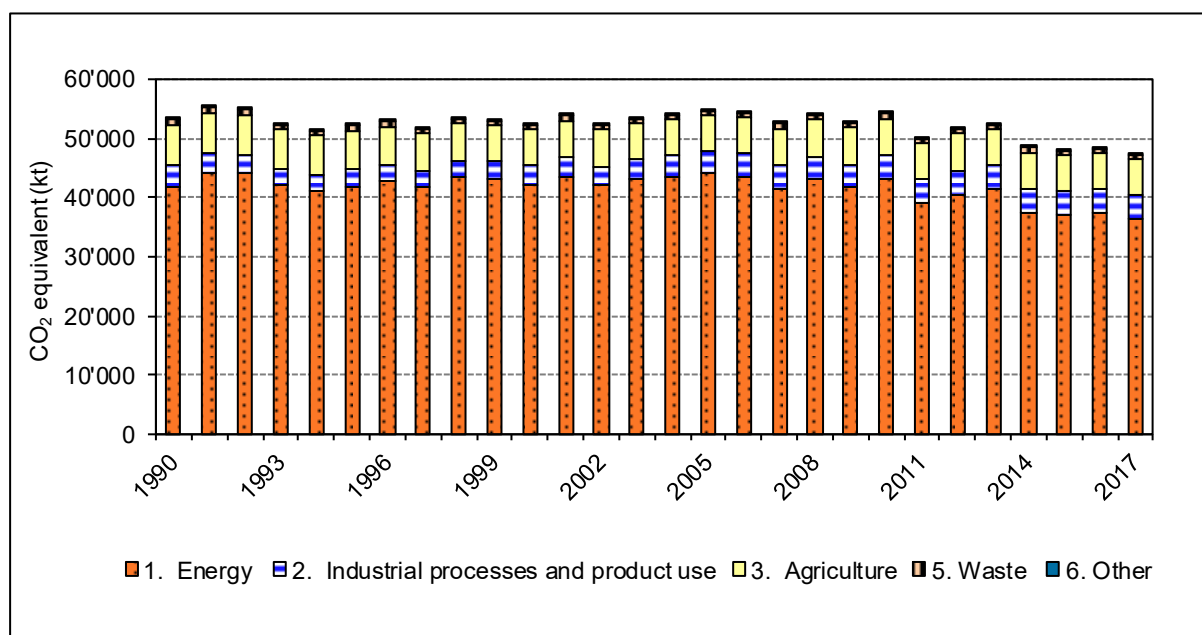


Figure E- 2 Greenhouse gas emissions in CO₂ equivalent (kt) by sectors (excluding LULUCF, excluding indirect CO₂).

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 2017. When comparing the contributions in 2017 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 CO₂) in CO₂ 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	41'826	78.5%	41'869	80.2%	42'181	80.6%	43'991	80.4%	43'203	79.8%
1A1 Energy industries	2'519	4.7%	2'643	5.1%	3'172	6.1%	3'816	7.0%	3'846	7.1%
1A2 Manufacturing industries and construction	6'443	12.1%	6'192	11.9%	5'925	11.3%	5'974	10.9%	5'814	10.7%
1A3 Transport	14'639	27.5%	14'257	27.3%	15'927	30.4%	15'855	29.0%	16'326	30.2%
1A4 Other sectors	17'641	33.1%	18'184	34.8%	16'648	31.8%	17'895	32.7%	16'800	31.0%
1A5 Other	220	0.4%	163	0.3%	151	0.3%	139	0.3%	137	0.3%
1B Fugitive emissions from fuels	363	0.7%	431	0.8%	360	0.7%	313	0.6%	279	0.5%
2. Industrial processes and product use	3'576	6.7%	2'911	5.6%	3'143	6.0%	3'771	6.9%	3'968	7.3%
3. Agriculture	6'766	12.7%	6'523	12.5%	6'185	11.8%	6'094	11.1%	6'159	11.4%
5. Waste	1'071	2.0%	874	1.7%	830	1.6%	845	1.5%	775	1.4%
6. Other	12	0.0%	12	0.0%	13	0.0%	14	0.0%	12	0.0%
Total (excluding LULUCF)	53'252	100.0%	52'189	100.0%	52'352	100.0%	54'714	100.0%	54'117	100.0%

Source and Sink Categories	2013		2014		2015		2016		2017	
	kt CO ₂ eq	%	kt CO ₂ eq	%	kt CO ₂ eq	%	kt CO ₂ eq	%	kt CO ₂ eq	%
1. Energy	41'451	79.4%	37'405	77.3%	37'071	77.5%	37'461	77.7%	36'468	77.3%
1A1 Energy industries	3'736	7.2%	3'607	7.5%	3'292	6.9%	3'380	7.0%	3'299	7.0%
1A2 Manufacturing industries and construction	5'478	10.5%	5'079	10.5%	4'962	10.4%	4'965	10.3%	4'918	10.4%
1A3 Transport	16'167	31.0%	16'059	33.2%	15'321	32.0%	15'151	31.4%	14'884	31.6%
1A4 Other sectors	15'700	30.1%	12'295	25.4%	13'142	27.5%	13'606	28.2%	13'017	27.6%
1A5 Other	133	0.3%	139	0.3%	135	0.3%	139	0.3%	128	0.3%
1B Fugitive emissions from fuels	236	0.5%	226	0.5%	218	0.5%	219	0.5%	223	0.5%
2. Industrial processes and product use	3'975	7.6%	4'046	8.4%	3'919	8.2%	3'914	8.1%	3'910	8.3%
3. Agriculture	6'057	11.6%	6'178	12.8%	6'097	12.8%	6'093	12.6%	6'077	12.9%
5. Waste	732	1.4%	723	1.5%	716	1.5%	703	1.5%	691	1.5%
6. Other	14	0.0%	12	0.0%	12	0.0%	12	0.0%	13	0.0%
Total (excluding LULUCF)	52'229	100.0%	48'364	100.0%	47'816	100.0%	48'183	100.0%	47'159	100.0%

ES.3.2 KP-LULUCF activities

An overview of net CO₂ 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 the years 1990–2017 is reported in chp. 11.4, chp. 11.5, and displayed in Table 11-1. Annual changes in the emissions from Afforestation and Deforestation can be directly attributed to the changes in their area (Table 11-2). 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 losses from living biomass, dead wood and litter pools. The extraordinary high emissions of the Forest management sector in 2000 and the small removals in the following year 2001 originate from winter storm “Lothar” at the end of 1999, which caused large-scale damages in the forest stands and increased losses of living biomass due to salvage logging. Harvesting rates in Swiss forests gradually increased between 1991 and 2007, reaching peak values in 2006 and 2007, resulting in small removals from Forest management in those years. Because harvesting rates started to decline in 2008 (Table 6-18) due to the international and domestic economic framework conditions, removals from Forest management are increasing since 2008 with a large year-to-year variability. The relatively small removals in 2014 are due to the comparably high harvesting rates (highest in period 2012–2017) and the rather high losses in the litter pool (related to climatic circumstances). Fluctuations in the HWP pool are mainly caused by changes in the production of sawnwood and paper and paperboard (see chp. 6.11 and Table 6-34).

Table E- 7 Net CO₂ eq emissions (positive sign) and removals (negative sign) of activities accounted for under Article 3, paragraph 3 (Afforestation, Deforestation) and paragraph 4 (Forest management and Harvested wood products HWP) of the Kyoto Protocol in kt CO₂ eq.

	1990	1995	2000	2005
	kt CO ₂ equivalent			
A. Article 3.3 activities	88.29	110.45	126.08	131.79
Afforestation	-3.06	-15.01	-19.52	-23.23
Deforestation	91.35	125.46	145.60	155.03
B. Article 3.4 Forest Management	-2'464.60	-4'614.09	4'224.64	-3'439.90
Forest management excl. HWP	-1'159.90	-4'110.64	4'933.78	-2'700.91
HWP	-1'304.70	-503.45	-709.14	-738.99

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	kt CO ₂ equivalent									
A. Article 3.3 activities	115.15	128.76	139.40	142.04	143.51	143.40	134.09	121.56	127.98	146.23
Afforestation	-25.20	-25.87	-24.14	-21.92	-21.09	-20.07	-17.89	-19.42	-19.18	-18.85
Deforestation	140.35	154.63	163.55	163.96	164.59	163.47	151.98	140.98	147.16	165.09
B. Article 3.4 Forest Management	-2'257.42	-3'230.73	-3'155.17	-1'849.62	-3'109.88	-2'877.37	-1'611.08	-3'096.04	-2'975.10	-2'902.22
Forest management excl. HWP	-1'875.03	-2'821.07	-2'740.18	-1'390.98	-2'816.15	-2'787.91	-1'311.57	-2'867.88	-2'850.11	-2'736.14
HWP	-382.39	-409.67	-415.00	-458.64	-293.72	-89.47	-299.51	-228.17	-124.99	-166.07

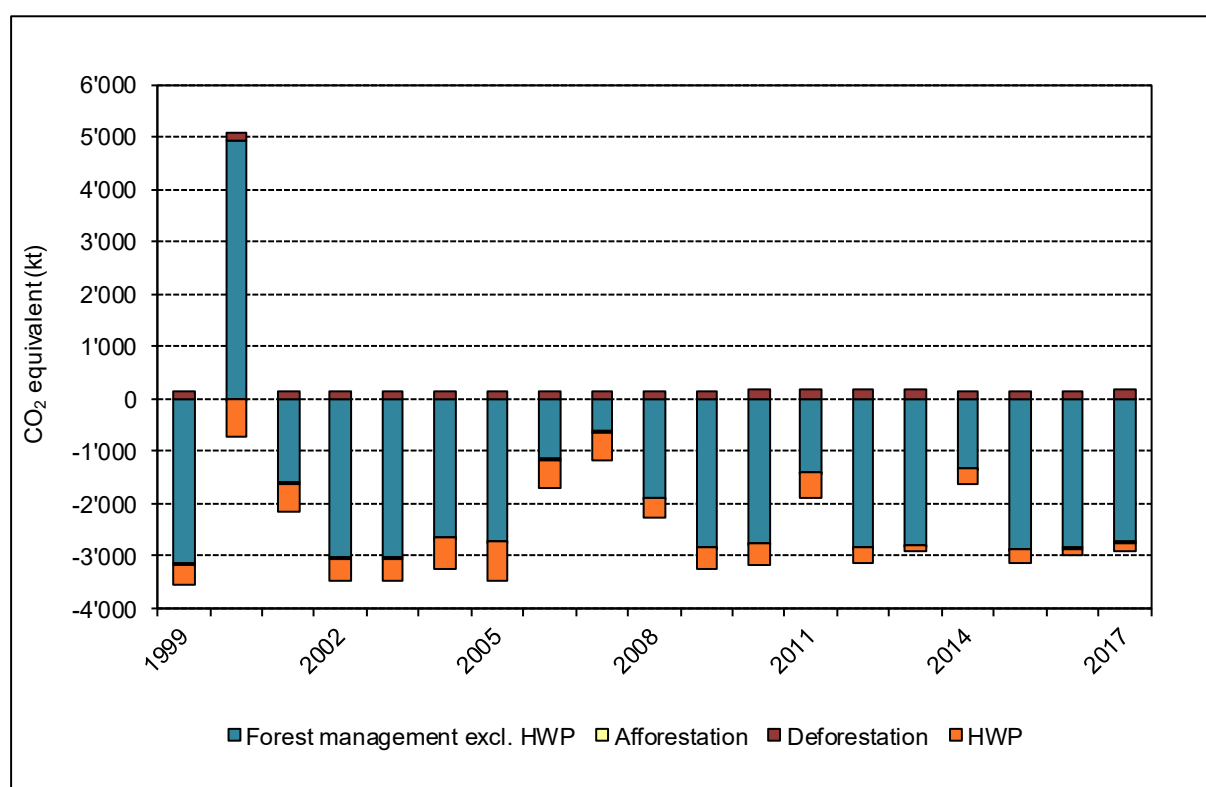


Figure E- 3 Greenhouse gas emissions (positive sign) and removals (negative sign) from Afforestation (too small to be distinguishable) and Deforestation under Article 3, paragraph 3, Forest management excluding HWP, and HWP under Article 3, paragraph 4.

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, Reforestation and Deforestation) and Article 3, paragraph 4 (Forest management, Cropland management, Grazing land management, and Revegetation) as well as indirect CO₂ 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 CO₂ 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.

Annex A sources	Sector	Base year initial report	1990	1991	1992	1993	1994	1995	1996	1997	1998
		CO ₂ equivalent (kt)									
Annex A sources	1 Energy + indirect CO ₂ from this sector	41'881	41'870	44'260	44'296	42'121	41'002	41'896	42'768	41'847	43'417
	2 Industrial processes and product use + indirect CO ₂ from this sector	3'887	3'932	3'531	3'341	3'002	3'177	3'146	2'998	2'895	2'992
	3 Agriculture	6'804	6'766	6'706	6'593	6'571	6'545	6'523	6'400	6'228	6'199
	5 Waste + indirect CO ₂ from this sector	1'135	1'073	983	984	933	875	876	865	852	837
	Total (Annex A sources)	53'707	53'641	55'480	55'214	52'627	51'598	52'441	53'031	51'822	53'445
Annex A sources	Sector	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
		CO ₂ equivalent (kt)									
Annex A sources	1 Energy + indirect CO ₂ from this sector	43'207	42'198	43'614	42'010	43'203	43'569	44'004	43'614	41'565	42'956
	2 Industrial processes and product use + indirect CO ₂ from this sector	3'050	3'303	3'397	3'421	3'497	3'751	3'875	3'931	4'006	4'034
	3 Agriculture	6'068	6'185	6'190	6'113	5'986	5'962	6'094	6'049	6'143	6'213
	5 Waste + indirect CO ₂ from this sector	827	831	846	858	836	855	846	845	829	811
	Total (Annex A sources)	53'152	52'517	54'047	52'403	53'522	54'137	54'818	54'439	52'542	54'014
KP-LULUCF	Art. 3.3	Afforestation & Reforestation									-25
		Deforestation									140
		Forest management									-2'257
KP-LULUCF	Art. 3.4	Cropland management									NA
		Grazing land management									NA
		Revegetation									NA
Annex A sources	Sector	2009	2010	2011	2012	2013	2014	2015	2016	2017	2017 vs. 1990
		CO ₂ equivalent (kt)									
											%
Annex A sources	1 Energy + indirect CO ₂ from this sector	41'846	43'211	39'148	40'539	41'459	37'413	37'078	37'467	36'474	-13%
	2 Industrial processes and product use + indirect CO ₂ from this sector	3'895	4'067	4'093	4'087	4'069	4'137	4'009	4'001	3'998	2%
	3 Agriculture	6'131	6'159	6'120	6'182	6'057	6'178	6'097	6'093	6'077	-10%
	5 Waste + indirect CO ₂ from this sector	789	776	761	739	733	724	717	704	692	-36%
	Total (Annex A sources)	52'661	54'213	50'122	51'547	52'319	48'453	47'901	48'265	47'241	-12%
KP-LULUCF	Art. 3.3	Afforestation & Reforestation	-26	-24	-22	-21	-20	-18	-19	-19	-19
		Deforestation	155	164	164	165	163	141	147	165	
		Forest management	-3'231	-3'155	-1'850	-3'110	-2'877	-1'611	-3'096	-2'975	-2'902
KP-LULUCF	Art. 3.4	Cropland management	NA	NA	NA	NA	NA	NA	NA	NA	
		Grazing land management	NA	NA	NA	NA	NA	NA	NA	NA	
		Revegetation	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 CO₂ equivalent (kt), as well as emissions and removals under KP-LULUCF.

Annex A sources	GHG	Base year initial report	1990	1991	1992	1993	1994	1995	1996	1997	1998
		CO ₂ equivalent (kt)									
		CO ₂ + indirect CO ₂	CH ₄	N ₂ O	HFCs	PFCs	SF ₆	NF ₃	Total (Annex A sources)		
		44'516	44'553	46'505	46'352	43'908	42'953	43'668	44'331	43'249	44'806
		6'086	6'004	5'936	5'854	5'746	5'696	5'687	5'645	5'502	5'434
		2'852	2'830	2'800	2'771	2'785	2'742	2'733	2'651	2'568	2'575
		0.0	0.0	1.5	15	32	79	242	294	358	454
		117	117	99	81	35	21	17	20	21	24
		137	137	139	141	121	107	93	90	124	153
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total (Annex A sources)	53'707	53'641	55'480	55'214	52'627	51'598	52'441	53'031	51'822	53'445

Annex A sources	GHG	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
		CO ₂ equivalent (kt)									
		CO ₂ + indirect CO ₂	CH ₄	N ₂ O	HFCs	PFCs	SF ₆	NF ₃	Total (Annex A sources)		
		44'620	43'778	45'231	43'597	44'767	45'337	45'885	45'471	43'462	44'809
		5'337	5'285	5'323	5'280	5'200	5'166	5'182	5'194	5'173	5'249
		2'498	2'626	2'584	2'515	2'417	2'374	2'455	2'374	2'434	2'422
		531	634	733	822	908	1'009	1'049	1'159	1'255	1'274
		26	50	30	30	67	65	44	55	47	39
		140	144	145	158	165	186	203	186	172	222
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
	Total (Annex A sources)	53'152	52'517	54'047	52'403	53'522	54'137	54'818	54'439	52'542	54'014

KP-LULUCF	Art.3.3	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O
							113
							NO
							2.6
							-2'261
							2.7
							1.2

Annex A sources	GHG	2009	2010	2011	2012	2013	2014	2015	2016	2017	2017 vs.1990
		CO ₂ equivalent (kt)									
		CO ₂ + indirect CO ₂	CH ₄	N ₂ O	HFCs	PFCs	SF ₆	NF ₃	Total (Annex A sources)		
		43'629	45'140	41'073	42'341	43'269	39'319	38'814	39'270	38'255	-14%
		5'156	5'126	5'075	5'049	4'987	4'987	4'962	4'917	4'853	-19%
		2'386	2'448	2'395	2'458	2'350	2'395	2'330	2'362	2'393	-15%
		1'271	1'308	1'381	1'455	1'436	1'472	1'514	1'491	1'512	see caption
		34	34	32	36	24	21	25	18	31	-74%
		180	148	160	209	252	259	256	207	197	43%
		5.1	8.5	6.2	0.4	0.1	0.4	0.5	0.5	0.5	NA
	Total (Annex A sources)	52'661	54'213	50'122	51'547	52'319	48'453	47'901	48'265	47'241	-12%

KP-LULUCF	Art.3.3	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O
		126	137	139	141	141	131
		NO	NO	NO	NO	NO	NO
		2.7	2.8	2.8	2.8	2.9	2.9
		-3'235	-3'158	-1'856	-3'113	-2'881	-1'615
		2.7	2.3	4.1	2.2	2.2	2.4
		1.2	1.0	2.2	1.0	1.0	1.1

ES.4. Other information

Emissions from precursor gases show a very pronounced decline (see Table 2-6 and Figure 2-9). A strict air pollution control policy led to strong decreases in emissions of precursor gases and SO₂ over the period 1990–2017. The main reduction measures were abatement of exhaust emissions from road vehicles and stationary combustion equipment, taxation of solvents and sulphured fuels, and voluntary agreements within the industry sector.

PART 1

1 Introduction

Responsibilities for Introduction	
Author	Regine Röthlisberger (FOEN)
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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), superseding an earlier report of the Swiss Advisory Body on Climate Change (OcCC) (OcCC 2008). 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 degrees Celsius compared to +0.9 degrees Celsius 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 per cent, 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 glaciers will be even more dramatic. Modelling studies indicate a strong future area loss of 50–90 per cent (for a temperature increase between two and six degrees Celsius) 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. 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 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 wave in 2003 and 2015 (FOEN 2016I). 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).

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 7th June 2018 (ISO 9001:2015, Swiss Safety Center 2018). 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 7th 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 2019 inventory submission under the UNFCCC and under the Kyoto Protocol includes the NIR on hand, the greenhouse gas inventory 1990 to 2017, the Kyoto Protocol LULUCF tables 2008 to 2017 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

Information on KP-LULUCF is provided in chp. 11 of PART 2.

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 2013–2017, data for the years 1990–2012 are available and shown in Switzerland's NIR.

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.

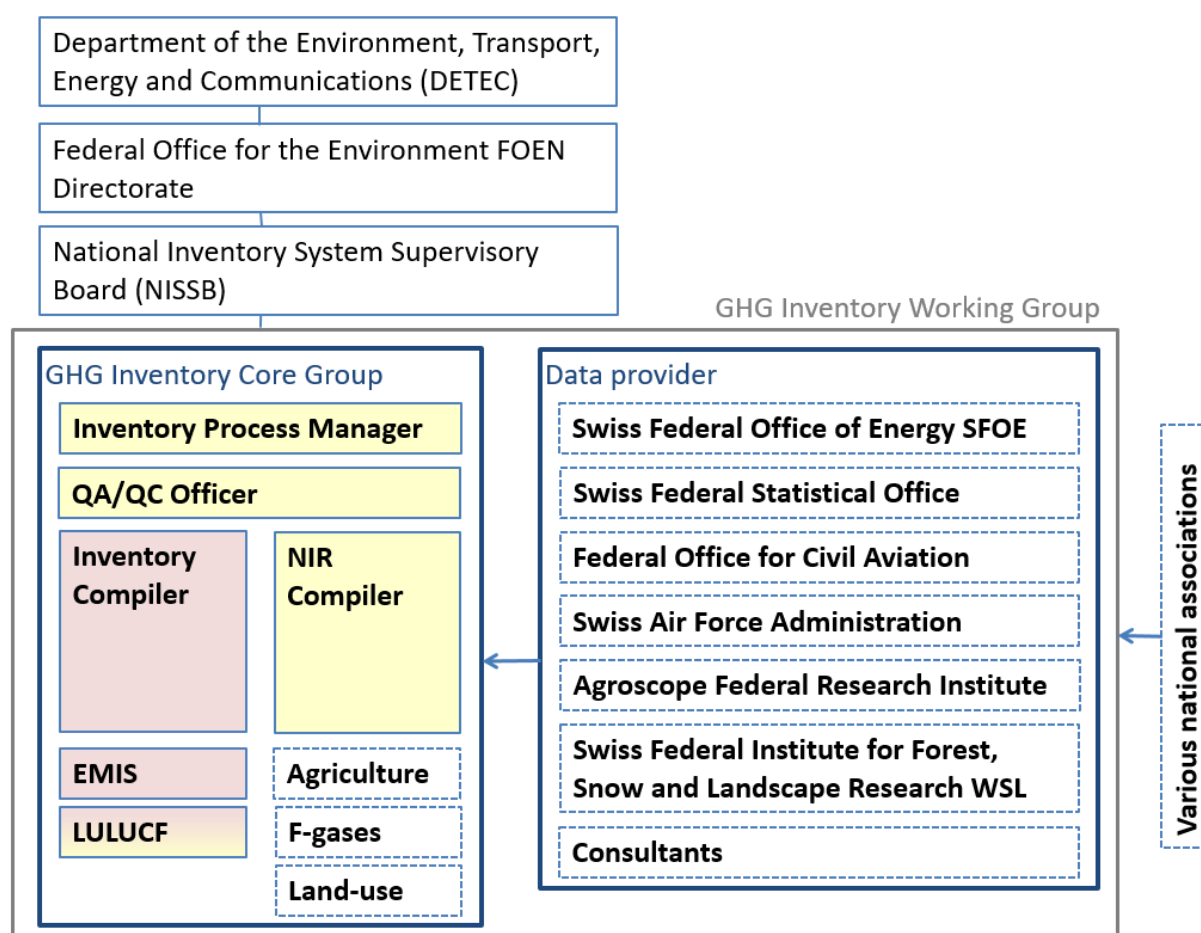


Figure 1-1 Institutional arrangements of the National Inventory System. Colours refer to divisions at FOEN. Yellow: Climate division, red: Air Pollution Control and Chemicals division, Forest division. Boxes with dashed lines refer to external mandates.

Legal arrangements

The CO₂ act (Swiss Confederation 2011) and the CO₂ 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.

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 area survey data are provided by the Swiss Federal Statistical Office (SFSO). Two consultancies (Sigmaplan/Meteotest) are mandated to process the area 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 Forest division of the FOEN, who is compiling forestry emissions and removals. 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
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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 / Infrast	Data handling and NIR editing

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 2018). 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 2019a) 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: a first check is 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 2019a), 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 waste water treatment was completed with experts by the Eawag (Eidgenössische Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz) (EAWAG 2018). An expert peer review concerning F-gases is currently being conducted and results will be considered by the sectoral expert and the core group in the course of the next inventory preparation

cycle. Previous expert peer reviews covered the Industrial Processes (CSD 2013), LULUCF (VTI 2011) and Waste sector (Ryttec 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 asl), 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 5.1.

Furthermore, an ongoing project is developing an independent estimate of CH₄ and N₂O 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 CH₄ and reasonable agreement within the uncertainties for N₂O. A summary of the current state of these verification activities is provided in Annex 5.2.

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:

- (i) Emission data that refer to a single enterprise are in general confidential.
- (ii) The reporting of disaggregated emissions from F-gases is confidential (not confidential as aggregated data).
- (iii) In the civil aviation sub-sector one data source (FOCA 1991) has been marked confidential by the Federal Office of Civil Aviation (FOCA).
- (iv) Unpublished AREA land use statistics raw data have been temporarily classified confidential by the Swiss Federal Statistical Office (SFSO).

The FOEN collects the data needed for calculating emissions of HFCs, PFCs, NF₃ and SF₆ from private companies or industry associations. In the National Inventory Report, the activity data underlying emission estimates of HFCs, PFCs, NF₃ and SF₆ 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.climate reporting.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)):

There are no changes to arrangements with other institutions of the federal administration. Two four-year contracts with private companies have been renewed for another four-year period (F-gases and LULUCF). The previous mandate comprising NIR compiling and uncertainty analysis was renewed under different terms and conditions. From May 2019, the responsibility for NIR compilation is held by the FOEN Climate division, while two contractors, who both have been involved in inventory and NIR preparation previously, are mandated to support data operation in EMIS and updating of the NIR. Uncertainty analysis (approach 1) is now performed by FOEN. Provided that the necessary resources are available, approach 2 will be implemented in the EMIS database software and reported again in future submissions.

Changes in staff and capacity (24/CP.19, 22. (b)):

As of May 2019, the responsibility for NIR compilation is held by the FOEN Climate division. Apart from this, there are no changes to staff and capacity.

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 Swiss Federal Statistical Office is compiled by Meteotest/Sigmaplan, in close collaboration with the Forest division of the FOEN. The Swiss Federal Institute for Forest, Snow and Landscape Research WSL provides further input, which is processed by the Forest Division. Emission and removal estimates from forest land are calculated by the Forest division of the FOEN.

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 2019/NFR-Code” in this report.

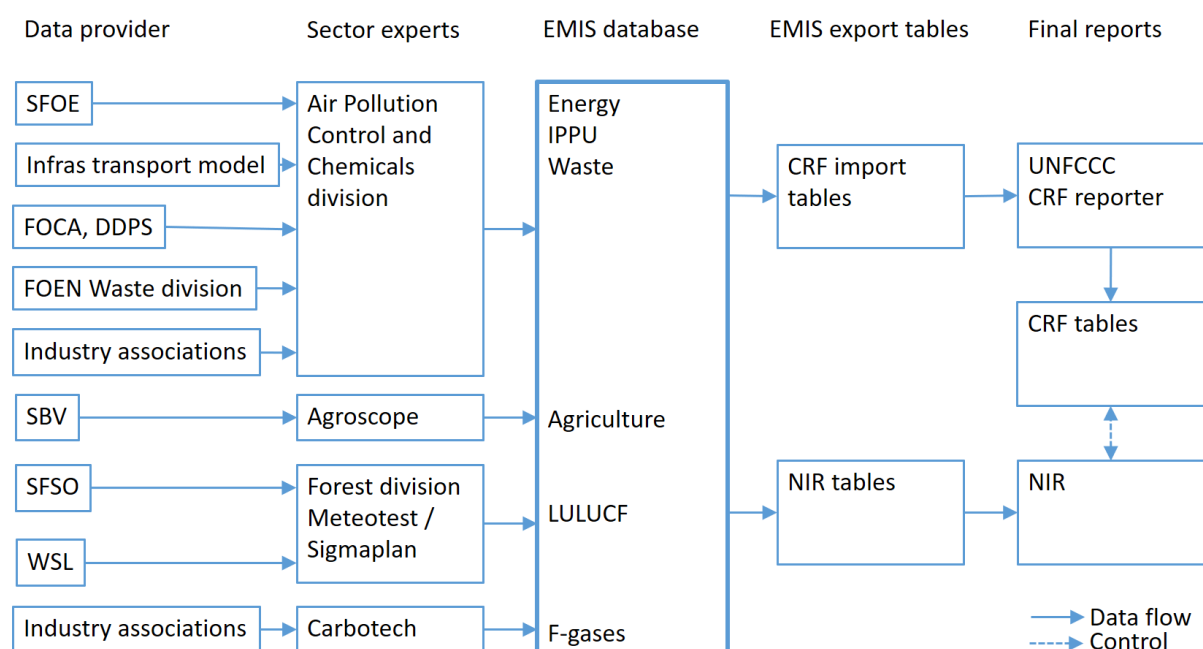


Figure 1-2 Schematic overview: Data collection and processing, compilation in EMIS database, import into CRF Reporter and National Inventory Report (NIR). Abbreviations: see glossary.

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), 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. CO ₂ / N ₂ O
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). Data collection as well as quality assurance and control are prioritised for key categories during the inventory resource allocation.

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 2017 including all GHG (CO₂, CH₄, N₂O, HFCs, PFCs, SF₆ and NF₃). A total of 163 categories are used to disaggregate Switzerland's total GHG emissions for the purpose of this key category analysis. 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. A table showing the key category analysis with all 163 categories is provided in the annex (Table A – 1).

Both, Approach 1 (with a proposed threshold of 95%) and Approach 2 (with a proposed threshold of 90%) level and trend assessments are applied, including emissions from sector 4 LULUCF (with a tool directly implemented in the software Mesap of the emissions database EMIS; see Sevenzone 2017 for technical details). Indirect CO₂ emissions are included in the key category analysis, indirect N₂O emissions are not.

Uncertainty data for key category analysis Approach 2 stem from the uncertainty analysis Approach 1 (see chp. 1.6.1.2) and therefore do not incorporate correlations.

1.5.1.2 KCA (including LULUCF categories)

Approach 1

For 2017, among the total of 163 categories, 30 are identified as **level key categories** under Approach 1 (see Table 1-4).

Fifteen of the key categories belong to sector 1 Energy, accounting for the largest share of CO₂ equivalent emissions in 2017. The other key categories are more or less equally distributed between sectors 2 Industrial processes and product use (3 key categories), 3 Agriculture (5 key categories), 4 LULUCF (5 key categories) and 5 Waste (2 key categories).

There are three major key sources, each contributing more than 10% to the level assessment, all being part of sector 1 Energy:

- 1A3b Fuel Combustion, Road Transportation, Diesel, CO₂
- 1A3b Fuel Combustion, Road Transportation, Gasoline, CO₂
- 1A4b Fuel Combustion, Other Sectors, Residential, Liquid Fuels, CO₂

Within the ten most relevant key categories (level contribution), only 3A Enteric fermentation and 4A1 Forest land remaining forest land are not part of sector 1 Energy.

Table 1-4 Switzerland's Approach 1 level key categories for the year 2017 including LULUCF categories, sorted by emission contribution to the national total.

APPROACH 1 LEVEL ASSESSMENT FOR 2017						
Code	IPCC Category	GHG	Ex,t (kt CO ₂ eq)	Ex,t (kt CO ₂ eq)	Lx,t	Cumulative Total
1A3b	Road transportation: Diesel	CO ₂	7260	7260	13.8%	13.8%
1A3b	Road transportation: Gasoline	CO ₂	7196	7196	13.7%	27.6%
1A4b	Residential: Liquid fuels	CO ₂	5621	5621	10.7%	38.3%
3A	Enteric Fermentation	CH ₄	3294	3294	6.3%	44.5%
1A4b	Residential: Gaseous fuels	CO ₂	2722	2722	5.2%	49.7%
1A4a	Commercial: Liquid fuels	CO ₂	2634	2634	5.0%	54.8%
4A1	Forest land remaining forest land	CO ₂	-2622	2622	5.0%	59.8%
1A1	Energy industries: Other fuels	CO ₂	2438	2438	4.6%	64.4%
1A2	Manufacturing industries and construction: Gaseous fuels	CO ₂	2285	2285	4.4%	68.8%
1A2	Manufacturing industries and construction: Liquid fuels	CO ₂	1763	1763	3.4%	72.1%
2A1	Cement production	CO ₂	1760	1760	3.4%	75.5%
1A4a	Commercial: Gaseous fuels	CO ₂	1486	1486	2.8%	78.3%
2F1	Refrigeration and air conditioning	HFC	1406	1406	2.7%	81.0%
3Da	Direct emissions from managed soils	N ₂ O	1176	1176	2.2%	83.2%
4B1	Cropland remaining cropland	CO ₂	764	764	1.5%	84.7%
3B1-3B4	Manure management	CH ₄	747	747	1.4%	86.1%
4A2	Land converted to forest land	CO ₂	-575	575	1.1%	87.2%
1A1	Energy industries: Gaseous fuels	CO ₂	485	485	0.9%	88.1%
1A2	Manufacturing industries and construction: Solid fuels	CO ₂	428	428	0.8%	88.9%
3Db	Indirect emissions from managed soils	N ₂ O	407	407	0.8%	89.7%
1A4c	Agriculture and forestry: Liquid fuels	CO ₂	403	403	0.8%	90.5%
1A2	Manufacturing industries and construction: Other fuels	CO ₂	402	402	0.8%	91.2%
1A1	Energy industries: Liquid fuels	CO ₂	349	349	0.7%	91.9%
5A	Solid waste disposal	CH ₄	318	318	0.6%	92.5%
4C1	Grassland remaining grassland	CO ₂	316	316	0.6%	93.1%
3B5	Indirect N ₂ O emissions from manure management	N ₂ O	271	271	0.5%	93.6%
4C2	Land converted to grassland	CO ₂	226	226	0.4%	94.1%
1B2	Oil and natural gas energy production	CH ₄	192	192	0.4%	94.4%
2G	Other product manufacture and use	SF ₆	189	189	0.4%	94.8%
5D	Wastewater treatment and discharge	CH ₄	187	187	0.4%	95.1%

For the **base year 1990**, 32 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 reporting year:

- 1A3a Civil Aviation, Liquid Fuels, CO₂
- 1A5 Other (Military), Liquid fuels, CO₂
- 2A4 Other process uses of carbonates, CO₂
- 2 Indirect CO₂ emissions, CO₂
- 3B1-3B4 Manure management, N₂O
- 4E2 Land converted to settlements, CO₂
- 4G HWP Harvested wood products, CO₂ biog.

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

- 2F1 Refrigeration and air conditioning, HFC
- 2G Other product manufacture and use, SF₆
- 4C2 Land converted to grassland, CO₂
- 5D Wastewater treatment and discharge, CH₄

Table 1-5 Switzerland's Approach 1 level key categories for the base year 1990 including LULUCF categories, sorted by emission contribution to the national total.

APPROACH 1 LEVEL ASSESSMENT FOR BASE YEAR						
Code	IPCC Category	GHG	Ex,0 (kt CO2 eq)	Ex,0 (kt CO2 eq)	Lx,0	Cumulative Total
1A3b	Road transportation: Gasoline	CO2	11334	11334	19.6%	19.6%
1A4b	Residential: Liquid fuels	CO2	10099	10099	17.5%	37.0%
1A4a	Commercial: Liquid fuels	CO2	4261	4261	7.4%	44.4%
1A2	Manufacturing industries and construction: Liquid fuels	CO2	3889	3889	6.7%	51.1%
3A	Enteric Fermentation	CH4	3585	3585	6.2%	57.3%
1A3b	Road transportation: Diesel	CO2	2633	2633	4.5%	61.9%
2A1	Cement production	CO2	2581	2581	4.5%	66.3%
1A1	Energy industries: Other fuels	CO2	1492	1492	2.6%	68.9%
1A4b	Residential: Gaseous fuels	CO2	1451	1451	2.5%	71.4%
4G	HWP Harvested wood products	CO2 biog.	-1305	1305	2.3%	73.7%
1A2	Manufacturing industries and construction: Solid fuels	CO2	1275	1275	2.2%	75.9%
3Da	Direct emissions from managed soils	N2O	1270	1270	2.2%	78.1%
4A1	Forest land remaining forest land	CO2	-1112	1112	1.9%	80.0%
1A2	Manufacturing industries and construction: Gaseous fuels	CO2	1050	1050	1.8%	81.8%
1A4a	Commercial: Gaseous fuels	CO2	990	990	1.7%	83.5%
3B1-3B4	Manure management	CH4	869	869	1.5%	85.0%
5A	Solid waste disposal	CH4	763	763	1.3%	86.3%
1A1	Energy industries: Liquid fuels	CO2	686	686	1.2%	87.5%
4A2	Land converted to forest land	CO2	-610	610	1.1%	88.6%
3Db	Indirect emissions from managed soils	N2O	567	567	1.0%	89.5%
1A4c	Agriculture and forestry: Liquid fuels	CO2	485	485	0.8%	90.4%
2	Indirect CO2 emissions	CO2	356	356	0.6%	91.0%
1B2	Oil and natural gas energy production	CH4	336	336	0.6%	91.6%
4C1	Grassland remaining grassland	CO2	-276	276	0.5%	92.1%
1A3a	Civil aviation: Liquid fuels	CO2	253	253	0.4%	92.5%
1A1	Energy industries: Gaseous fuels	CO2	243	243	0.4%	92.9%
4B1	Cropland remaining cropland	CO2	238	238	0.4%	93.3%
3B5	Indirect N2O emissions from manure management	N2O	236	236	0.4%	93.7%
4E2	Land converted to settlements	CO2	224	224	0.4%	94.1%
1A5	Other (military): Liquid fuels	CO2	218	218	0.4%	94.5%
1A2	Manufacturing industries and construction: Other fuels	CO2	192	192	0.3%	94.8%
3B1-3B4	Manure management	N2O	191	191	0.3%	95.2%

Regarding the **trend assessment** between the base year 1990 and the latest reporting year, 32 categories are identified as trend key categories under Approach 1 (see Table 1-6).

Table 1-6 Switzerland's Approach 1 trend key categories between 1990 and 2017 including LULUCF categories, sorted by contribution to the trend assessment.

APPROACH 1 TREND ASSESSMENT FOR 2017							
Code	IPCC Category	GHG	Ex,0 (kt CO2 eq)	Ex,t (kt CO2 eq)	Trend Assessment	Contribution to Trend	Cumulative Total
1A3b	Road transportation: Diesel	CO2	2633	7260	0.085%	17.0%	17.0%
1A4b	Residential: Liquid fuels	CO2	10099	5621	0.059%	11.7%	28.7%
1A3b	Road transportation: Gasoline	CO2	11334	7196	0.050%	10.1%	38.7%
1A2	Manufacturing industries and construction: Liquid fuels	CO2	3889	1763	0.029%	5.9%	44.6%
1A4b	Residential: Gaseous fuels	CO2	1451	2722	0.025%	4.9%	49.5%
2F1	Refrigeration and air conditioning	HFC	0	1406	0.024%	4.9%	54.4%
4A1	Forest land remaining forest land	CO2	-1112	-2622	0.024%	4.8%	59.2%
1A2	Manufacturing industries and construction: Gaseous fuels	CO2	1050	2285	0.023%	4.7%	63.8%
4G	HWP Harvested wood products	CO2 biog.	-1305	-166	0.022%	4.4%	68.3%
1A4a	Commercial: Liquid fuels	CO2	4261	2634	0.020%	4.0%	72.3%
1A1	Energy industries: Other fuels	CO2	1492	2438	0.019%	3.8%	76.1%
1A2	Manufacturing industries and construction: Solid fuels	CO2	1275	428	0.012%	2.4%	78.6%
4C1	Grassland remaining grassland	CO2	-276	316	0.011%	2.1%	80.7%
1A4a	Commercial: Gaseous fuels	CO2	990	1486	0.010%	2.1%	82.8%
4B1	Cropland remaining cropland	CO2	238	764	0.010%	1.9%	84.7%
2A1	Cement production	CO2	2581	1760	0.009%	1.9%	86.6%
5A	Solid waste disposal	CH4	763	318	0.006%	1.3%	87.8%
1A1	Energy industries: Gaseous fuels	CO2	243	485	0.005%	0.9%	88.7%
1A1	Energy industries: Liquid fuels	CO2	686	349	0.005%	0.9%	89.6%
2	Indirect CO2 emissions	CO2	356	87	0.004%	0.8%	90.4%
1A2	Manufacturing industries and construction: Other fuels	CO2	192	402	0.004%	0.8%	91.2%
4C2	Land converted to grassland	CO2	99	226	0.002%	0.5%	91.7%
2C3	Aluminium production	CO2	139	0	0.002%	0.4%	92.1%
1B2	Oil and natural gas energy production	CH4	336	192	0.002%	0.4%	92.5%
1A3a	Civil aviation: Liquid fuels	CO2	253	119	0.002%	0.4%	92.9%
2C3	Aluminium production	PFC	116	0	0.002%	0.4%	93.2%
1A3b	Road transportation: Gasoline	N2O	134	18	0.002%	0.4%	93.6%
4A2	Land converted to forest land	CO2	-610	-575	0.002%	0.3%	93.9%
3Db	Indirect emissions from managed soils	N2O	567	407	0.002%	0.3%	94.3%
3A	Enteric Fermentation	CH4	3585	3294	0.002%	0.3%	94.6%
1A3b	Road transportation: Gasoline	CH4	98	12	0.001%	0.3%	94.9%
1A4b	Residential: Biomass	CH4	110	25	0.001%	0.3%	95.1%

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**, 21 out of 163 categories are identified as key categories for the latest reporting year (see Table 1-7).

The most relevant sources in 2017 which contribute 10% or more to the level assessment are the following:

- 4A1 Forest land remaining forest land, CO₂
- 4B1 Cropland remaining cropland, CO₂

- 4C1 Grassland remaining grassland, CO₂
- 3Da Direct emissions from managed soils, N₂O

Table 1-7 Switzerland's Approach 2 level key categories for the year 2017 including LULUCF categories, sorted by contribution to the uncertainty of the level assessment.

APPROACH 2 LEVEL ASSESSMENT FOR 2017						
Code	IPCC Category	GHG	Ex,t (kt CO ₂ eq)	Ex,t (kt CO ₂ eq)	Lx,t	Cumulative Total
4A1	Forest land remaining forest land	CO ₂	-2622	2622	18.6%	18.6%
4B1	Cropland remaining cropland	CO ₂	764	764	13.7%	32.3%
4C1	Grassland remaining grassland	CO ₂	316	316	11.6%	44.0%
3Da	Direct emissions from managed soils	N ₂ O	1176	1176	11.1%	55.1%
3B5	Indirect N ₂ O emissions from manure management	N ₂ O	271	271	5.8%	60.9%
3Db	Indirect emissions from managed soils	N ₂ O	407	407	5.6%	66.5%
3A	Enteric Fermentation	CH ₄	3294	3294	4.7%	71.2%
4A2	Land converted to forest land	CO ₂	-575	575	4.1%	75.2%
3B1-3B4	Manure management	CH ₄	747	747	3.1%	78.4%
1A1	Energy industries: Other fuels	CO ₂	2438	2438	2.0%	80.3%
2F1	Refrigeration and air conditioning	HFC	1406	1406	1.6%	81.9%
5D	Wastewater treatment and discharge	N ₂ O	100	100	1.2%	83.1%
1A4b	Residential: Gaseous fuels	CO ₂	2722	2722	1.1%	84.2%
2	Indirect CO ₂ emissions	CO ₂	87	87	0.9%	85.1%
1A2	Manufacturing industries and construction: Gaseous fuels	CO ₂	2285	2285	0.9%	86.0%
4C2	Land converted to grassland	CO ₂	226	226	0.8%	86.8%
5D	Wastewater treatment and discharge	CH ₄	187	187	0.8%	87.6%
5A	Solid waste disposal	CH ₄	318	318	0.7%	88.3%
4G	HWP Harvested wood products		-166	166	0.7%	89.0%
4E2	Land converted to settlements	CO ₂	184	184	0.7%	89.7%
2A1	Cement production	CO ₂	1760	1760	0.6%	90.4%

Regarding the **trend assessment** between the base year 1990 and the latest reporting year, 17 categories are identified as trend key categories under Approach 2 (see Table 1-8).

Table 1-8 Switzerland's Approach 2 trend key categories between 1990 and 2017 including LULUCF categories, sorted by contribution to the trend assessment.

APPROACH 2 TREND ASSESSMENT WITH UNCERTAINTIES FOR 2017							
Code	IPCC Category	GHG	Ex,0 (kt CO ₂ eq)	Ex,t (kt CO ₂ eq)	Trend Assessment	Contribution to Trend	Cumulative Total
4C1	Grassland remaining grassland	CO ₂	-295	338	4.823%	32.7%	32.7%
4B1	Cropland remaining cropland	CO ₂	227	726	2.347%	15.9%	48.6%
4A1	Forest land remaining forest land	CO ₂	-1109	-2582	2.258%	15.3%	63.8%
4G	HWP Harvested wood products	CO ₂ biog.	-1300	-164	1.246%	8.4%	72.3%
2	Indirect CO ₂ emissions	CO ₂	358	86	0.537%	3.6%	75.9%
2F1	Refrigeration and air conditioning	HFC	0	1409	0.350%	2.4%	78.3%
3Db	Indirect emissions from managed soils	N ₂ O	580	425	0.292%	2.0%	80.3%
3B5	Indirect N ₂ O emissions from manure management	N ₂ O	225	281	0.281%	1.9%	82.2%
1A1	Energy industries: Other fuels	CO ₂	1491	2436	0.201%	1.4%	83.5%
5A	Solid waste disposal	CH ₄	766	318	0.192%	1.3%	84.8%
4A2	Land converted to forest land	CO ₂	-607	-577	0.161%	1.1%	85.9%
1A4b	Residential: Gaseous fuels	CO ₂	1450	2721	0.131%	0.9%	86.8%
1A2	Manufacturing industries and construction: Gaseous fuels	CO ₂	1049	2285	0.118%	0.8%	87.6%
4C2	Land converted to grassland	CO ₂	98	224	0.117%	0.8%	88.4%
3Da	Direct emissions from managed soils	N ₂ O	1292	1164	0.093%	0.6%	89.0%
2G	Other product manufacture and use	N ₂ O	106	31	0.092%	0.6%	89.6%
1A3b	Road transportation: Gasoline	N ₂ O	134	18	0.089%	0.6%	90.2%

Comparison of the results of approaches 1 and 2

Due to large differences in the uncertainties of specific source categories, the key category analyses under Approach 1 and Approach 2 show different results. This is particularly the case for large source categories in the energy sector with relatively small uncertainties, which dominate the level assessment in Approach 1, and large source categories in the agriculture or LULUCF sector with large uncertainties, which dominate the level assessment in Approach 2.

Several categories being key categories under Approach 1 are not key anymore when assessed with Approach 2. Nevertheless, there are six categories only being key under Approach 2 (for year 2017):

- 2 Indirect CO₂ emissions, CO₂ (level)
- 2G Other product manufacture and use, N₂O (trend)
- 3B5 Indirect N₂O emissions from manure management, N₂O (trend)
- 3Da Direct emissions from managed soils, N₂O (trend)
- 4E2 Land converted to settlements, CO₂ (level)
- 4G HWP Harvested wood products, CO₂ biog. (level)
- 5D Wastewater treatment and discharge, N₂O (level)

The categories listed above, which are only key under the Approach 2 assessments, are subject to rather high uncertainties (combined uncertainties according to uncertainty analysis, see chp. 1.6.1.3).

1.5.1.3 Summary of combined KCA including LULUCF categories

A summary of the key category analysis for 2017 is shown in Table 1-9, considering level and trend assessments for both, Approach 1 and Approach 2.

Table 1-9 Summary of Switzerland's combined KCA for the year 2017 including LULUCF categories, sorted by NFR code (first column). The abbreviations used in the last column indicate both, the approach and whether a certain category is identified as key because of the level or trend assessment (L1 = level according to Approach 1, T1 = trend according to Approach 1; L2 = level according to Approach 2, T2 = trend according to Approach 2).

SUMMARIES TO IDENTIFY KEY CATEGORIES			
Code	IPCC Category	GHG	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, L2, T1, T2
1A2	Manufacturing industries and construction: Gaseous fuels	CO2	L1, L2, T1, T2
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
1A3a	Civil aviation: Liquid fuels	CO2	T1
1A3b	Road transportation: Gasoline	CH4	T1
1A3b	Road transportation: Gasoline	CO2	L1, T1
1A3b	Road transportation: Gasoline	N2O	T1, T2
1A3b	Road transportation: Diesel	CO2	L1, T1
1A4a	Commercial: Gaseous fuels	CO2	L1, T1
1A4a	Commercial: Liquid fuels	CO2	L1, T1
1A4b	Residential: Biomass	CH4	T1
1A4b	Residential: Gaseous fuels	CO2	L1, L2, T1, T2
1A4b	Residential: Liquid fuels	CO2	L1, T1
1A4c	Agriculture and forestry: Liquid fuels	CO2	L1
1B2	Oil and natural gas energy production	CH4	L1, T1
2A1	Cement production	CO2	L1, L2, T1
2C3	Aluminium production	CO2	T1
2C3	Aluminium production	PFC	T1
2F1	Refrigeration and air conditioning	HFC	L1, L2, T1, T2
2G	Other product manufacture and use	N2O	T2
2G	Other product manufacture and use	SF6	L1
2	Indirect CO2 emissions	CO2	L2, T1, T2
3A	Enteric Fermentation	CH4	L1, L2, T1
3B1-3B4	Manure management	CH4	L1, L2
3B5	Indirect N2O emissions from manure management	N2O	L1, L2, T2
3Da	Direct emissions from managed soils	N2O	L1, L2, T2
3Db	Indirect emissions from managed soils	N2O	L1, L2, T1, T2
4A1	Forest land remaining forest land	CO2	L1, L2, T1, T2
4A2	Land converted to forest land	CO2	L1, L2, T1, T2
4B1	Cropland remaining cropland	CO2	L1, L2, T1, T2
4C1	Grassland remaining grassland	CO2	L1, L2, T1, T2
4C2	Land converted to grassland	CO2	L1, L2, T1, T2
4E2	Land converted to settlements	CO2	L2
4G	HWP Harvested wood products	CO2 biog.	L2, T1, T2
5A	Solid waste disposal	CH4	L1, L2, T1, T2
5D	Wastewater treatment and discharge	CH4	L1, L2
5D	Wastewater treatment and discharge	N2O	L2

1.5.2 KP-LULUCF inventory

Switzerland identified 1 key category for activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol (Forest management). The approach relies on full inventory KCA (with LULUCF), KP – CRF association and qualitative assessment. A detailed description is presented in chp. 11.6.1.

1.6 General uncertainty evaluation

1.6.1 GHG inventory

This chapter presents the main results of the uncertainty evaluation concerning the GHG inventory.

1.6.1.1 Methodology

The uncertainty analyses are conducted in accordance with the 2006 IPCC Guidelines (IPCC 2006/Chapter 3 Uncertainties) and calculated using spreadsheets. Important assumptions and requirements for both approaches are described in the IPCC guidelines (IPCC 2006). Here, we only recapitulate the main aspects of both approaches:

- Approach 1: based on propagation of error, uncertainty in the emission level in 2017 and in the trend between the reporting year (2017) and the base year (1990) is estimated for the inventory total and for the single source categories and gases using uncertainty ranges of corresponding activity data and emission factors.
- Approach 2: is based on Monte Carlo analysis (IPCC 2006, UNFCCC 2014a). This approach provides a detailed category-by-category assessment of uncertainty, particularly where uncertainties are large, distribution is non-normal, the algorithms are complex functions and/or there are correlations between some of the activity data, emission factors or both. The principle of Monte Carlo analysis is to select random values for emission factor and activity data from within their individual probability distributions, and to calculate the corresponding emission values. This procedure is repeated 100'000 times until an adequately stable result has been found, i.e. until the change of the simulated mean of the total GHG emissions is small. The results of all realisations yield the overall emission probability distribution.

Note that no Approach 2 uncertainty analysis is conducted for Submission 2019. Provided that the necessary resources are available, approach 2 will be implemented in the EMIS database software and reported again in future submissions.

All uncertainties are given as half of the 95% confidence interval divided by the mean and expressed as a percentage (approximately two standard deviations) as suggested by the 2006 IPCC Guidelines (IPCC 2006).

The following chapters present the overall results of the uncertainty evaluation. Specific information about the uncertainty estimation for activity data, emission factors or emissions of each source category is included in the respective sectoral chapters (chp. 3 to 9) below. Detailed results of the Approach 1 assessment is presented in Annex A2.

1.6.1.2 Data used

The evaluation includes uncertainties regarding activity data, emission factors and – in a few cases – emissions. Uncertainties in the GWP values are not taken into account.

Uncertainties are estimated for the reporting year only (except LULUCF). Several uncertainty values have been changed for submission 2019. For instance, the uncertainties of emissions of F-Gases have been adapted corresponding to the values given in the chapters on F-Gas use. Further adjustments of uncertainties have been made in sectors Agriculture (e.g. uncertainties for N₂O emissions under 3B and 3D), in the LULUCF sector and for precursors (mainly CO and NMVOC). Detailed uncertainty data is shown in Annex A2.1. Probability distributions are assumed to be symmetric for Approach 1.

For categories with quantitative uncertainty data available, the input information from studies or from the data suppliers is used for the uncertainty evaluation. This is mainly the case for key categories. However, no explicit information on uncertainties is available for a few key categories. For these cases, 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. The data sources can be found in the relevant sub-sections on “Uncertainties and time-series consistency” in each of the sectoral chapters (chp. 3 to 9) below.

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 Internat. Workshop on Uncertainty in Greenhouse Gas Inventories (Vienna 27-28 September 2007), and by expert judgement from sectoral experts and authors.

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 NF₃, 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 ₂ O	low	40%
	medium	80%
	high	150%
HFC	medium	20%
PFC	medium	20%
SF ₆	medium	20%

1.6.1.3 Results of Approach 1 uncertainty evaluation

Level and trend uncertainty analyses are carried out excluding and including the LULUCF sector. Table 1-11 gives a summary for the Approach 1 uncertainties for the national total emissions and removals.

Table 1-11 Switzerland's relative uncertainties for national total GHG emission excluding and including the LULUCF sector – Approach 1: Level uncertainties 2017 and trend uncertainties 1990–2017. The uncertainty analysis is based on emissions including indirect CO₂ emissions.

Approach 1 Uncertainty Analysis		
Inventory	Level uncertainty 2017	Trend uncertainty 1990-2017
excl. LULUCF	3.85%	1.39%
incl. LULUCF	7.14%	5.37%

Uncertainty analysis results for Switzerland's GHG inventory 2017 and including indirect CO₂ emissions with Approach 1:

- The level uncertainty 2017 is **3.85%** excluding LULUCF and **7.14%** including LULUCF.
- The trend uncertainty 1990–2017 is **1.39%** excluding LULUCF and **5.37%** including LULUCF.

Compared to the results of the previous inventory 2016:

- The level uncertainty in 2016 was 4.65% excluding LULUCF and 6.62% including LULUCF.
- The trend uncertainty 1990–2016 was 3.49% excluding LULUCF and 5.72% including LULUCF.

Changes in total level and trend uncertainty are on one hand due to changes in the uncertainties of the emission factors and activity data in the different source categories. On the other hand, changes in the activity data and emission factors cause changes in the contribution to the total level and trend uncertainty of each source category. Contribution to level uncertainty and the uncertainty introduced to the trend in total national emissions of each source category are shown in Table A – 2.

Compared to the results of the uncertainty analysis of the previous submission, the overall uncertainties for the inventory excluding LULUCF categories have decreased (for the level and the trend assessment). The major reason for this overall decline of uncertainties is the reduced uncertainty for HFC emission factors and corresponding activity data under source category 2F1 Refrigeration and air conditioning. In submission 2018, there was an error in the compilation of the uncertainties, using 107% instead of 14% for the combined uncertainty of 2F1 HFC.

When assessing the uncertainty for the complete inventory including LULUCF categories, the uncertainty has increased for the level and decreased for the trend assessment in comparison to the previous submission. The decreasing effect of the reduced uncertainties under category 2F1 due the correction of an error is still relevant. However, an increase of emissions/removals within LULUCF categories (due to recalculations under 4A1 Forest land remaining forest land and 4C1 Grassland remaining grassland) reverses this effect and leads to an overall increase of the level uncertainty (when including LULUCF categories). For the trend uncertainty, the main reason for the reduction compared to the previous submission is source category 4A1. In category 4A1, the trend between the base year and the latest reporting year is less pronounced than it was in the previous submission, which leads to a smaller contribution to trend uncertainty. This effect, in combination with the corrected (lower) uncertainty for category 2F1, compensates for the emission/removal trend under 4C1 and leads to a slightly lower total trend uncertainty in this submission than in the previous one.

Detailed results of the Approach 1 uncertainty analysis for GHG emissions 2017 per category are shown in Table A – 2. Details of the uncertainty estimates for specific source categories are provided in the sub-sections on “Uncertainties and time-series consistency” in each of the chapters on source categories below.

It should be noted that the results of the Approach 1 uncertainty analysis for GHG emissions do not, or not fully, take into account the following factors that may further increase uncertainties:

- correlations between source categories that are not considered by Approach 1 (e.g. production data used for industry emissions in both categories 1A2 Manufacturing industries and 2 Industrial processes and product use, or cattle numbers used for emissions related to enteric fermentation and animal manure production);
- errors due to neglected temporal variability when assuming constant parameters over time (e.g. emission factors).
- errors due to non-normal, asymmetric distribution of the uncertainties;
- errors due to methodological shortcomings, i.e. simplified approaches;
- errors due to sources not reported (these are assumed to be very small).

The Approach 2 uncertainty evaluation does explicitly take into account correlations between sources and asymmetric distributions. Note that no Approach 2 assessment is conducted for submission 2019. The latest Approach 2 uncertainty results can be seen in Switzerland's previous NIR (see FOEN 2018).

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. In line with UNFCCC (2017/ID#L.12) the soil carbon model Yasso07 will be further developed and results from various research projects will be evaluated to improve the accuracy in the estimates of carbon changes in mineral soil, litter and dead wood in forest land (see chp. 6.4.6 for details). A Tier 3 methodological approach for the quantification of carbon stock changes in agricultural soils (cropland remaining cropland and grassland remaining grassland) was developed at Agroscope research station and implemented in categories 4B and 4C. Together with further studies (cf. chp. 6.5.6 and chp. 6.6.6) the advancement in domestic soil carbon modelling will continue addressing the shortcomings of missing spatially inclusive and comprehensive soil information in Switzerland. In the agriculture sector, a research project run by Agroscope looks into CH₄ and N₂O emissions from current pasture practices using micrometeorological measurements and modelling approaches. With regard to HFC emissions, the FOEN supports a long-term monitoring initiative at Jungfrauoch to derive independent emission estimates from atmospheric concentrations (Annex 5.1). Another, more recent verification activity addresses national total CH₄ and N₂O emissions (Annex 5.2).

1.6.2 KP-LULUCF inventory

Uncertainty estimates for KP-LULUCF activities are presented in chp. 11.3.1.5.

1.7 General assessment of completeness

1.7.1 GHG inventory

Source and sink categories that are not estimated or included elsewhere are listed in CRF Table9.

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

- CH₄ emissions from 1A1a iv Other / Municipal and special waste incineration plants / Other Fossil Fuels. According to a study carried out in 2013 (Mohn 2013), CH₄ emissions are negligible (see chp. 3.2.5.2.1)
- CH₄ 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.
- N₂O 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 1A2g viii due to limited data availability regarding wood use in the relevant source categories (see chp. 3.2.4.5.2).
- 1A2f Non-metallic minerals/Biomass: CH₄ 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.
- 2B1 Ammonia production: CO₂ 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: CO₂ emissions are reported under 4D1.3 Other wetlands remaining other wetlands/surface water
- 4(I)E Direct N₂O emissions from nitrogen inputs to managed soils/Settlements: Emissions are reported together with 3.D(a) Agriculture because no data are available for a further disaggregation of fertiliser use.
- 4(II) Emissions and removals from drainage and rewetting and other management of organic soils: CO₂ emissions from 4A Forest land, 4B Cropland, and 4C Grassland, and 4D Wetlands are reported under organic soils in tables 4.A, 4.B, 4.C and 4.D respectively.
- 4(III)C1 Direct N₂O from N Mineralisation/Immobilisation/Grasslands remaining grasslands: N₂O emissions are reported under 3.D(a)5 Agriculture, as grasslands are normally part of the agricultural area.
- 4(IV) Indirect N₂O emissions from managed soils/Atmospheric deposition: Emissions are reported under 3.D(b) Agriculture because no data are available for a further disaggregation.
- 4(V) Biomass Burning: Emissions from 4(V)A.2 and 4(V)C.2 are reported under 4(V)A.1 and 4(V)C.2 because no data are available for a further disaggregation. CO₂ emissions from 4(V)A.1 and 4(V)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 CH₄ recovered and emissions from its use in stationary motors (CHP) and boilers are reported under 1A2gviii Other / Biomass (CHP at industrial biogas plants) and 1A4ai Commercial/institutional / Stationary / Biomass (CHP and boilers at agricultural biogas plants).
- 5C1 Waste Incineration Biogenic: CH₄ and N₂O emissions from municipal solid waste are reported under 5C1 Waste Incineration Non-biogenic.

- 5D2 Industrial wastewater: CH₄ and N₂O 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 sources and sinks, complete estimates are accomplished for the current submission. Notation keys for the activity coverage and the reported pools are displayed in CRF NIR-1. A detailed justification for the reported method is given in chapter 11.3.1.2.

2 Trends in greenhouse gas emissions and removals

Responsibilities for Trends in GHG emissions and removals	
Authors	Regine Röthlisberger (FOEN), Andreas Schellenberger (FOEN, for LULUCF), Nele Rogiers (FOEN, for KP-LULUCF)
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Internal review	Michael Bock (FOEN), Markus Didion (WSL), Daniel Bretscher (Agroscope), Christoph Könitzer (Sigmaplan)

This chapter provides an overview of Switzerland's GHG emissions and removals in 2017 as well as trends for the period 1990–2017. 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 2017 (UNFCCC)

Table 2-1 shows the aggregated emissions of all greenhouse gases (GHG) 2017 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, CO₂ is the main contributor to total GHG emissions followed by CH₄, N₂O 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 emissions in 2017.

Table 2-1 Switzerland's GHG emissions in CO₂ equivalent (kt) by gas and sector in 2017 (without indirect emissions).

Sectors	CO ₂	CH ₄	N ₂ O	HFCs	PFCs	SF ₆	NF ₃	Total	Share
	CO ₂ equivalent (kt)								
1 Energy	35'974	274	221					36'468	77.3%
2 IPPU	2'129	3	39	1'512	31	197	0.5	3'910	8.3%
3 Agriculture	48	4'040	1'989					6'077	12.9%
5 Waste	10	536	145					691	1.5%
6 Other	12	0.6	0.5					13	0.0%
Total (excluding LULUCF)	38'172	4'854	2'394	1'512	31	197	0.5	47'159	100.0%
4 LULUCF	-1'658	14	46					-1'598	-3.4%
Total (including LULUCF)	36'514	4'868	2'440	1'512	31	197	0.5	45'561	96.6%
<i>International aviation bunkers</i>	5'302	0.5	43					5'345	
<i>International marine bunkers</i>	22	0.00	0.21					22	

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 47'159 kt of CO₂ equivalent (excluding LULUCF, excluding indirect CO₂) corresponds to 5.6 tonnes of CO₂ equivalent per capita¹ (CO₂: 4.5 tonnes per capita) emitted to the atmosphere in 2017 (Table 2-1).

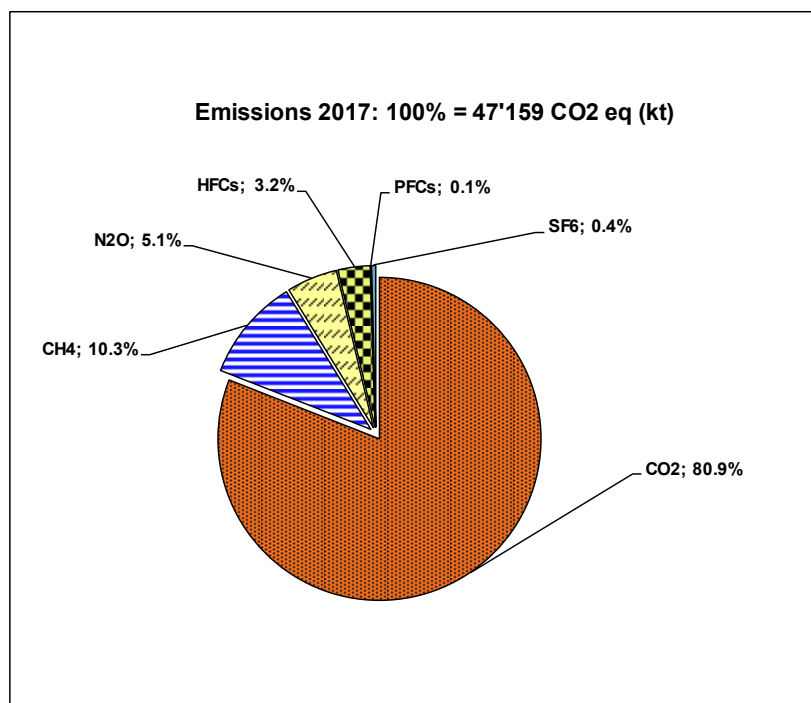


Figure 2-1 Contribution of individual gases to total greenhouse gas emissions (excluding LULUCF, excluding indirect CO₂) in 2017.

¹ Emissions per capita calculated based on population statistics from the Swiss Federal Statistical Office.

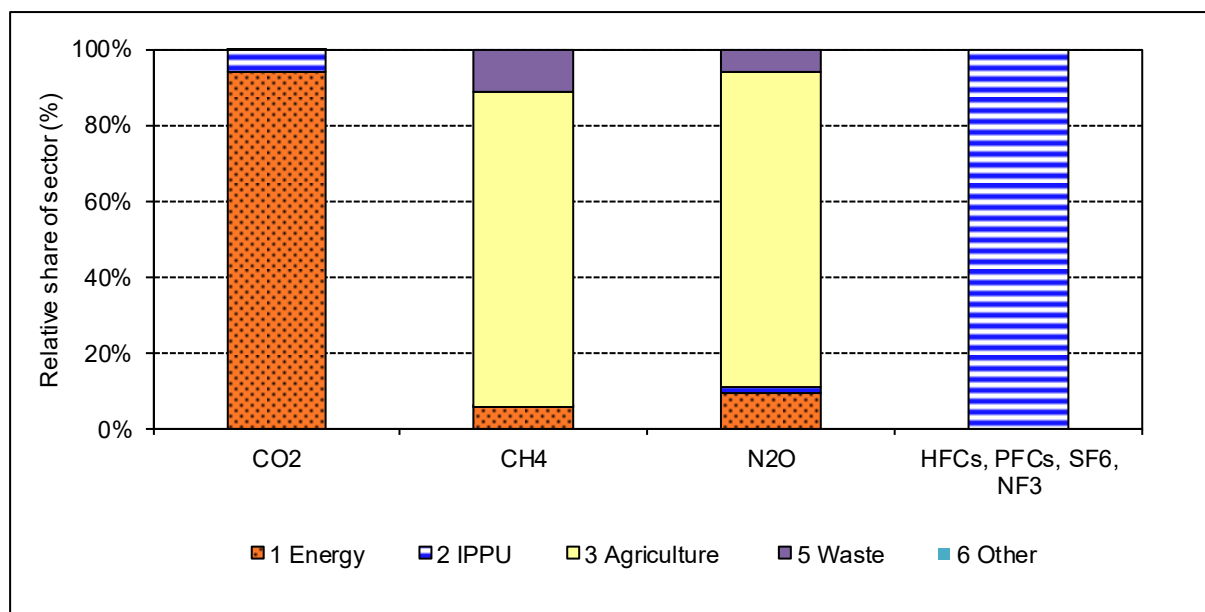


Figure 2-2 Relative contributions of the individual sectors (excluding LULUCF) to GHG emissions in 2017.

A clear dominance of CO₂ emissions in 2017 is related to source category 1A Fuel combustion within sector 1 Energy. CH₄ and N₂O emissions mainly originate from sector 3 Agriculture, while F-gas emissions by definition only stem from sector 2 Industrial processes and product use.

2.2 Emission trends by gas

Emission trends by gas for the period 1990–2017 are summarized in Table 2-2.

Table 2-2 Greenhouse gas emissions in CO₂ equivalent (kt) by gas. The column below on the far right indicates the percentage change in emissions in the latest year compared to the base year 1990. HFC emissions increased by more than 5 million per cent when compared to 1990 levels (1990 = 0.025 kt CO₂ equivalent).

Greenhouse Gas Emissions	1990	1995	2000	2005
	CO ₂ equivalent (kt)			
CO ₂ emissions including net CO ₂ from LULUCF	41'592	39'509	49'119	43'229
CO ₂ emissions excluding net CO ₂ from LULUCF	44'162	43'414	43'612	45'780
CH ₄ emissions including CH ₄ from LULUCF	6'034	5'708	5'301	5'196
CH ₄ emissions excluding CH ₄ from LULUCF	6'005	5'688	5'286	5'182
N ₂ O emissions including N ₂ O from LULUCF	2'887	2'784	2'674	2'502
N ₂ O emissions excluding N ₂ O from LULUCF	2'831	2'734	2'626	2'456
HFCs	0.02	242	634	1'049
PFCs	117	17	50	44
SF ₆	137	93	144	203
NF ₃	0	0	0	0
Total (including LULUCF)	50'767	48'354	57'921	52'223
Total (excluding LULUCF)	53'252	52'189	52'352	54'714

Greenhouse Gas Emissions	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2017 vs. 1990
	CO ₂ equivalent (kt)										%
CO ₂ emissions including net CO ₂ from LULUCF	42'326	40'347	42'365	39'496	40'323	41'049	38'509	36'482	37'007	36'514	-12.2%
CO ₂ emissions excluding net CO ₂ from LULUCF	44'707	43'529	45'043	40'979	42'248	43'179	39'229	38'728	39'187	38'172	-13.6%
CH ₄ emissions including CH ₄ from LULUCF	5'263	5'171	5'140	5'090	5'062	5'000	5'000	4'976	4'933	4'868	-19.3%
CH ₄ emissions excluding CH ₄ from LULUCF	5'250	5'157	5'127	5'075	5'050	4'987	4'987	4'963	4'917	4'854	-19.2%
N ₂ O emissions including N ₂ O from LULUCF	2'469	2'434	2'495	2'443	2'504	2'398	2'443	2'377	2'411	2'440	-15.5%
N ₂ O emissions excluding N ₂ O from LULUCF	2'422	2'387	2'449	2'396	2'458	2'350	2'395	2'330	2'362	2'394	-15.4%
HFCs	1'274	1'271	1'308	1'381	1'455	1'436	1'472	1'514	1'491	1'512	see caption
PFCs	39	34	34	32	36	24	21	25	18	31	-73.6%
SF ₆	222	180	148	160	209	252	259	256	207	197	43.5%
NF ₃	0.1	5.1	8	6	0	0.1	0.4	0.5	0.5	0.5	-
Total (including LULUCF)	51'593	49'441	51'498	48'608	49'589	50'161	47'705	45'630	46'067	45'561	-10.3%
Total (excluding LULUCF)	53'914	52'562	54'117	50'029	51'456	52'229	48'364	47'816	48'183	47'159	-11.4%

As shown in Table 2-2, Table 2-3, and Figure 2-3, total emissions excluding LULUCF in 2017 are clearly below base year emissions. There is no discernible trend in the period 1990–2005. Only from 2005 onwards, a decreasing trend starts to develop. Compared to 2016, emissions have decreased in 2017 (by 2.1%). 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 CO₂ sink generated by LULUCF categories was generally smaller after 1997 (see Figure 6-3). Total emissions reached a minimum in 2017, for both cases including and excluding LULUCF, which was 11.4% and 10.3% below base year emissions in 1990, respectively.

There is a strong correlation between CO₂ emissions and winter climatic conditions (number of heating degree days; see footnote 2, page 62 for further information) in the period 1990–2017. However, the relative developments of heating degree days and CO₂ 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 2017, CH₄ 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. 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, N₂O emissions that mainly stem from manure management and agricultural soils decrease between 1990 und 2017 as well.

HFC emissions increased significantly in 2017 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). SF₆ emissions show relatively large fluctuations between 1990 and 2017. 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 recent increase of SF₆ emissions compared to 2008 is due the disposal of sound proof windows. Although soundproof windows containing SF₆ are not produced or installed in Switzerland anymore, the disposal of old windows still leads to emissions. On the other hand, the SF₆ emissions from electrical equipment (2G1) are decreasing due to the agreement of SWISSMEM and FOEN on the reduction of SF₆ emissions since 2008. Furthermore, the import of SF₆ for magnesium foundries (2C4) is prohibited in Switzerland since 2017, leading to an additional decrease of SF₆ emissions over the past couple of years. NF₃ 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 CO₂) in CO₂ equivalent (kt) and (%).

Greenhouse Gas Emissions (excluding LULUCF)	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	%
CO ₂	44'162	82.9%	43'414	83.2%	43'612	83.3%	45'780	83.7%	45'043	83.2%
CH ₄	6'005	11.3%	5'688	10.9%	5'286	10.1%	5'182	9.5%	5'127	9.5%
N ₂ O	2'831	5.3%	2'734	5.2%	2'626	5.0%	2'456	4.5%	2'449	4.5%
HFCs	0	0.0%	242	0.5%	634	1.2%	1'049	1.9%	1'308	2.4%
PFCs	117	0.2%	17	0.0%	50	0.1%	44	0.1%	34	0.1%
SF ₆	137	0.3%	93	0.2%	144	0.3%	203	0.4%	148	0.3%
NF ₃	0	0.0%	0	0.0%	0	0.0%	0	0.0%	8	0.0%
Total (excluding LULUCF)	53'252	100%	52'189	100%	52'352	100%	54'714	100%	54'117	100%

Greenhouse Gas Emissions (excluding LULUCF)	2013		2014		2015		2016		2017	
	kt CO ₂ eq	%	kt CO ₂ eq	%	kt CO ₂ eq	%	kt CO ₂ eq	%	kt CO ₂ eq	%
CO ₂	43'179	82.7%	39'229	81.1%	38'728	81.0%	39'187	81.3%	38'172	80.9%
CH ₄	4'987	9.5%	4'987	10.3%	4'963	10.4%	4'917	10.2%	4'854	10.3%
N ₂ O	2'350	4.5%	2'395	5.0%	2'330	4.9%	2'362	4.9%	2'394	5.1%
HFCs	1'436	2.7%	1'472	3.0%	1'514	3.2%	1'491	3.1%	1'512	3.2%
PFCs	24	0.0%	21	0.0%	25	0.1%	18	0.0%	31	0.1%
SF ₆	252	0.5%	259	0.5%	256	0.5%	207	0.4%	197	0.4%
NF ₃	0.1	0.0%	0.4	0.0%	0.5	0.0%	0.5	0.0%	0.5	0.0%
Total (excluding LULUCF)	52'229	100%	48'364	100%	47'816	100%	48'183	100%	47'159	100%

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

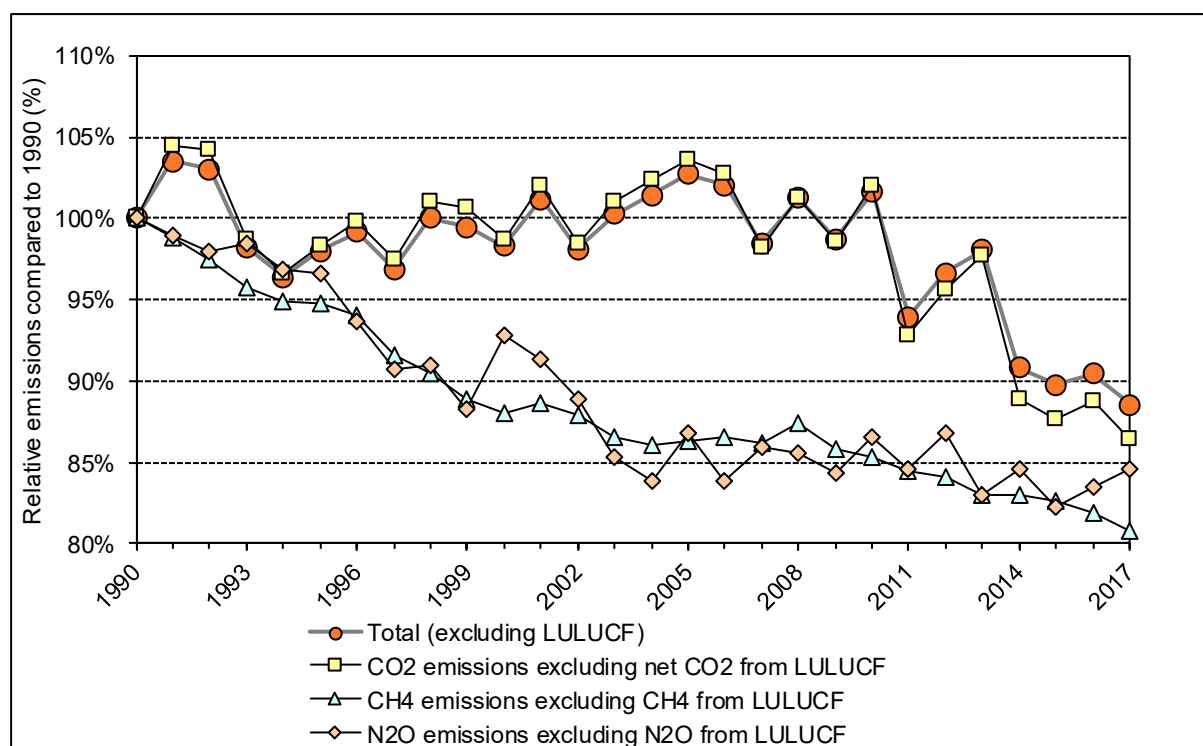


Figure 2-3 Relative trends of Switzerland's main greenhouse gas emissions (excluding LULUCF). The base year 1990 represents 100%. F-gases are not illustrated (see Figure 4-3).

2.3 Emission trends by sources and sinks

Table 2-4 shows the emission trends for all major sources 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 2014, except for the economically difficult year 2009. Since 2014, emissions from the sector have stagnated. The Ordinance on Chemical Risk Reduction (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 1/3 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. Source category 2G Other product manufacture and use (in particular SF₆ and PFC emissions from electrical equipment and other product use, as well as N₂O emissions from the application in households and hospitals) has increased by

approximately factor 1.5 since 1990. 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, thus leading to a decrease in CH₄ and N₂O 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 2017, 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 1990 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 on a very low level. Emissions from sector 6 Other are not accounted for under the Kyoto Protocol and are of minor importance.

Table 2-4 Greenhouse gas emissions (excluding indirect CO₂) in CO₂ equivalent (kt) by individual source (positive numbers) and sink (negative numbers) categories.

Source and Sink Categories	1990	1995	2000	2005
	CO ₂ equivalent (kt)			
1. Energy	41'826	41'869	42'181	43'991
1A1 Energy industries	2'519	2'643	3'172	3'816
1A2 Manufacturing industries and construction	6'443	6'192	5'925	5'974
1A3 Transport	14'639	14'257	15'927	15'855
1A4 Other sectors	17'641	18'184	16'648	17'895
1A5 Other	220	163	151	139
1B Fugitive emissions from fuels	363	431	360	313
2. Industrial processes and product use	3'576	2'911	3'143	3'771
3. Agriculture	6'766	6'523	6'185	6'094
5. Waste	1'071	874	830	845
6. Other	12	12	13	14
Total (excluding LULUCF)	53'252	52'189	52'352	54'714
4. Land use, land-use change and forestry	-2'484	-3'835	5'569	-2'491
Total (including LULUCF)	50'767	48'354	57'921	52'223

Source and Sink Categories	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2017 vs. 1990
	CO ₂ equivalent (kt)										%
1. Energy	42'945	41'835	43'203	39'140	40'531	41'451	37'405	37'071	37'461	36'468	-12.8%
1A1 Energy industries	3'837	3'674	3'846	3'598	3'641	3'736	3'607	3'292	3'380	3'299	30.9%
1A2 Manufacturing industries and construction	6'018	5'701	5'814	5'376	5'387	5'478	5'079	4'962	4'965	4'918	-23.7%
1A3 Transport	16'644	16'438	16'326	16'144	16'259	16'167	16'059	15'321	15'151	14'884	1.7%
1A4 Other sectors	16'040	15'622	16'800	13'614	14'853	15'700	12'295	13'142	13'606	13'017	-26.2%
1A5 Other	131	133	137	125	132	133	139	135	139	128	-41.9%
1B Fugitive emissions from fuels	275	268	279	283	259	236	226	218	219	223	-38.6%
2. Industrial processes and product use	3'933	3'796	3'968	3'995	3'990	3'975	4'046	3'919	3'914	3'910	9.3%
3. Agriculture	6'213	6'131	6'159	6'120	6'182	6'057	6'178	6'097	6'093	6'077	-10.2%
5. Waste	810	788	775	760	738	732	723	716	703	691	-35.5%
6. Other	13	13	12	13	14	14	12	12	12	13	3.5%
Total (excluding LULUCF)	53'914	52'562	54'117	50'029	51'456	52'229	48'364	47'816	48'183	47'159	-11.4%
4. Land use, land-use change and forestry	-2'321	-3'122	-2'619	-1'420	-1'866	-2'069	-659	-2'186	-2'115	-1'598	-35.7%
Total (including LULUCF)	51'593	49'441	51'498	48'608	49'589	50'161	47'705	45'630	46'067	45'561	-10.3%

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 CO₂) in CO₂ 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	41'826	78.5%	41'869	80.2%	42'181	80.6%	43'991	80.4%	43'203	79.8%
1A1 Energy industries	2'519	4.7%	2'643	5.1%	3'172	6.1%	3'816	7.0%	3'846	7.1%
1A2 Manufacturing industries and construction	6'443	12.1%	6'192	11.9%	5'925	11.3%	5'974	10.9%	5'814	10.7%
1A3 Transport	14'639	27.5%	14'257	27.3%	15'927	30.4%	15'855	29.0%	16'326	30.2%
1A4 Other sectors	17'641	33.1%	18'184	34.8%	16'648	31.8%	17'895	32.7%	16'800	31.0%
1A5 Other	220	0.4%	163	0.3%	151	0.3%	139	0.3%	137	0.3%
1B Fugitive emissions from fuels	363	0.7%	431	0.8%	360	0.7%	313	0.6%	279	0.5%
2. Industrial processes and product use	3'576	6.7%	2'911	5.6%	3'143	6.0%	3'771	6.9%	3'968	7.3%
3. Agriculture	6'766	12.7%	6'523	12.5%	6'185	11.8%	6'094	11.1%	6'159	11.4%
5. Waste	1'071	2.0%	874	1.7%	830	1.6%	845	1.5%	775	1.4%
6. Other	12	0.0%	12	0.0%	13	0.0%	14	0.0%	12	0.0%
Total (excluding LULUCF)	53'252	100.0%	52'189	100.0%	52'352	100.0%	54'714	100.0%	54'117	100.0%

Source and Sink Categories	2013		2014		2015		2016		2017	
	kt CO ₂ eq	%	kt CO ₂ eq	%	kt CO ₂ eq	%	kt CO ₂ eq	%	kt CO ₂ eq	%
1. Energy	41'451	79.4%	37'405	77.3%	37'071	77.5%	37'461	77.7%	36'468	77.3%
1A1 Energy industries	3'736	7.2%	3'607	7.5%	3'292	6.9%	3'380	7.0%	3'299	7.0%
1A2 Manufacturing industries and construction	5'478	10.5%	5'079	10.5%	4'962	10.4%	4'965	10.3%	4'918	10.4%
1A3 Transport	16'167	31.0%	16'059	33.2%	15'321	32.0%	15'151	31.4%	14'884	31.6%
1A4 Other sectors	15'700	30.1%	12'295	25.4%	13'142	27.5%	13'606	28.2%	13'017	27.6%
1A5 Other	133	0.3%	139	0.3%	135	0.3%	139	0.3%	128	0.3%
1B Fugitive emissions from fuels	236	0.5%	226	0.5%	218	0.5%	219	0.5%	223	0.5%
2. Industrial processes and product use	3'975	7.6%	4'046	8.4%	3'919	8.2%	3'914	8.1%	3'910	8.3%
3. Agriculture	6'057	11.6%	6'178	12.8%	6'097	12.8%	6'093	12.6%	6'077	12.9%
5. Waste	732	1.4%	723	1.5%	716	1.5%	703	1.5%	691	1.5%
6. Other	14	0.0%	12	0.0%	12	0.0%	12	0.0%	13	0.0%
Total (excluding LULUCF)	52'229	100.0%	48'364	100.0%	47'816	100.0%	48'183	100.0%	47'159	100.0%

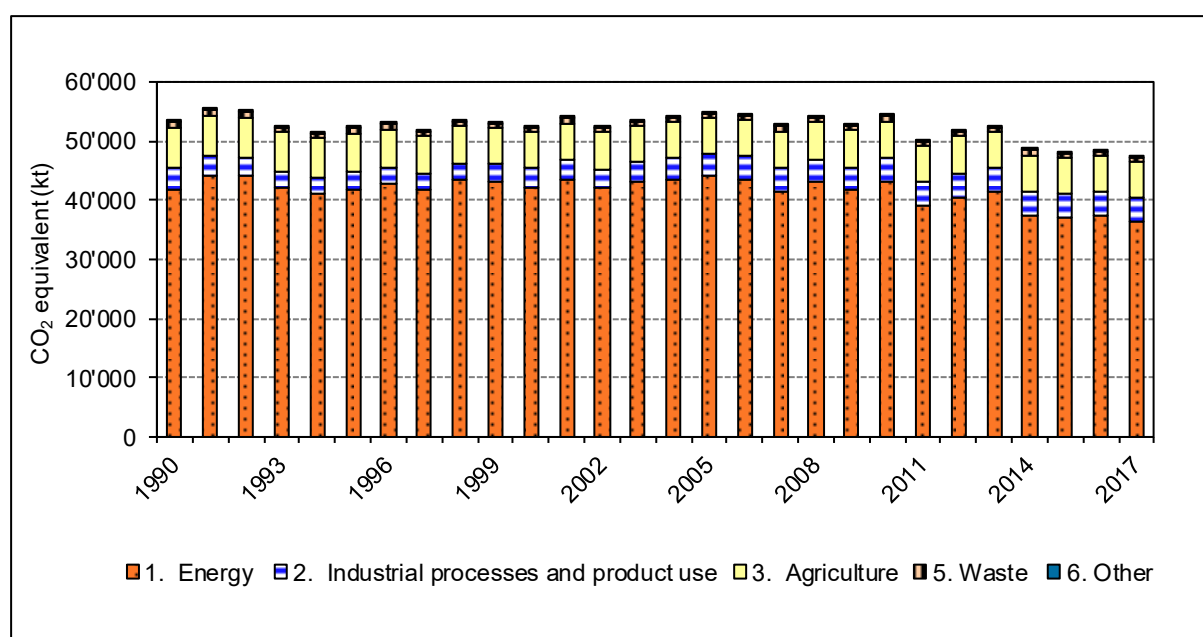


Figure 2-4 Greenhouse gas emissions in CO₂ equivalent (kt) by sectors (excluding LULUCF, excluding indirect CO₂).

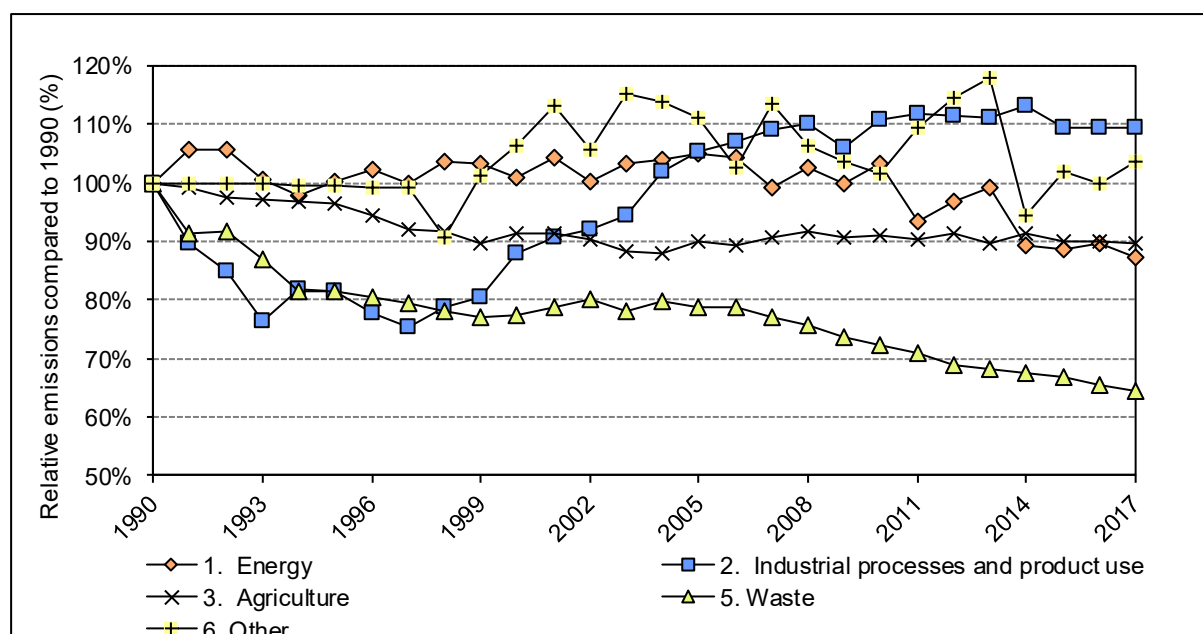


Figure 2-5 Relative emission trends (CO₂ eq) by main source categories (base year 1990 = 100%).

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. Values are given in Table 2-5.

It is noteworthy that due to Switzerland’s electricity production structure (the most of it is generated by hydroelectric and nuclear power plants in 2017; see SFOE (2018), 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 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 1990–2005. From 2006 – 2017, the combination of effective reduction measures and warm winters (see Figure 2-7) led to a decreasing trend in emissions (see further details below under 1A4 Other sectors).
- Overall emissions from source category 1A1 Energy industry in 2017 are higher than in 1990. The time series shows an increase until 2006 and a decreasing trend from then on, fluctuations being caused by varying combustion activities in the petroleum refinery industry, waste-to-energy, new installations of district heating and weather related forcing of heating activities (see Figure 2-6 and values in Table 2-5).
- The trend for category 1A3 Transport is quite stable with minor fluctuations. They are representing the overall economic development in Switzerland fairly well (gross domestic product) (SFSO 2018h). The slight decrease of transport emissions since 2008 as well as the drop from 2014 to 2017 is largely caused by decreasing fuel tourism (EV 2015a) (see chp. 3.2.9.2.2).
- The trend for source category 1A4 Other sectors reflects the impact of climatic variations on energy demand for heating. The strong correlation with the number of “heating degree

days"² – used as an index of cold weather conditions – is apparent from Figure 2-7, which shows CO₂ emissions from source category 1A4 Fuel combustion – Other sectors (only stationary sources) and the number of heating degree days. The number of heating degree days in 2017 decreased compared to 2016. CO₂ emissions caused by fuel combustion in source category 1A4 Other sectors – stationary sources decreased as well (see Figure 2-7). In the period 1990–2017, 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 one third. 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.

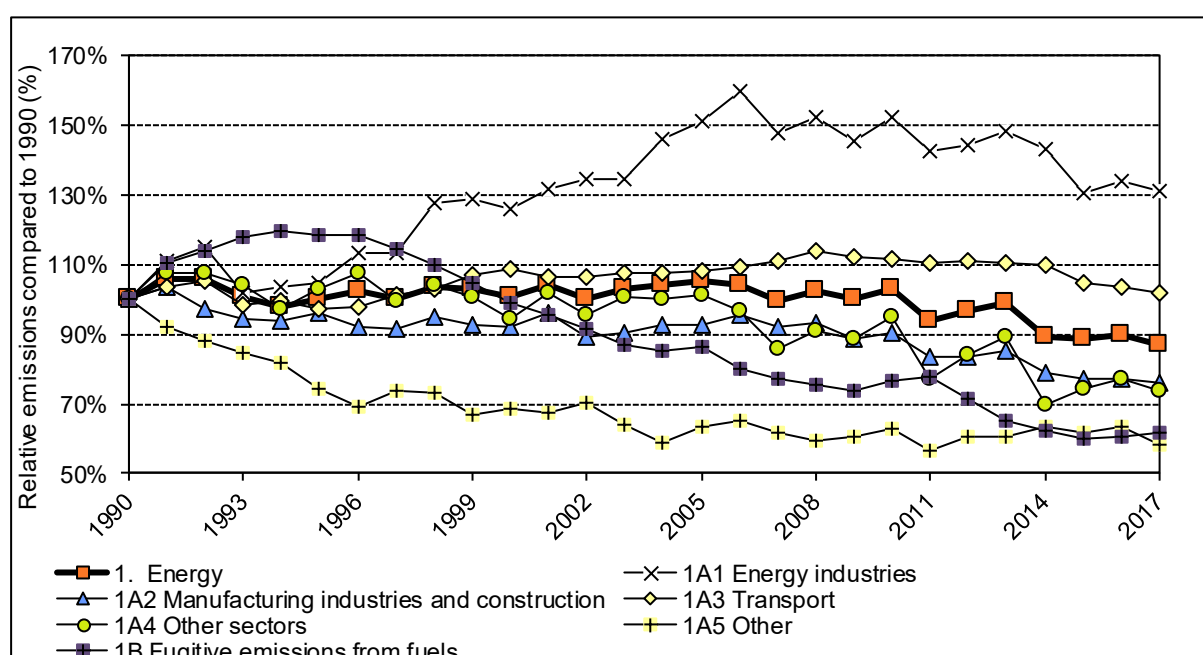


Figure 2-6 Emission trends (CO₂ eq) for the source categories in sector 1 Energy. The trend for the entire sector 1 Energy is represented by the bold line with orange squares.

² Heating degree days: 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*.

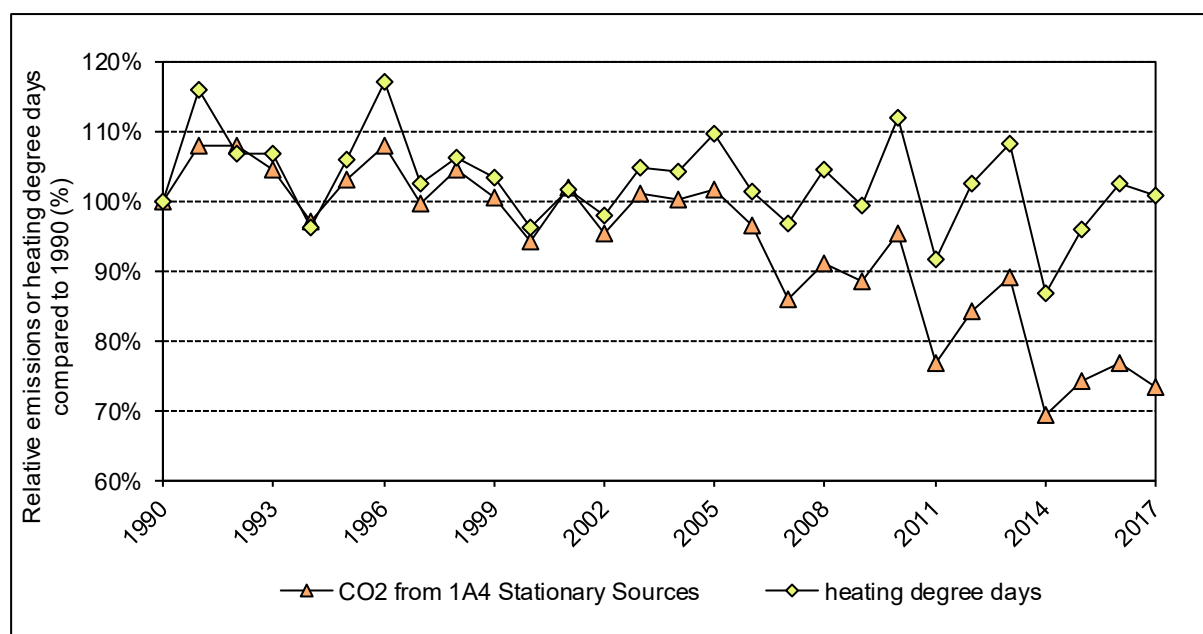


Figure 2-7 Relative trend for CO₂ emissions from 1A4 Fuel Combustion – Other Sectors (stationary sources only) compared with the number of heating degree days.

2.3.3 Emission trends in sector 4 LULUCF

Figure 2-8 illustrates the net emissions and removals of sector 4 LULUCF. Associated data are given in Table 2-4. LULUCF GHG emissions are dominated by biomass dynamics in forests. Except for the year 2000, the removals in sector 4 LULUCF were higher than the emissions over the inventory period. A strong year-to-year variation is evident over the whole period. The reasons for the high net CO₂ eq emissions in 2000 (and the relatively small removals in 1990 and 2001) are the storms Vivian (February 1990) and Lothar (December 1999), respectively, which caused great damages in the forest stands and markedly increased harvesting. In a medium-term perspective, harvesting rates in Swiss forests appeared to increase since 1991 and peaked in 2000 (storm Lothar, see above) and in 2006 and 2007 resulting in minor removals in 2006 and 2007. Primarily because harvesting rates started to decline in 2008 due to the international and domestic economic framework conditions, removals from LULUCF increased again since 2008 and showed a moderate year-to-year variation over the last inventory years. The relatively small removals in 2014 are due to the comparably high harvesting rates (highest in period 2012-2017) and the rather high losses in the litter pool (related to climatic circumstances). The annual contributions of CH₄ and N₂O emissions to LULUCF overall GHG net emissions over the inventory period was small compared to the CO₂ fluxes.

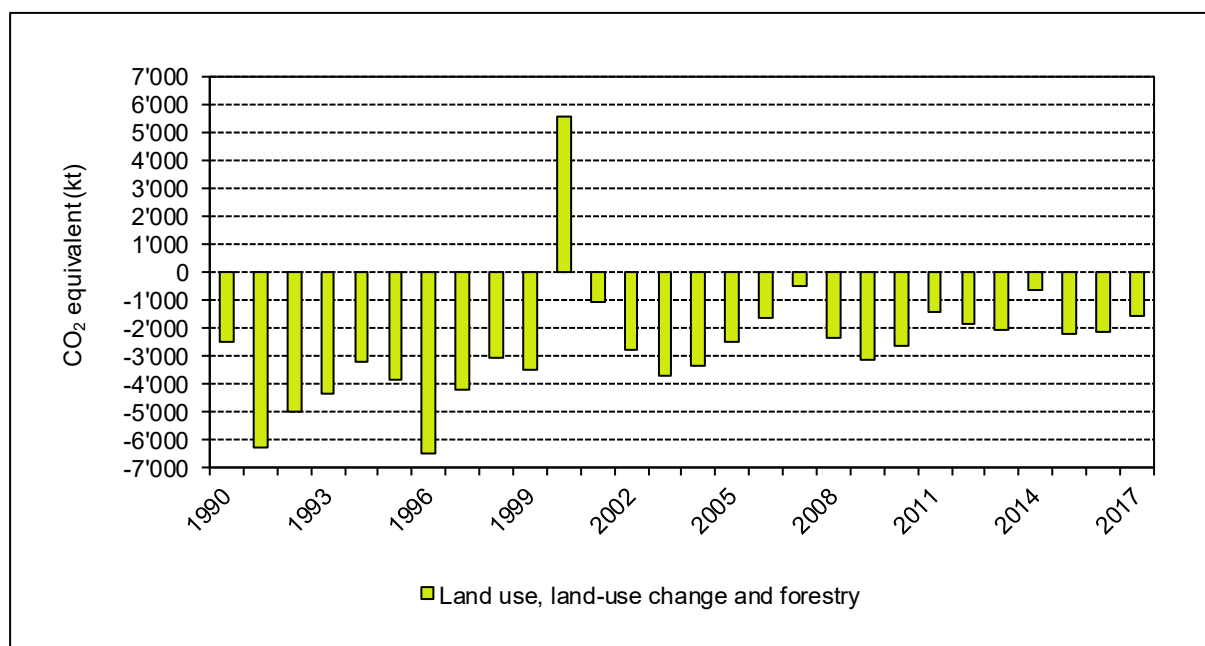


Figure 2-8 Net GHG emissions and removals of sector 4 Land use, land-use change and forestry (LULUCF), in kt CO₂ eq. Positive values refer to net emissions, negative values refer to net removals.

2.4 Emission trends for precursor gases and SO₂

Emission trends for precursor gases (IPCC 2006, Volume 1, Chapter 7) show a very pronounced decline (see Table 2-6 and Figure 2-9). A strict air pollution control policy and the implementation of a large number of emission reduction measures led to decreasing emissions of precursor gases and SO₂ over the period 1990–2017. The main reduction measures were abatement of exhaust emissions from road vehicles and stationary combustion equipment, taxation of solvents and sulphured fuels, and voluntary agreements within the industry sector.

Table 2-6 Emissions of precursor gases and SO₂ (kt) (excluding NMVOC from LULUCF).

Precursor gases and SO ₂	1990	1995	2000	2005
	kt			
NO _x	140	115	104	91
CO	731	490	384	302
NMVOC	301	203	147	107
SO ₂	37	26	16	14

Precursor gases and SO ₂	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2017 vs. 1990
	kt										%
NO _x	84	78	77	72	72	72	68	64	62	60	-58%
CO	254	238	228	207	199	192	173	164	160	154	-79%
NMVOC	99	95	92	89	88	86	82	80	78	78	-74%
SO ₂	12	10	10	8	9	8	7	6	5	5	-86%

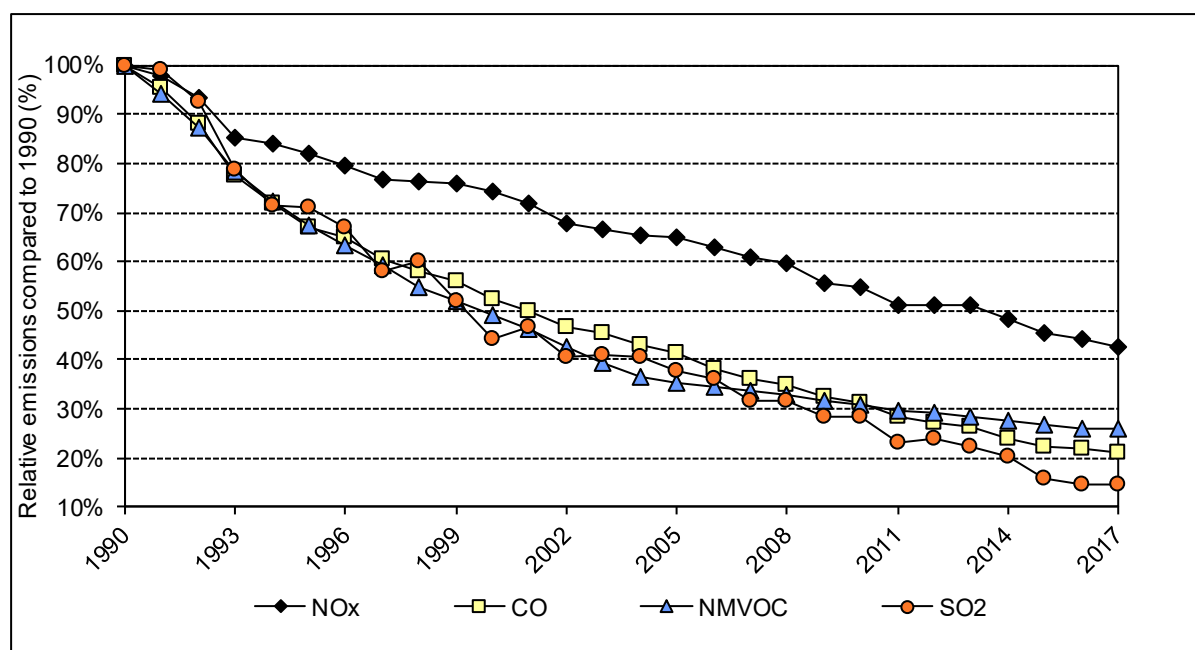


Figure 2-9: Relative trends for precursor and SO₂ emissions (excluding NMVOC from LULUCF; base year 1990 = 100%).

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 2 Industrial processes and product use is the dominant source besides NMVOC emissions from LULUCF (see Figure 2-10). The total shown in Table 2-7 includes NMVOC emissions from LULUCF, which are estimated at almost 100 kt per year according to SAEFL (1996a).

Table 2-7: Precursor and SO₂ emissions (kt) by source category in 2017. SO₂ emissions from 5B and 5D cannot be reported in the respective reporting tables (CRF). However, these emissions are included in this table, what causes a little difference.

Sectors	NO _x		CO		NMVOC		SO ₂	
	kt	%	kt	%	kt	%	kt	%
1 Energy	54.99	92.3%	149.97	96.5%	16.93	11.8%	4.37	82.5%
2 IPPU	0.29	0.5%	1.90	1.2%	42.02	29.3%	0.83	15.8%
3 Agriculture	3.94	6.6%	NA	NA	17.71	12.3%	NA	NA
4 LULUCF	0.05	0.1%	1.25	0.8%	65.30	45.5%	NA	NA
5 Waste	0.19	0.3%	1.55	1.0%	1.36	1.0%	0.08	1.5%
6 Other sources	0.10	0.2%	0.69	0.4%	0.21	0.1%	0.01	0.2%
Total	59.56	100.0%	155.36	100.0%	143.54	100.0%	5.30	100.0%

Figure 2-10 shows the relative contributions of the various sectors for each individual precursor gas excluding LULUCF (data deduced from Table 2-7).

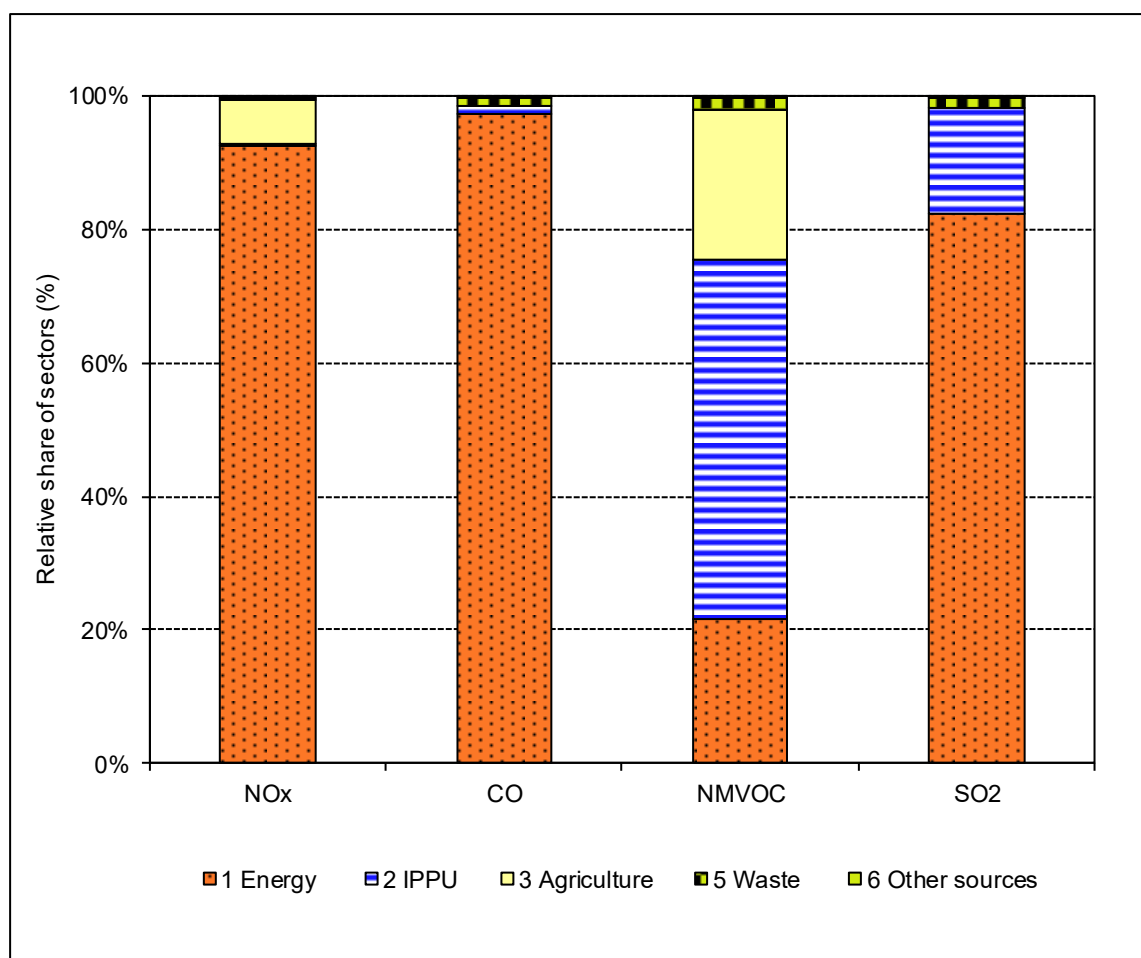


Figure 2-10: Relative contributions of individual sectors to precursor and SO₂ emissions in 2017 (excluding LULUCF).

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, Reforestation and Deforestation) and Article 3, paragraph 4 (Forest management, Cropland management, Grazing land management, and Revegetation) 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 CO₂ 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.

Annex A sources	Sector	Base year initial report	1990	1991	1992	1993	1994	1995	1996	1997	1998
		CO ₂ equivalent (kt)									
Annex A sources	1 Energy + indirect CO ₂ from this sector	41'881	41'870	44'260	44'296	42'121	41'002	41'896	42'768	41'847	43'417
	2 Industrial processes and product use + indirect CO ₂ from this sector	3'887	3'932	3'531	3'341	3'002	3'177	3'146	2'998	2'895	2'992
	3 Agriculture	6'804	6'766	6'706	6'593	6'571	6'545	6'523	6'400	6'228	6'199
	5 Waste + indirect CO ₂ from this sector	1'135	1'073	983	984	933	875	876	865	852	837
	Total (Annex A sources)	53'707	53'641	55'480	55'214	52'627	51'598	52'441	53'031	51'822	53'445

Annex A sources	Sector	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
		CO ₂ equivalent (kt)									
Annex A sources	1 Energy + indirect CO ₂ from this sector	43'207	42'198	43'614	42'010	43'203	43'569	44'004	43'614	41'565	42'956
	2 Industrial processes and product use + indirect CO ₂ from this sector	3'050	3'303	3'397	3'421	3'497	3'751	3'875	3'931	4'006	4'034
	3 Agriculture	6'068	6'185	6'190	6'113	5'986	5'962	6'094	6'049	6'143	6'213
	5 Waste + indirect CO ₂ from this sector	827	831	846	858	836	855	846	845	829	811
	Total (Annex A sources)	53'152	52'517	54'047	52'403	53'522	54'137	54'818	54'439	52'542	54'014

KP-LULUCF	Sector	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
		CO ₂ equivalent (kt)									
KP-LULUCF	Afforestation & Reforestation										-25
	Deforestation										140
	Forest management										-2'257
	Cropland management										NA
	Grazing land management										NA
KP-LULUCF	Revegetation										NA

Annex A sources	Sector	2009	2010	2011	2012	2013	2014	2015	2016	2017	2017 vs. 1990
		CO ₂ equivalent (kt)									
											%
Annex A sources	1 Energy + indirect CO ₂ from this sector	41'846	43'211	39'148	40'539	41'459	37'413	37'078	37'467	36'474	-13%
	2 Industrial processes and product use + indirect CO ₂ from this sector	3'895	4'067	4'093	4'087	4'069	4'137	4'009	4'001	3'998	2%
	3 Agriculture	6'131	6'159	6'120	6'182	6'057	6'178	6'097	6'093	6'077	-10%
	5 Waste + indirect CO ₂ from this sector	789	776	761	739	733	724	717	704	692	-36%
	Total (Annex A sources)	52'661	54'213	50'122	51'547	52'319	48'453	47'901	48'265	47'241	-12%

KP-LULUCF	Sector	2009	2010	2011	2012	2013	2014	2015	2016	2017	2017 vs. 1990
		CO ₂ equivalent (kt)									
											%
KP-LULUCF	Afforestation & Reforestation	-26	-24	-22	-21	-20	-18	-19	-19	-19	
	Deforestation	155	164	164	165	163	152	141	147	165	
	Forest management	-3'231	-3'155	-1'850	-3'110	-2'877	-1'611	-3'096	-2'975	-2'902	
	Cropland management	NA	NA	NA	NA	NA	NA	NA	NA	NA	
	Grazing land management	NA	NA	NA	NA	NA	NA	NA	NA	NA	
KP-LULUCF	Revegetation	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 CO₂ equivalent (kt), as well as emissions and removals under KP-LULUCF.

Annex A sources		GHG	Base year initial report	1990	1991	1992	1993	1994	1995	1996	1997	1998
			CO ₂ equivalent (kt)									
		CO ₂ + indirect CO ₂	44'516	44'553	46'505	46'352	43'908	42'953	43'668	44'331	43'249	44'806
		CH ₄	6'086	6'004	5'936	5'854	5'746	5'696	5'687	5'645	5'502	5'434
		N ₂ O	2'852	2'830	2'800	2'771	2'785	2'742	2'733	2'651	2'568	2'575
		HFCs	0.0	0.0	1.5	15	32	79	242	294	358	454
		PFCs	117	117	99	81	35	21	17	20	21	24
		SF ₆	137	137	139	141	121	107	93	90	124	153
		NF ₃	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Total (Annex A sources)		53'707	53'641	55'480	55'214	52'627	51'598	52'441	53'031	51'822

Annex A sources		GHG	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
			CO ₂ equivalent (kt)									
		CO ₂ + indirect CO ₂	44'620	43'778	45'231	43'597	44'767	45'337	45'885	45'471	43'462	44'809
		CH ₄	5'337	5'285	5'323	5'280	5'200	5'166	5'182	5'194	5'173	5'249
		N ₂ O	2'498	2'626	2'584	2'515	2'417	2'374	2'455	2'374	2'434	2'422
		HFCs	531	634	733	822	908	1'009	1'049	1'159	1'255	1'274
		PFCs	26	50	30	30	67	65	44	55	47	39
		SF ₆	140	144	145	158	165	186	203	186	172	222
		NF ₃	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
		Total (Annex A sources)		53'152	52'517	54'047	52'403	53'522	54'137	54'818	54'439	52'542

KP-LULUCF	Art.3.3	CO ₂										113
		CH ₄										NO
		N ₂ O										2.6
	Art.3.4	CO ₂										-2'261
		CH ₄										2.7
		N ₂ O										1.2

Annex A sources		GHG	2009	2010	2011	2012	2013	2014	2015	2016	2017	2017 vs.1990	
			CO ₂ equivalent (kt)										%
		CO ₂ + indirect CO ₂	43'629	45'140	41'073	42'341	43'269	39'319	38'814	39'270	38'255		-14%
		CH ₄	5'156	5'126	5'075	5'049	4'987	4'987	4'962	4'917	4'853		-19%
		N ₂ O	2'386	2'448	2'395	2'458	2'350	2'395	2'330	2'362	2'393		-15%
		HFCs	1'271	1'308	1'381	1'455	1'436	1'472	1'514	1'491	1'512		see caption
		PFCs	34	34	32	36	24	21	25	18	31		-74%
		SF ₆	180	148	160	209	252	259	256	207	197		43%
		NF ₃	5.1	8.5	6.2	0.4	0.1	0.4	0.5	0.5	0.5		NA
		Total (Annex A sources)		52'661	54'213	50'122	51'547	52'319	48'453	47'901	48'265	47'241	

KP-LULUCF	Art.3.3	CO ₂	126	137	139	141	141	131	119	125	143	
		CH ₄	NO	NO	NO	NO	NO	NO	NO	NO	NO	
		N ₂ O	2.7	2.8	2.8	2.8	2.9	2.9	2.9	2.9	2.9	
	Art.3.4	CO ₂	-3'235	-3'158	-1'856	-3'113	-2'881	-1'615	-3'100	-2'983	-2'907	
		CH ₄	2.7	2.3	4.1	2.2	2.2	2.4	2.4	5.1	3.1	
		N ₂ O	1.2	1.0	2.2	1.0	1.0	1.1	1.1	2.9	1.6	

3 Energy

Responsibilities for sector Energy	
Method updates	Anouk-Aimée Bass (FOEN)
Authors / sector experts	Anouk-Aimée Bass (FOEN; Overview, Stationary sources in 1A1, 1A4, Bunker fuels, Country-specific issues, Mobile sources in 1A2-1A5), 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), Benedict Notter (INFRAS; non-road and Road transportation)
EMIS database operation	Anouk-Aimée Bass (FOEN), Sabine Schenker (FOEN)
Annual updates (NIR text, tables, figures)	Felix Weber (INFRAS), Dominik Eggli (Meteotest), Beat Rihm (Meteotest), Adrian Schilt (FOEN)
Quality control (annual updates)	Felix Weber (INFRAS), Dominik Eggli (Meteotest), Adrian Schilt (FOEN), Regine Röthlisberger (FOEN)
Internal review	Anouk-Aimée Bass (FOEN), Sabine Schenker (FOEN), Adrian Schilt (FOEN), Regine Röthlisberger (FOEN), Theo Rindlisbacher (FOCA)

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 1990–2017 are illustrated in Figure 3-1 and Table 3-1.

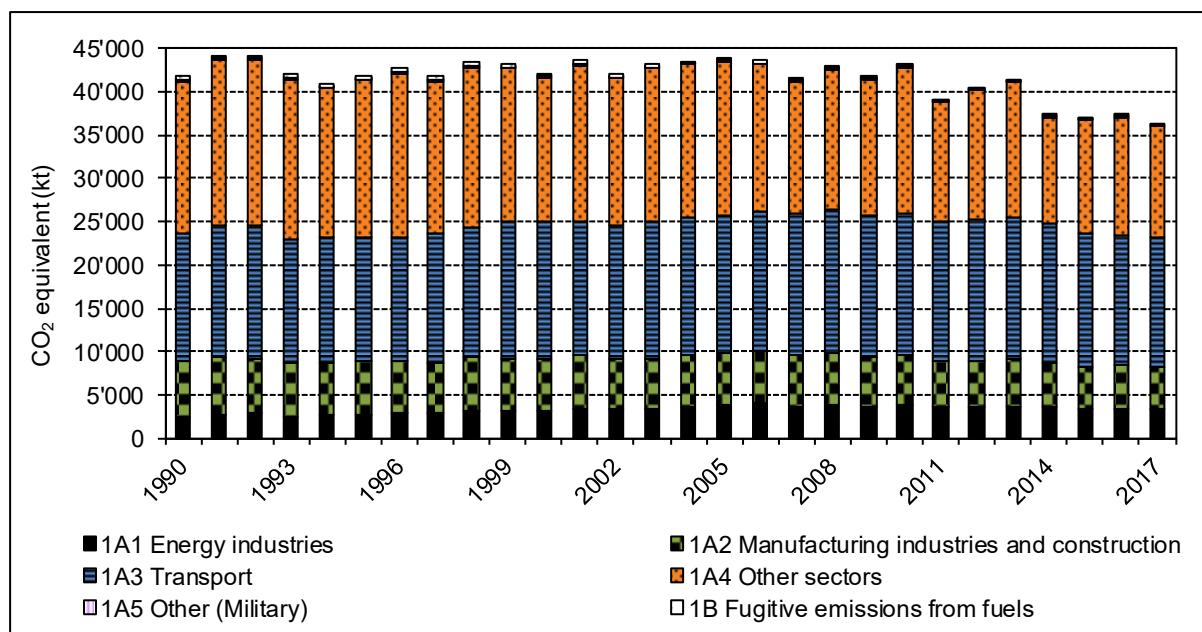


Figure 3-1 Switzerland's GHG emissions of sector 1 Energy in CO₂ equivalent (kt).

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 years 2014–2017 show the lowest values of the entire period 1990–2017. Four source categories dominate the emissions:

- 1A3 Transport and 1A4 Other sectors are the main sources of the sector 1 Energy.
- 1A1 Energy industries and 1A2 Manufacturing industries and construction are less important.
- 1A5 Other (Military) and 1B Fugitive emissions from fuels play only a minor role.

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 CO₂. Fluctuations reflect inter alia the climatic variability in Switzerland (see Figure 2-7 and related comments).
- The decreasing trend of CH₄ emissions 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 also contribute to the decreasing trend.
- The changes in N₂O emissions can mainly be explained by changes in the emission of road transportation due to changes in emission factors for diesel and gasoline combustion. The first generation of catalytic converters generated N₂O as an unintended by-product in the exhaust gases, leading to an increase in N₂O emissions until 1997. With new converter materials being used, the emission factors are decreasing since 2001 with strongest reduction during 2003 and 2004. For further details, see chp. 3.2.9.2.2.

Table 3-1 GHG emissions of source category 1 Energy by gas in CO₂ equivalent (kt)

Gas	1990	1995	2000	2005
	CO ₂ equivalent (kt)			
CO ₂	40'900	40'916	41'345	43'343
CH ₄	634	635	515	418
N ₂ O	292	318	322	230
Sum	41'826	41'869	42'181	43'991

Gas	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2016 vs. 2017	1990 vs. 2017
	CO ₂ equivalent (kt)										%	
CO ₂	42'354	41'260	42'612	38'594	39'989	40'916	36'912	36'580	36'962	35'974	-3%	-12%
CH ₄	365	351	361	331	318	305	278	277	279	274	-2%	-57%
N ₂ O	226	224	230	216	224	230	215	214	220	221	0%	-25%
Sum	42'945	41'835	43'203	39'140	40'531	41'451	37'405	37'071	37'461	36'468	-3%	-13%

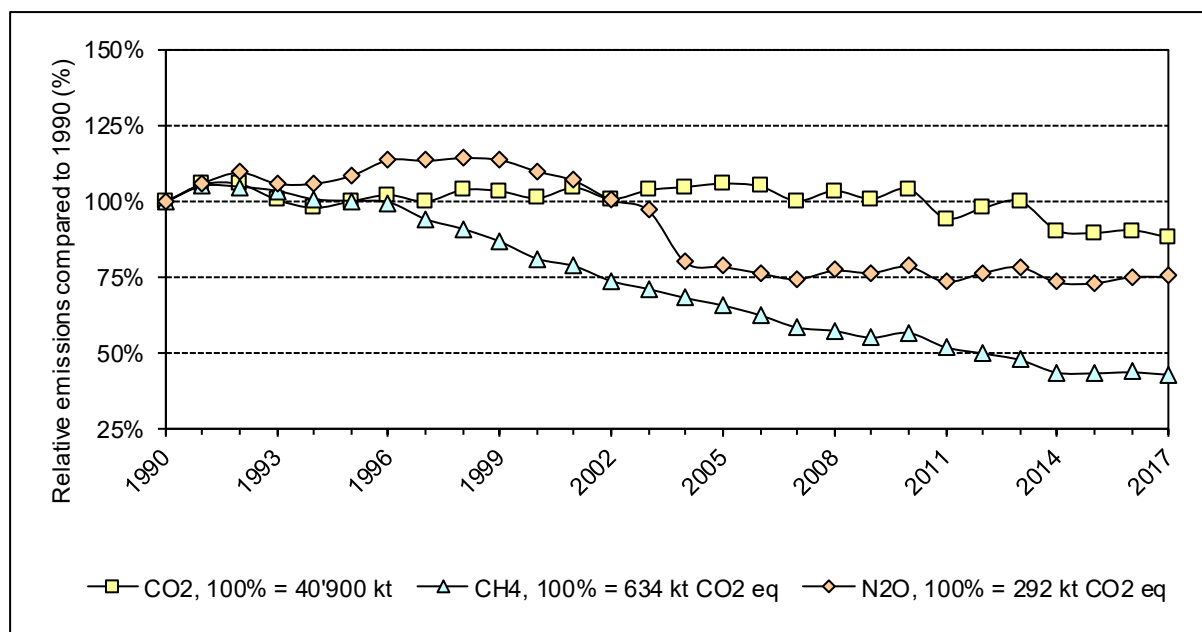


Figure 3-2 Relative trends of the greenhouse gas emissions of sector 1 Energy. The base year 1990 represents 100%.

The following table summarises the emissions of sector 1 Energy in 2017. The table also includes emissions from international bunkers (aviation and marine) as well as CO₂ 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 2017 in kt CO₂ equivalent (Total: rounded values). For full biomass CO₂ emissions see Table 3-20.

Sector Energy	CO ₂	CH ₄	N ₂ O	Total
	CO ₂ equivalent (kt)			
1 Energy	35'974	273.7	220.5	36'468
1A Fuel combustion	35'943	81.8	220.5	36'245
1A1 Energy industries	3'271	0.6	27.3	3'299
1A2 Manufacturing industries and construction	4'877	5.0	35.3	4'918
1A3 Transport	14'775	13.2	96.1	14'884
1A4 Other sectors	12'894	62.9	60.7	13'017
1A5b Other (mobile)	126	0.0	1.1	128
1B Fugitive emissions from fuels	31	191.9	0.0	223
International bunkers	5'323	0.5	43.6	5'368
CO ₂ emissions from biomass	7'429	-	-	7'429

In 2017, 41 key source categories are identified in the Swiss greenhouse gas inventory according to level or trend (Table 1-9). Amongst these, 19 belong to the sector 1 Energy. The key categories (according to level and trend) from sector 1 Energy are shown in Figure 3-3 (Approach 1) and Figure 3-4 (Approach 2).

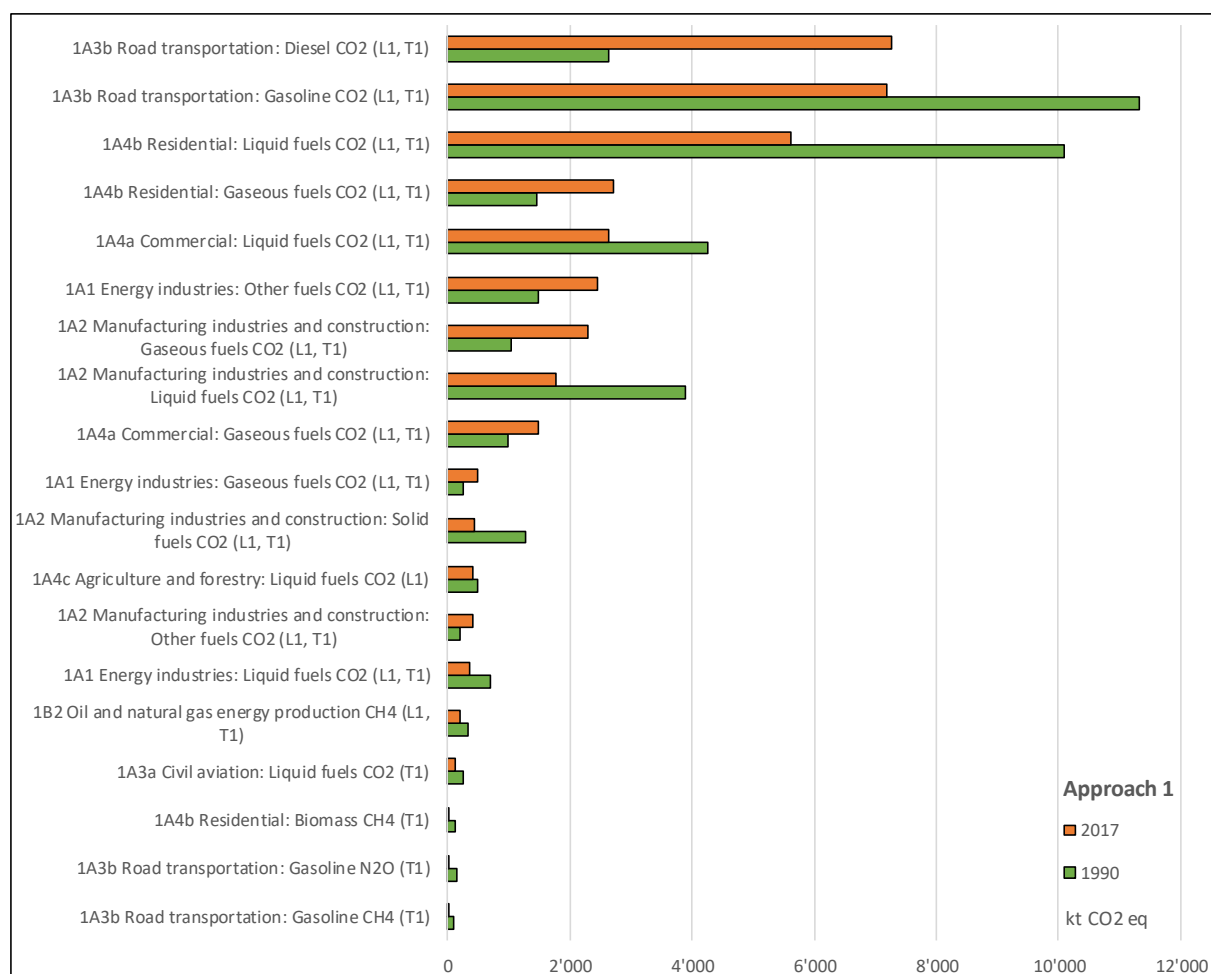


Figure 3-3 Key categories in the Swiss GHG inventory from sector 1 Energy determined by Approach 1 (L1 = key category according to Approach 1 level in 2017; T1 = key category according to Approach 1 trend 1990–2017).

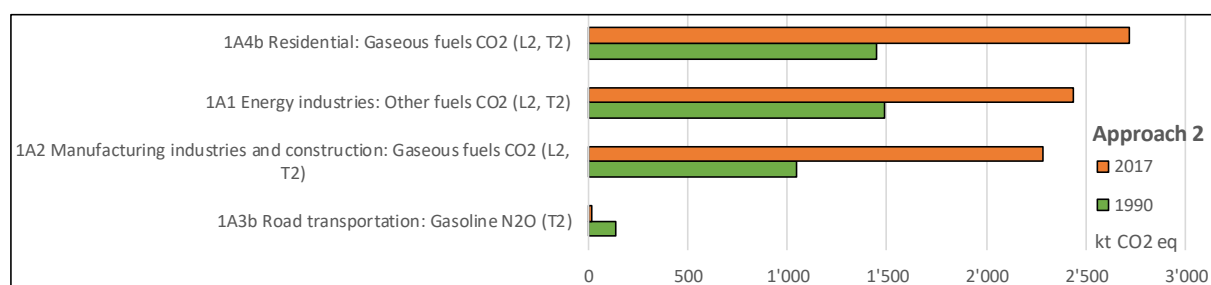


Figure 3-4 Key categories in the Swiss GHG inventory from sector 1 energy determined by Approach 2 (L2 = key category according to Approach 2 level in 2017; T2 = key category according to Approach 2 trend 1990–2017).

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 CO₂ 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 3-5 shows the input data used and the disaggregation of fuel types for each of the two approaches.

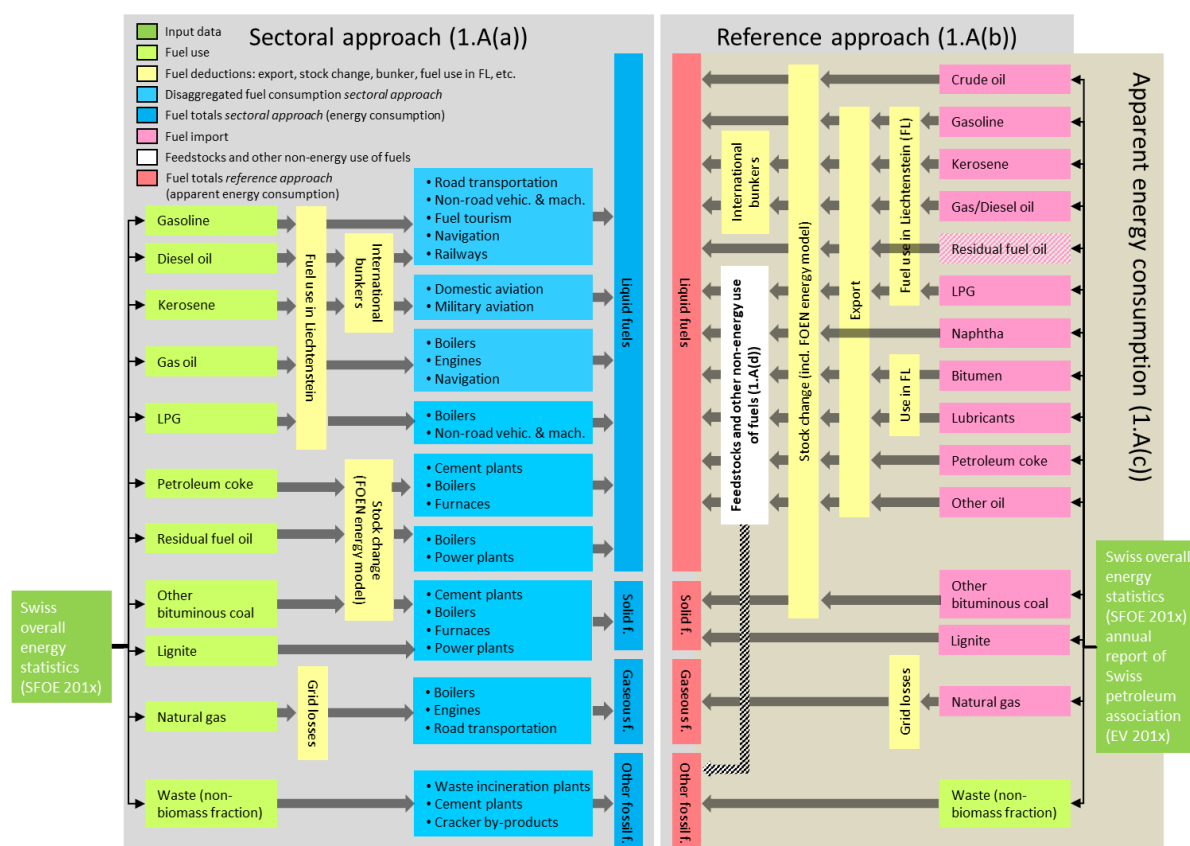


Figure 3-5 Calculation of Reference and Sectoral Approach. The input data for both approaches stem from the Swiss overall energy statistics (SFOE 2018). For the Reference Approach, additional information from the Swiss Petroleum Association (EV 2018) is used. While the Reference Approach considers the 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 CO₂ emissions from cracker by-products (originating from feedstock use of LPG 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.

The Sectoral Approach is based on sectoral energy consumption data from the Swiss overall energy statistics (SFOE 2018) 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 2018). Apparent consumption (in tonnes) is derived from imports and exports of primary fuels (crude oil, natural gas, coal³), 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 3-9 and Table 3-10, Table 3-12 and Table 3-13 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 CO₂ 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 CO₂ 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). 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 3-9. In contrast, marine bunkers consist of diesel oil only and are reported using the country-specific NCV as of Table 3-9.
- Liechtenstein's liquid fossil fuel consumption is subtracted from the input figures in SFOE (2018), 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 CO₂ 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 CO₂ emissions, as shown in Table 3-3 and in Figure 3-6. 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 Swiss 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 4.2.

³ Coke oven coke and anthracite are included under other bituminous coal.

Table 3-3 Differences in energy consumption and CO₂ emissions between the Reference and the Sectoral Approach. The difference is calculated according to $[(RA-SA)/SA] \cdot 100\%$ with RA = Reference Approach, SA = Sectoral Approach.

	1990	1995	2000	2005
	%			
Energy consumption	0.6	0.8	0.4	0.5
CO ₂ emissions	0.8	0.9	0.7	0.8

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	%									
Energy consumption	0.4	0.6	0.5	0.5	0.4	0.4	0.4	0.1	0.5	0.2
CO ₂ emissions	0.8	1.1	1.0	1.0	0.8	0.9	0.9	0.6	1.1	0.8

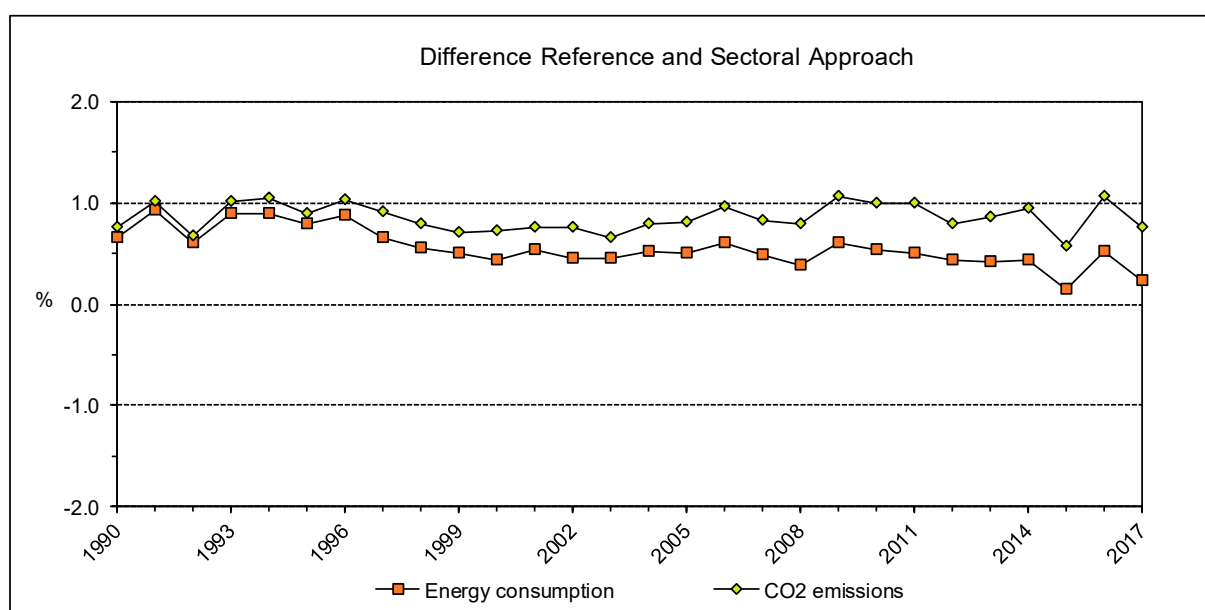


Figure 3-6 Time series for the differences between Reference and Sectoral Approach. Numbers are taken from Table 3-3. See caption there for further information.

3.2.1.1 Category-specific recalculations for the Reference Approach

No recalculations were carried out exclusively for the reference approach. Recalculations are described in the relevant chapters of the sectoral approach or the chapter on feedstock and non-energy use of fuels. Below, the most relevant recalculations, which also have an influence on the reference approach, are listed.

- Liquid fossil: Recalculations of stock changes of residual fuel oil in 2010 and 2014 (see chp. 3.2.6.5) result in revised values of apparent energy consumption and CO₂ emissions of liquid fuels in these years.
- Liquid fossil: The Swiss petroleum association has corrected a double-counting in the final consumption of the non-energy use of fuels for 2016 (EV 2018) which results in a lower value of carbon stored (C excluded) of other oil (see chp. 3.2.3.1) and thus, higher apparent energy consumption and CO₂ emissions of liquid fuels for 2016.

- Waste (non-biomass fraction): The CO₂ emission factors for four waste derived fuels used in the cement industry – i.e. waste oil, solvents, residues from distillation and plastics and CSS (mix of special waste with saw dust) were reassessed in 2017 (Cemsuisse 2018, see chp. 3.2.6.5) resulting in revised values of CO₂ emissions of other fossil fuels from 2011 onwards.

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	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 crossborder navigation on Lake Geneva and 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 3-74). 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 2018, FOCA 2018). 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 2017, the bunker fuel consumption and the emissions had to be expanded by the factor 1.032, the correction

factor was 0.968 (FOCA 2018). 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 for aviation.

Modelled and actual fuel sales	2010	2011	2012	2013	2014	2015	2016	2017
	Fuel consumption in t							
Modelled fuel sales domestic	39'252	42'047	43'414	42'064	44'462	43'680	44'716	37'985
Modelled fuel sales international	1'395'428	1'511'279	1'527'522	1'528'863	1'561'678	1'590'013	1'711'227	1'741'752
Actual fuel sales SFOE minus modelled fuel sales domestic	1'390'824	1'488'805	1'523'116	1'539'963	1'549'228	1'602'319	1'679'034	1'723'717
Correction factor for emission international	0.969	0.957	0.969	0.980	0.964	0.980	0.955	0.968
Overestimation emission international (modelled)	3.1%	4.3%	3.1%	2.0%	3.6%	2.0%	4.5%	3.2%

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
	Fuel consumption in TJ			
1D1 International aviation	41'884	49'918	63'726	47'775
1990 = 100%	100%	119%	152%	114%

1D1 International aviation	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	Fuel consumption in TJ									
1D1 International aviation	58'023	55'426	58'334	62'461	63'903	64'709	65'006	67'333	70'603	72'824
1990 = 100%	139%	132%	139%	149%	153%	154%	155%	161%	169%	174%

3.2.2.2 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 CO₂ (with country-specific carbon contents) and with a Tier 1 approach for CH₄ and N₂O 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 oils 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 1997–2017 (SFOE 2018g).
- 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 older data, proxies such as passenger data on a national basis had to be consulted. As marine lake bunkers provide only a minor share of the total international navigation (between 6% for the year 1990 and 23% for 2015) this approach is justified. The emission factor for CO₂ is country-specific and in accordance with Table 3-12.

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

1D2 International navigation	1990	1995	2000	2005
	Fuel consumption in TJ			
1D2 International navigation	813	756	526	500
1990 = 100%	100%	93%	65%	62%

1D2 International navigation	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	Fuel consumption in TJ									
1D2 International navigation	459	435	472	421	379	356	311	335	342	299
1990 = 100%	57%	54%	58%	52%	47%	44%	38%	41%	42%	37%

3.2.2.3 Uncertainties and time-series consistency for 1D

International aviation: 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

No category-specific recalculations were carried out.

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 2018) 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 the Swiss petroleum association (EV 2018). 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 new and more differentiated breakdown of feedstocks and non-energy use of fuels was developed. The reassessment of feedstocks and other non-energy use of fuels is documented 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 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 CO₂ 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 the Swiss petroleum association (EV 2018). 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 the Swiss petroleum association (EV 2018). Use of paraffin waxes is considered partly emissive (see source category 2D2 under 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. Please note that the net consumption of non-energy use of fuels reported in Swiss overall energy statistics includes sulphur produced by the refineries as well. 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.

<p>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 CO₂ emissions from feedstocks and non-energy use of fuels.</p>
--

3.2.3.1 Category-specific recalculations

1AD: The Swiss petroleum association (EV) has corrected a double-counting in the final consumption of the non-energy use of fuels for 2016 which results in recalculations of the fuel quantity and carbon excluded of other oil for 2016.

3.2.4 Country-specific issues of 1A Fuel combustion

3.2.4.1 System boundaries: Differences between UNFCCC and CLRTAP reporting

Switzerland 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. Thus, fuel sold in Switzerland but consumed abroad (“fuel tourism”) is accounted for in Switzerland’s GHG inventory, but not in the reporting under the CLRTAP. 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 memo items. For the reporting under the CLRTAP, landing and take-off (LTO) emissions of domestic and international flights are accounted for, while emissions of international and domestic cruise flights are reported as memo items (Figure 3-7).

Differences between reporting under CLRTAP and UNFCCC concerning the accounting to the national total			CLRTAP / NFR-Templates			UNFCCC / CRF-Tables	
			accounted to				
			National total	National total for compliance	Memo item	National total	Bunker 1 D
Road transportation 1 A 3 b	Fuel sold in 1 A 3 b	Fuel used 1 A 3 b i-vii	Yes	Yes	Yes	Yes	No
		Fuel tourism and statistical difference 1 A 3 b viii	Yes	No	No	Yes	No
Aviation 1 A 3 a	Civil/Domestic aviation	Landing and Take-Off (LTO)	Yes	Yes	No	Yes	No
		Cruise	No	No	Yes	Yes	No
	International aviation	Landing and Take-Off (LTO)	Yes	Yes	No	No	Yes
		Cruise	No	No	Yes	No	Yes

Figure 3-7 Accounting rules for emissions from 1A3a Domestic aviation and 1A3b Road transportation under the CLRTAP and the UNFCCC.

3.2.4.2 Net calorific values (NCVs)

Table 3-9 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 3-9 Net calorific values (NCVs) of various fuels. 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. 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 3-10.

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 (1998)
Liquefied petroleum gas	SFOE (2018)	46.0
Petroleum coke	SFOE (2018), Cemsuisse (2010a)	35.0 (1998), 31.8 (2010)
Other bituminous coal	SFOE (2018), Cemsuisse (2010a)	28.052 (1998), 25.5 (2010)
Lignite	SFOE (2018), Cemsuisse (2010a)	20.097 (1998), 23.6 (2010)
Natural gas	SGWA	see caption
Biofuel	Data sources	
Biodiesel	SFOE (2018)	38.0
Bioethanol	SFOE (2018)	26.5
Biogas	assumed equal to natural gas	see caption
Wood	SFOE (2018b)	8.6-14.6

Gasoline, jet kerosene, diesel oil and gas oil

The NCVs of gasoline, jet kerosene, diesel oil and gas oil are provided by national measurement campaigns and are the same as used by the Swiss Federal Office of Energy (SFOE 2018). 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 2018), is assumed to be constant over the entire reporting period. The same approach is applied for the CO₂ emission factor (see Table 3-12).

Liquefied petroleum gas

The NCV of liquefied petroleum gas is the same as used by the Swiss Federal Office of Energy (SFOE 2018) and is – as in the Swiss overall energy statistics – constant over the entire reporting period. It is assumed that LPG consists of 50% propane and 50% 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 2018). For these fuels, the Swiss overall energy statistics contains NCVs for the years 1998 and 2010. In between values 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 CO₂ emission factor of natural gas, see Table 3-13) 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 (2018). 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 (2018k). The NCV of biogas is assumed to be equal to the NVC of natural gas since the raw biogas is treated to become the same quality level including its energetic properties as natural gas.

Table 3-10 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 (2018). Spreadsheet to determine national averages: FOEN (2018k).

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	47.3

Wood

The NCV of wood depends on the wood fuel type (e.g. log wood, wood chips, pellets) and is based on the Swiss wood energy statistics (SFOE 2018b). Table 3-9 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 2018) 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 2018). 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 2018), 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 2018). 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 the 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 Customs Administration (FCA).
- Data provided by industry associations (GVS, SGWA, Cemsuisse, VSG, VSTB, etc.).
- Swiss renewable energy statistics (SFOE).
- Swiss wood energy statistics (SFOE).
- Swiss statistics on combined heat and power generation (SFOE).

As can be seen in Figure 3-8, fossil fuels amount to slightly more than half of primary energy consumption. 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.

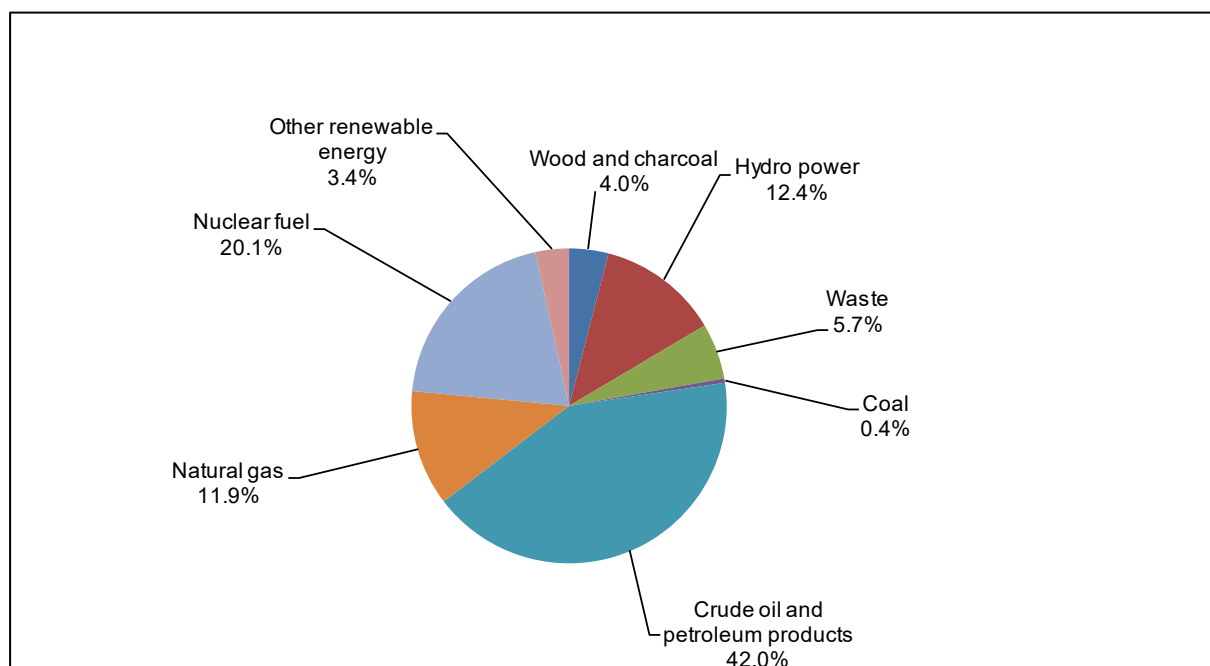


Figure 3-8 Switzerland's primary energy consumption in 2017 by fuels (see corresponding data in SFOE 2018).

Table 3-11 shows primary energy consumption excluding nuclear fuel and hydro power. Liquid fossil fuel consumption changed only little since 1990. This is the combined effect of a marked increase of the consumption in the transport sector and a substantial decrease of gas oil use in the residential and industry sector. Natural gas consumption increased since 1990, compensating to some extent the decreasing use of gas oil.

Table 3-11 Switzerland's energy consumption in 1990–2017 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 consumption from fuel tourism as well as all fuels sold for domestic and international aviation.

Year	Gasoline	Kerosene	Diesel	Gas oil	Residual fuel oil	Refinery gas & LPG	Petroleum coke	Solid fuels	Natural gas	Other fuels	Bio fuels	Total
	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ
1990	155'785	48'067	47'557	218'510	23'342	8'890	1'400	14'901	68'599	19'161	46'574	652'786
1991	162'225	46'562	48'154	238'602	23'590	12'437	980	12'162	76'902	18'596	48'552	688'762
1992	168'100	49'099	46'706	236'809	24'170	11'492	315	8'758	80'808	19'009	47'449	692'714
1993	155'897	50'776	44'978	225'920	17'165	12'388	1'120	7'442	84'758	19'158	47'713	667'315
1994	156'087	52'109	47'748	207'141	17'860	13'455	1'470	7'632	83'587	19'155	45'649	651'893
1995	151'290	54'947	48'604	217'523	17'278	12'756	1'260	7'962	92'123	19'688	47'615	671'047
1996	155'209	56'753	45'597	226'289	15'097	13'939	1'015	5'456	99'710	20'584	51'132	690'780
1997	161'171	58'774	47'385	212'223	12'581	14'236	280	4'590	96'260	21'655	48'066	677'221
1998	162'477	61'268	49'209	222'407	15'882	15'259	455	3'960	99'065	23'802	49'566	703'350
1999	168'025	65'244	52'184	212'349	11'058	15'805	521	4'105	102'588	24'403	50'279	706'561
2000	168'165	68'060	55'677	196'137	7'923	13'649	551	6'120	101'970	26'536	49'898	694'686
2001	163'543	64'208	56'709	213'089	9'942	14'069	410	6'233	106'132	27'068	53'222	714'626
2002	160'375	59'406	58'721	196'655	6'446	15'584	679	5'565	104'170	27'876	52'732	688'211
2003	159'636	53'438	62'251	208'040	7'061	13'642	202	5'663	110'116	27'642	55'202	702'894
2004	156'812	50'441	66'893	203'370	7'561	16'429	1'819	5'420	113'615	28'845	56'051	707'256
2005	152'062	51'101	73'065	205'729	5'805	16'432	2'906	5'940	116'646	29'236	58'115	717'036
2006	147'436	53'571	79'063	195'926	6'419	18'578	3'324	6'467	113'412	31'233	60'736	716'166
2007	146'012	57'165	84'885	171'313	5'179	15'587	2'730	7'196	110'395	30'015	59'468	689'946
2008	142'801	61'151	93'143	178'833	4'606	16'288	3'616	6'562	117'589	30'854	63'050	718'492
2009	138'968	58'665	94'569	173'219	3'575	16'301	3'254	6'193	112'807	29'811	62'898	700'259
2010	134'043	61'620	98'247	182'305	2'987	15'463	3'498	6'208	126'013	31'185	67'187	728'756
2011	128'856	65'696	100'876	143'760	2'292	14'856	2'957	5'792	111'774	30'882	63'182	670'924
2012	124'301	67'306	106'996	154'448	2'780	12'247	3'148	5'269	122'521	31'145	68'723	698'885
2013	118'634	68'068	111'824	162'532	1'959	15'053	2'735	5'567	129'027	30'925	71'916	718'239
2014	113'875	68'541	114'688	122'704	1'621	14'473	3'148	5'704	111'770	31'320	67'086	654'930
2015	105'591	70'788	113'161	129'349	892	9'822	1'145	5'205	119'420	32'084	70'285	657'742
2016	102'297	74'161	114'392	132'335	378	9'136	890	4'795	125'456	33'583	75'818	673'241
2017	99'155	75'933	114'022	123'736	355	8'770	763	4'609	125'730	33'342	78'823	665'239

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 2018). 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 2018), the Swiss renewable energy statistics (SFOE 2018a), the Swiss wood energy statistics (SFOE 2018b), the energy consumption statistics in the industry and services sectors (SFOE 2018d), as well as additional information from the industry.

The Swiss overall energy statistics is not only the main data input into the energy model, but also serves 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 3-9, 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.

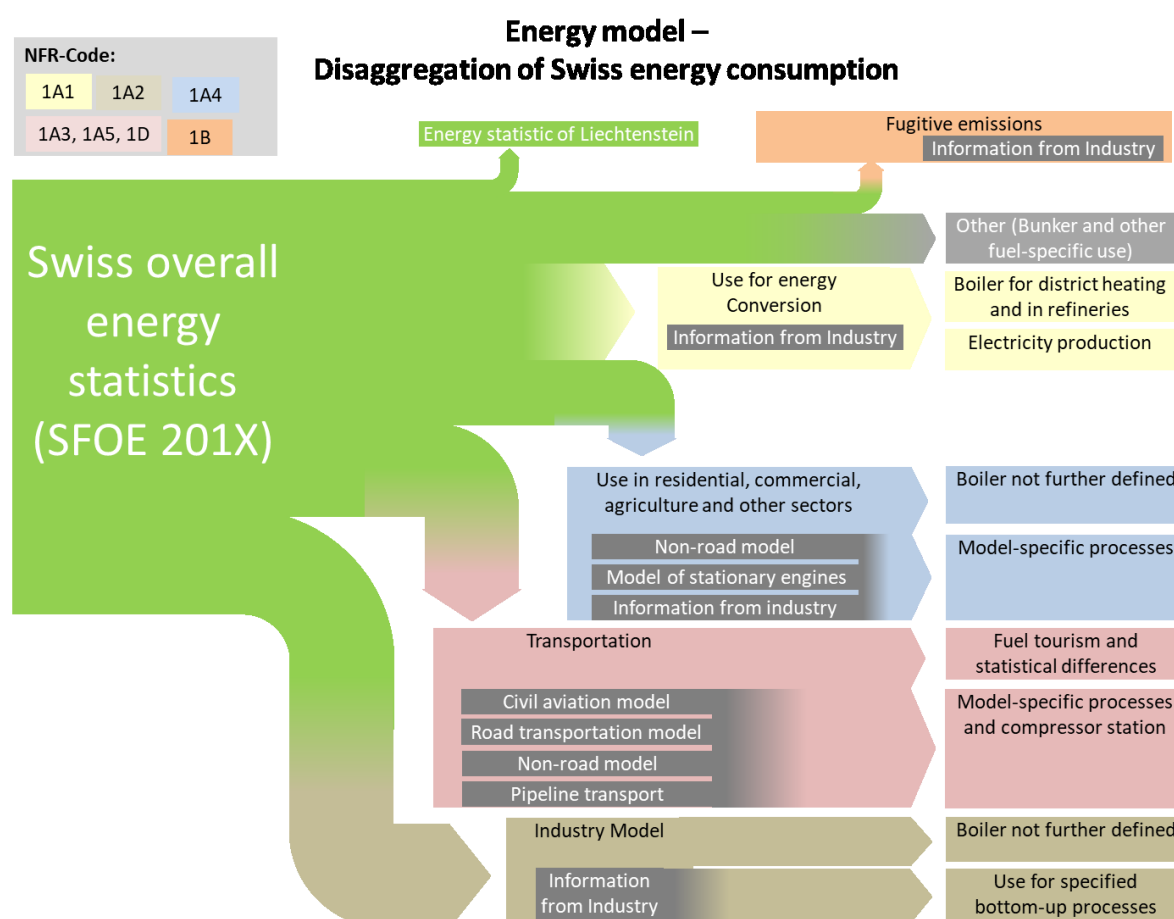


Figure 3-9 Overview of Switzerland's energy model. In the abbreviation SFOE 201X the "X" refers to the latest edition of the Swiss overall energy statistics.

Industry model (Details are given in chp. 3.2.6.2.1)

The industry model is based on two pillars: (i) the energy consumption statistics in the industry and services sectors (SFOE 2018d), which is a comprehensive annual survey of fuel consumptions for all years since 1999 or 2002 (depending on the fuel type), and (ii) 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. 3.2.9.2.13.2.9.2.1)

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 under fuel tourism and statistical differences.

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 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.

Energy model for wood combustion (Details are given in chp. 3.2.4.5.2)

Based on the Swiss wood energy statistics (SFOE 2018b), 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 2018) into the relevant source categories 1A1-1A5. Figure 3-11 to Figure 3-19 visualize for each fuel type separately the disaggregation process of the energy model (as shown schematically in Figure 3-9), the interaction between the different sub-models as well as additional data sources.

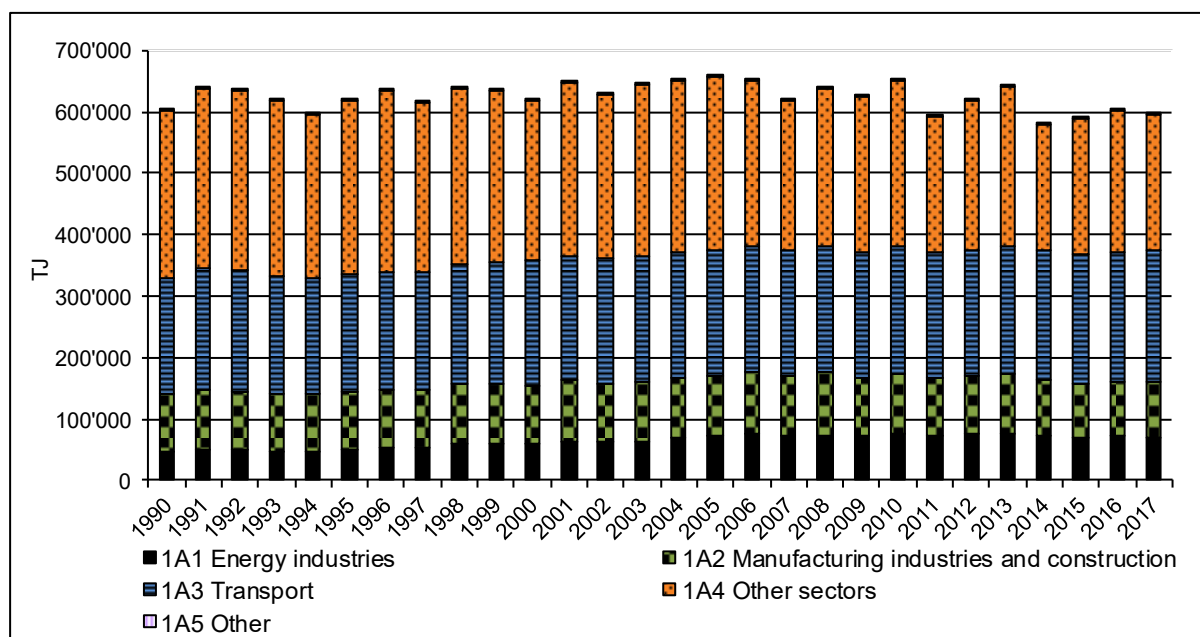


Figure 3-10 Switzerland's energy consumption by source categories 1A1-1A5 according to the Swiss energy model. Since 1990 population increased by more than 25%, industrial production by more than 70% and the motor vehicle fleet by about 60% (SFOE 2018, table 43b).

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 2015c). The residual energy is then assigned to boilers which are not further specified.

For source category 1A4c Other sectors – Agriculture/forestry/fishing, specific bottom-up industry information is available for grass drying. Its fuel consumption is determined by the Swiss association of grass drying plants (VSTB) and is subtracted from the total fuel consumption of 1A2.

In order to report all energy consumption, the statistical differences as reported in the Swiss overall energy statistics are allocated to source category 1A4a Other sectors – Commercial/institutional (stationary combustion) and 1A3bviii Fuel tourism and statistical differences.

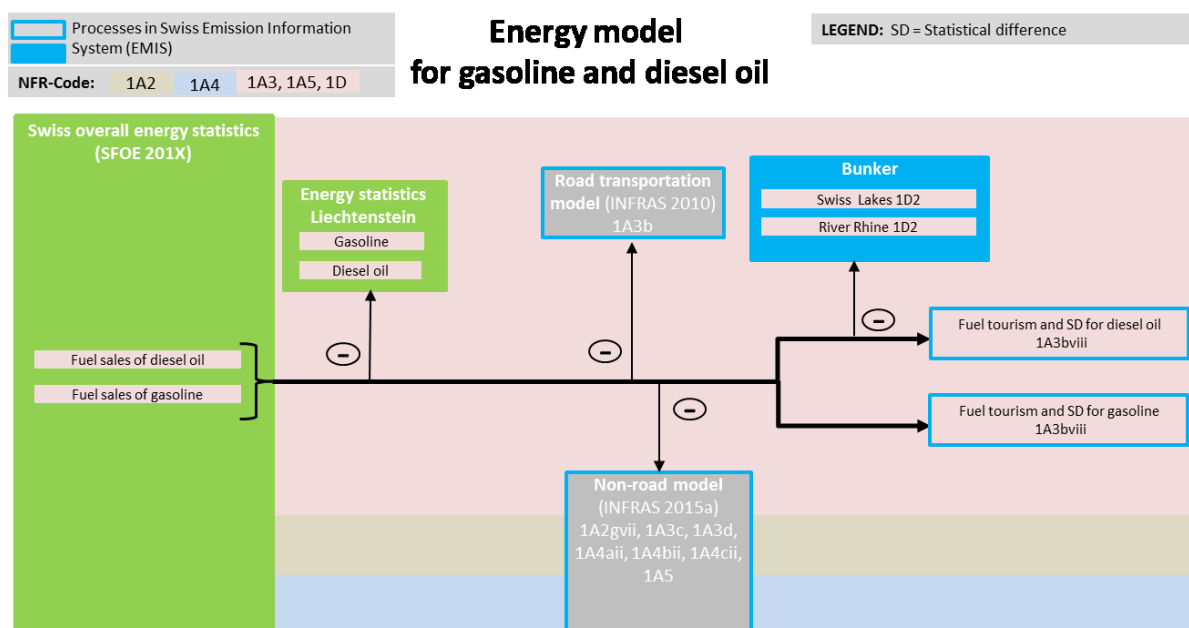


Figure 3-11 Schematic disaggregation of fuel consumption for gasoline and diesel oil. Marine bunker fuel consumption is based on the national customs statistics (see chp. 3.2.2.2.2).

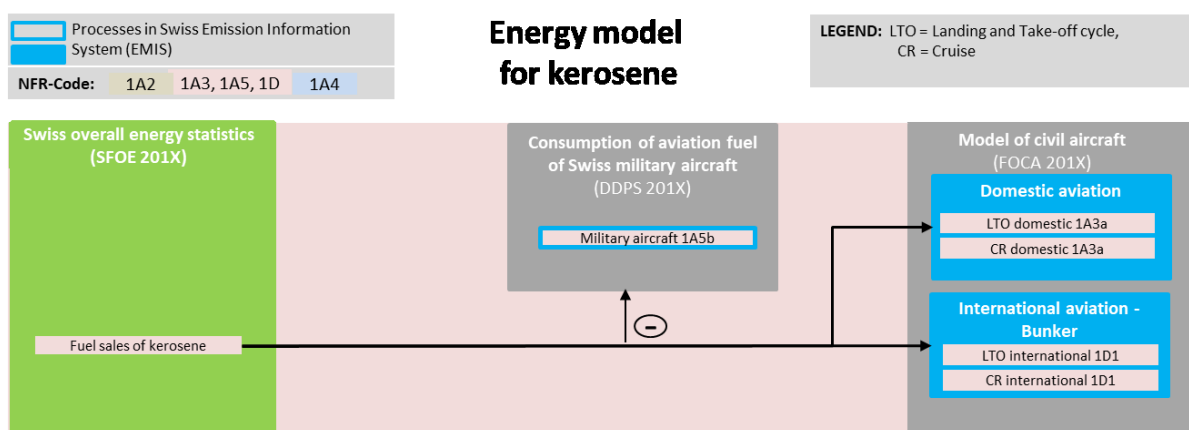


Figure 3-12 Schematic disaggregation of fuel consumption for kerosene. Fuel consumption for military aircraft is provided by the Federal Department of Defence, Civil Protection and Sport. The differentiation between domestic and international aviation as well as between CR and LTO is provided by the civil aviation model (see chp. 3.2.2.2.1).

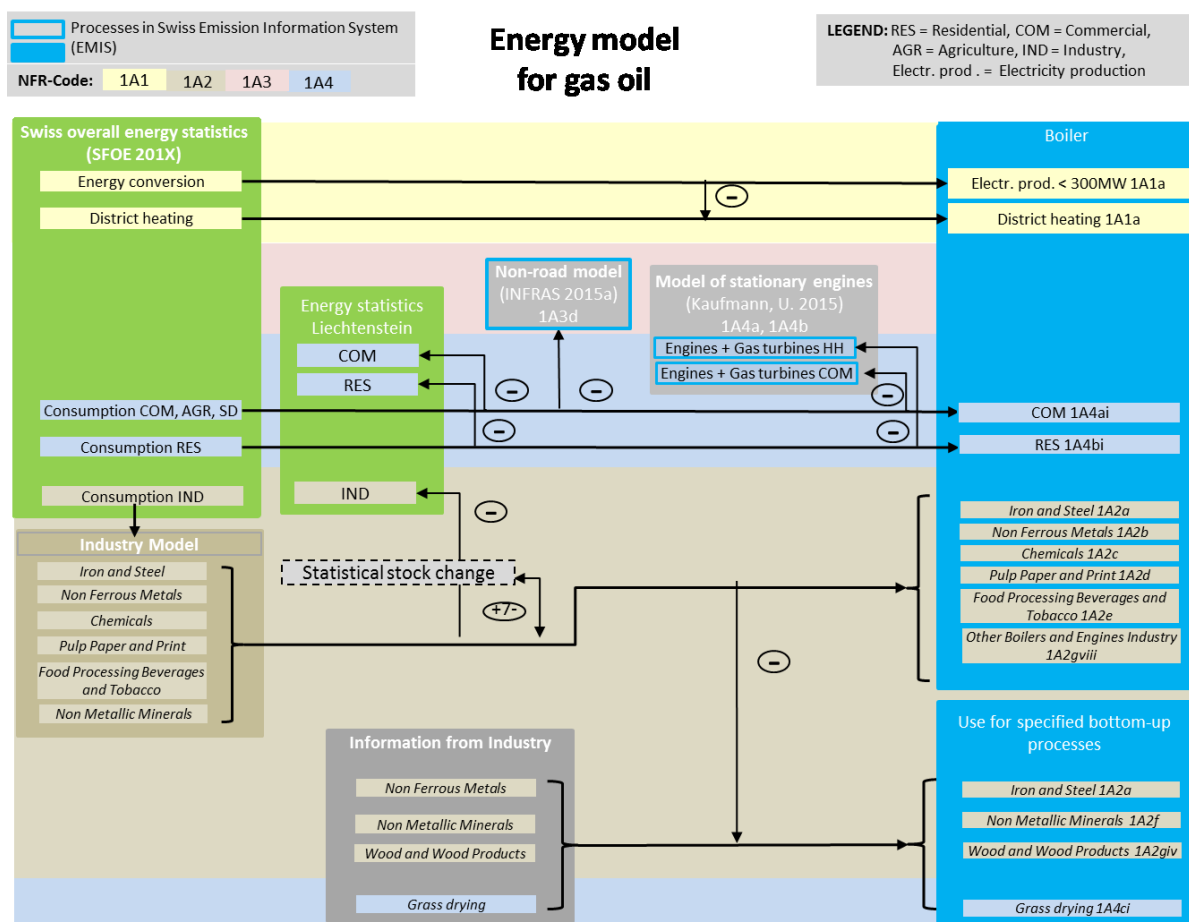


Figure 3-13 Schematic disaggregation of fuel consumption for gas oil. The Swiss overall energy statistics provides gas oil use for energy conversion and the amount thereof being used for district heating. Based on this information, gas oil use is split into 1A1a i Electricity generation and 1A1a iii Heat plants. According to the non-road model, a small amount of gas oil is consumed in source category 1A3d navigation (steam-powered vessels).

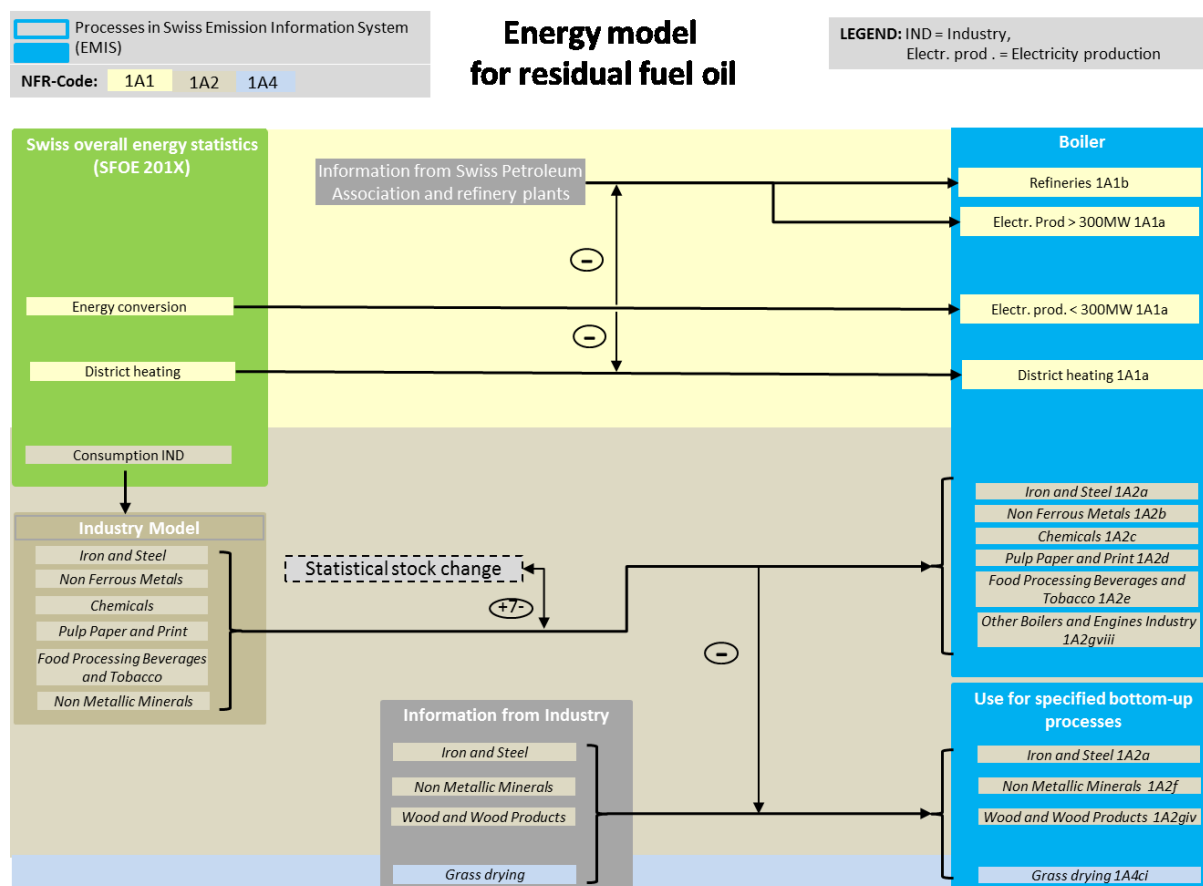


Figure 3-14 Schematic disaggregation of fuel consumption for residual fuel oil. The Swiss overall energy statistics reports residual fuel oil use in energy conversion and the amount thereof consumed in electricity production (one single fossil fuel power station, operational from 1985 to 1994), district heating, and in petroleum refineries. Based on this information, residual fuel oil use in Energy industries is split into 1A1a i Electricity generation, 1A1a iii Heat plants and 1A1b Petroleum refining.

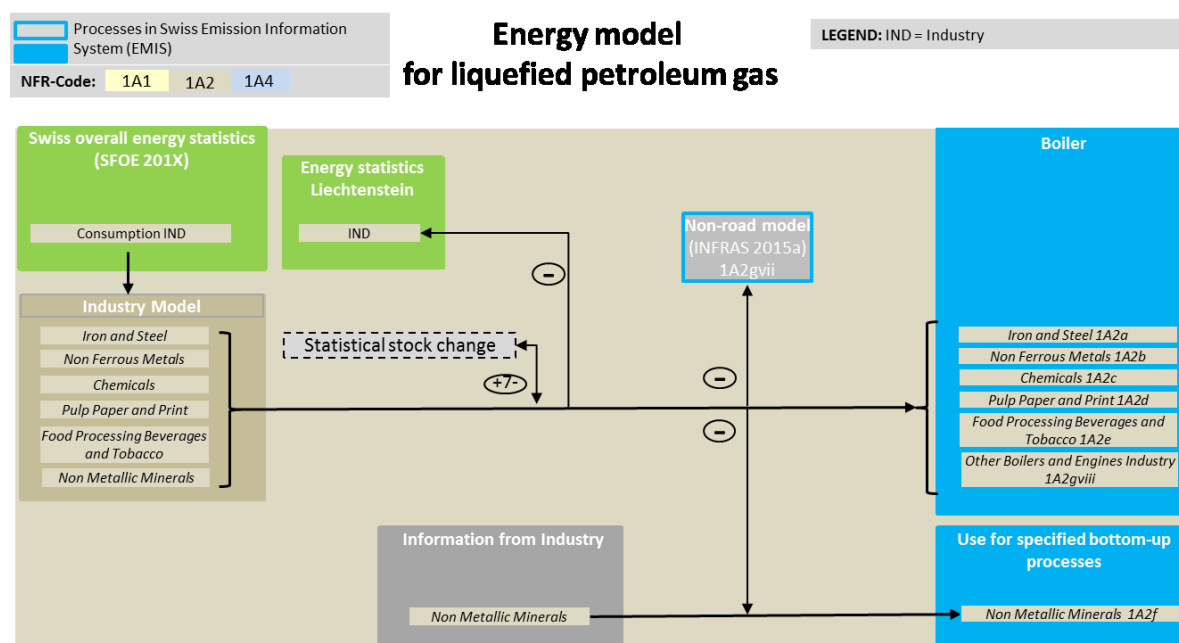


Figure 3-15 Schematic disaggregation of fuel consumption for liquefied petroleum gas (LPG).

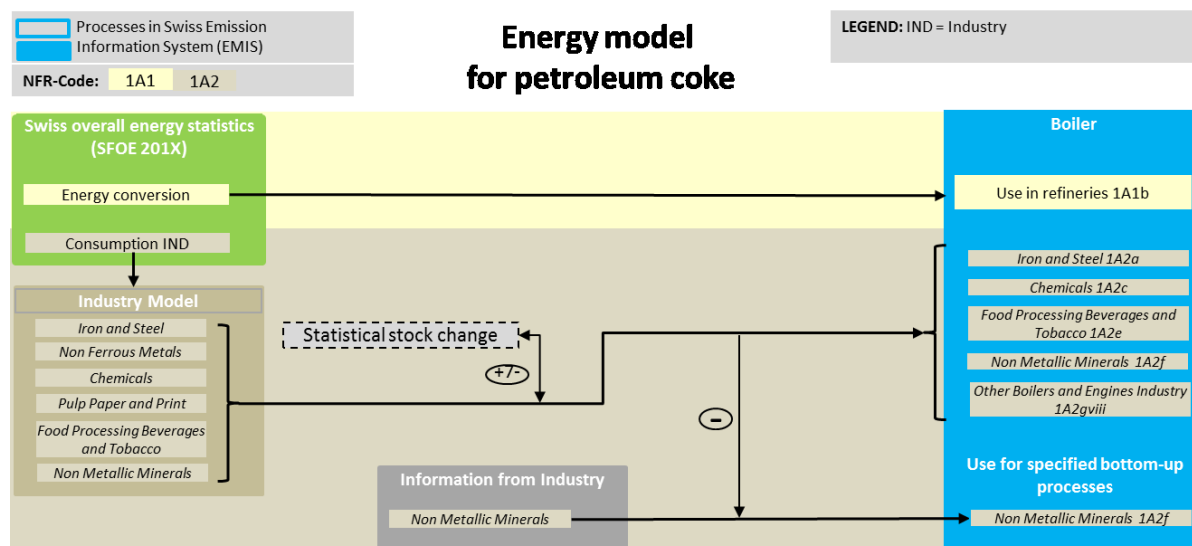


Figure 3-16 Schematic disaggregation of fuel consumption for petroleum coke.

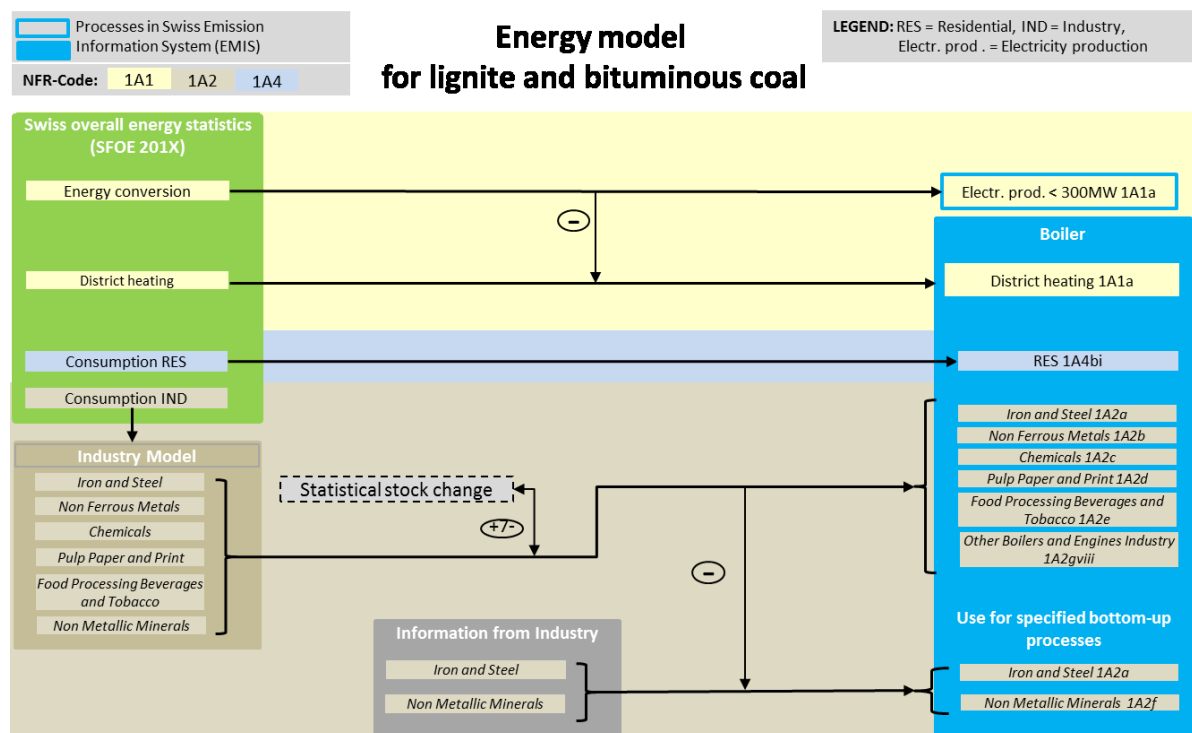


Figure 3-17 Schematic disaggregation of fuel consumption for lignite and bituminous coal. The Swiss overall energy statistics provides bituminous coal use for energy conversion and the amount thereof being used for district heating. Based on this information, use of bituminous coal in energy industries is split into 1A1a i Electricity generation and 1A1a iii Heat plants up to 1995. Coal consumption for Public electricity and heat production ceased thereafter.

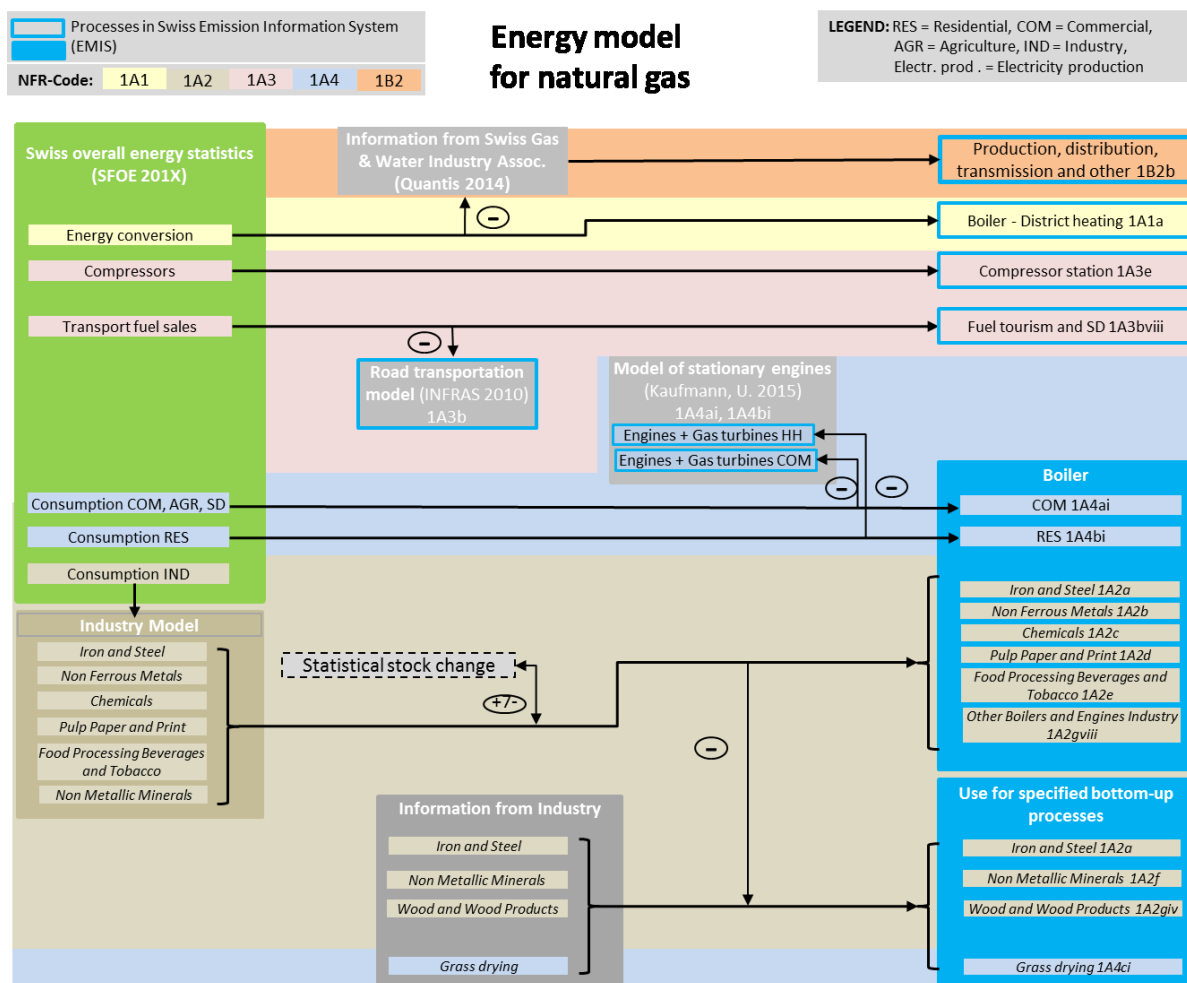


Figure 3-18 Schematic disaggregation of fuel consumption for natural gas. The Swiss overall energy statistics provides gas use in the transformation sector (energy conversion and distribution losses). Distribution losses as estimated by the Swiss Gas and Water Industry Association (SGWA) are subtracted and reported under source category 1B2 Fugitive emissions from fuels. The remaining fuel consumption for natural gas is reported under 1A1a Public electricity and heat production.

A corresponding Figure 3-18b is available in the confidential version of this chapter, providing more details.

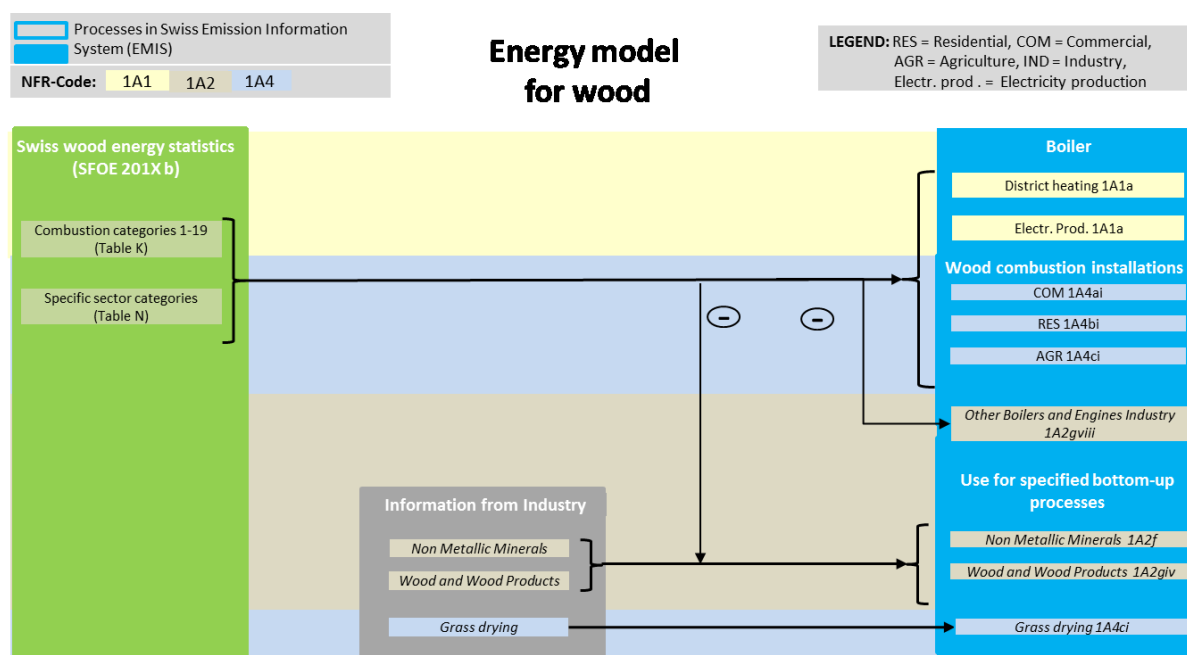


Figure 3-19 Schematic disaggregation of fuel consumption for wood (see chp. 3.2.4.5.2.)

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 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 CO₂ emissions from CO and NMVOC are implicitly reported as direct CO₂ emissions in sector 1A Energy and no indirect emissions are reported for sector 1A in chp. 9.

3.2.4.4.2 CO₂ emission factors for 1A Fuel combustion

General CO₂ emission factors

The CO₂ emission factors applied for the time series 1990–2017 are given in Table 3-12. 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 3-12 CO₂ 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	2013-2017
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 (2015d)	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

CO₂ emission factors for natural gas and biogas

Table 3-13 Time series of CO₂ 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
Fuel	CS/D	Data sources	t CO ₂ / TJ			
Natural gas/Biogas	CS	SGWA	56.1	55.7	56.2	56.4

CO ₂ emission factors			2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Fuel	CS/D	Data sources	t CO ₂ / TJ									
Natural gas/Biogas	CS	SGWA	56.5	56.5	56.5	56.6	56.5	56.4	56.5	56.4	56.4	56.3

CO₂ emission factors for wood

The CO₂ emission factor for wood combustion activities is taken from Cemsuisse (2010a).

3.2.4.4.3 CH₄ emission factors for 1A Fuel combustion

General CH₄ emission factors

An overview of the general CH₄ emission factors is given in Table 3-14. 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. For wood combustion, country-specific factors are used. Details are given below in Table 3-15. CH₄ emission factors related to transport activities (aviation, road and non-road transportation) are category-specific and given in the corresponding chapters.

Table 3-14 CH₄ emission factors for stationary combustion for the whole time period.

CH ₄ emission factors			1990-2017
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	Nussbaumer and Hälg (2015)	1.2 - 240

CH₄ emission factors for wood

There are many different combustion installations in use which have very different CH₄ emission factors. A detailed overview of all applied wood related CH₄ emission factors for the entire time series is given in Table 3-15.

The CH₄ emission factor for each combustion type is modelled based on VOC measurements at wood combustion installations (Nussbaumer and Hälg 2015), assuming a CH₄ to VOC ratio of 0.4.

The EF for the different combustion installations varies depending on the year, rated thermal input and technology used. The EF value 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 3-15 CH₄ emission factors for wood combustion installations.

1A Wood combustion	Unit	CH ₄			
		1990	1995	2000	2005
Open fireplaces	g/GJ	160	149	138	127
Closed fireplaces, log wood stoves	g/GJ	160	149	138	127
Pellet stoves	g/GJ	16	15	14	13
Log wood hearths	g/GJ	240	229	218	207
Log wood boilers	g/GJ	200	161	122	83
Log wood dual chamber boilers	g/GJ	240	229	218	207
Automatic chip boilers < 50 kW	g/GJ	20	17	13	10
Automatic pellet boilers < 50 kW	g/GJ	6.7	5.6	4.5	3.4
Automatic chip boilers 50-500 kW w/o wood proc. companies	g/GJ	20	16	13	8.9
Automatic pellet boilers 50-500 kW	g/GJ	6.7	5.4	4.1	2.8
Automatic chip boilers 50-500 kW within wood proc. companies	g/GJ	20	16	13	8.9
Automatic chip boilers > 500 kW w/o wood proc. companies	g/GJ	13	11	8.1	5.6
Automatic pellet boilers > 500 kW	g/GJ	6.7	5.4	4.1	2.8
Automatic chip boilers > 500 kW within wood proc. companies	g/GJ	13	11	8.1	5.6
Combined chip heat and power plants	g/GJ	13	11	8.1	5.6
Plants for renewable waste from wood products	g/GJ	13	11	8.1	5.6

1A Wood combustion	Unit	CH ₄									
		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Open fireplaces	g/GJ	120	120	120	120	120	120	120	119	118	117.1
Closed fireplaces, log wood stoves	g/GJ	120	117	113	110	107	103	100	98	96	94.3
Pellet stoves	g/GJ	12	12	12	12	12	12	12	12	11	10.9
Log wood hearths	g/GJ	200	193	187	180	173	167	160	157	154	151.4
Log wood boilers	g/GJ	60	58	57	55	53	52	50	49	47	45.7
Log wood dual chamber boilers	g/GJ	200	193	187	180	173	167	160	154	149	142.9
Automatic chip boilers < 50 kW	g/GJ	8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.7	7.5	7.2
Automatic pellet boilers < 50 kW	g/GJ	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.6	2.5	2.4
Automatic chip boilers 50-500 kW w/o wood proc. companies	g/GJ	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.5	6.3	6.0
Automatic pellet boilers 50-500 kW	g/GJ	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.9	1.9	1.8
Automatic chip boilers 50-500 kW within wood proc. companies	g/GJ	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.5	6.3	6.0
Automatic chip boilers > 500 kW w/o wood proc. companies	g/GJ	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.9	3.7	3.6
Automatic pellet boilers > 500 kW	g/GJ	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.9	1.8	1.8
Automatic chip boilers > 500 kW within wood proc. companies	g/GJ	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.9	3.7	3.6
Combined chip heat and power plants	g/GJ	4.0	3.6	3.1	2.7	2.2	1.8	1.3	1.3	1.2	1.2
Plants for renewable waste from wood products	g/GJ	4.0	3.6	3.1	2.7	2.2	1.8	1.3	1.3	1.2	1.2

3.2.4.4.4 N₂O emission factors for 1A Fuel combustion

Table 3-16 shows the general N₂O 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. N₂O emission factors related to transport activities (aviation, road and non-road transportation) are category-specific and given in the corresponding chapters.

Table 3-16 N₂O emission factors. Default emission factors are used for all fuels for the whole time period.

N ₂ O emission factors			1990-2017
Fuel	CS/D	Data sources	g N ₂ O / 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 CO₂, Fig. 3.4.1 in IPCC (2006)
- Tier 3 for railways CH₄, N₂O and precursors / SO₂, 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 and SO₂. Results are documented in FOEN (2015j). The non-road categories considered are listed in Table 3-17. All of them include several technologies (diesel oil, 2- or 4-stroke gasoline, LPG, gas oil), and emission standards according to the classification shown in Figure 3-20.

Table 3-17 Non-road categories as specified in FOEN (2015j) and the corresponding nomenclature in the 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 Residential, Off-road vehicles and other machinery
Agricultural machinery	1.A.4.c.ii Agriculture/forestry/fishing, Off-road vehicles and other machinery
Forestry machinery	1A.4.c.ii Agriculture/forestry/fishing, Off-road vehicles and other machinery
Military machinery (excl. aviation)	1.A.5.b Other, mobile, Military

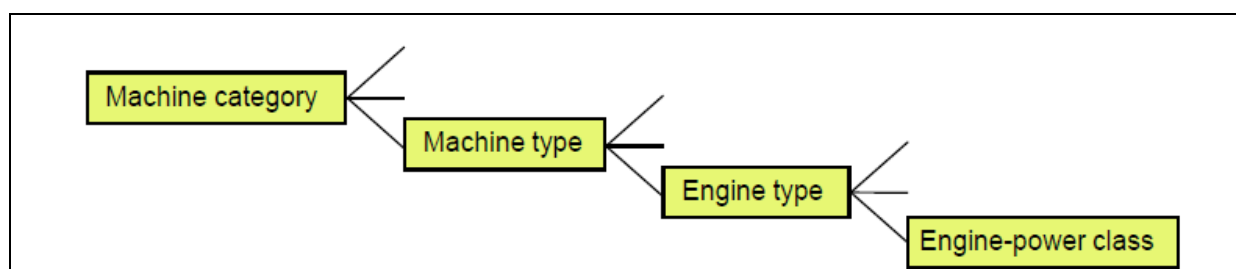


Figure 3-20 Each non-road vehicle is classified by its engine-power class, engine type, machine type and machine category (FOEN 2015j, INFRAS 2015a).

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)
λ	=	effective load factor (--)
ε	=	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 are calculated:

- GHG: CH₄, N₂O
- precursor gases: NO_x, CO
- air pollutant: VOC
- fuel consumption: in this case, ε represents the consumption instead of emission factor (in g/kWh)

For other gases, the following method is applied:

- CO₂ is calculated as product of fuel consumption and CO₂ emission factors (Table 3-12)
- SO₂ is calculated as product of fuel consumption and SO₂ emission factors (Table A – 13)
- NMVOC is calculated as the difference between VOC and CH₄
- CO₂ emissions from the use of lubricants as an additive in gasoline for 2-stroke engines are modelled separately and the corresponding CO₂ emissions from the lubricants are reported under 2D1 Lubricant use (chp. 4.5.2.1). Non-CO₂ 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, and machine types.

Emissions are only calculated in steps of 5 years 1980, 1985, 1990, ... 2050. Emissions for years in-between (1981, 1982 etc.) 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.

- CO₂ and SO₂ emission factors are country-specific, see Table 3-12 and Table A – 13.
- For other gases, the main data sources are EPA (2010), IFEU (2010), EMEP/EEA (2016) 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)⁴.

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 database of non-road vehicles (MOFIS) run by the 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 was developed like size distributions, modelling of the fleets, annual operating hours (age-dependent), load factors, year of placing on the market and age distribution. 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

⁴ <https://www.bafu.admin.ch/bafu/en/home/topics/air/state/non-road-datenbank.html>
[19.02.2019]

(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 Energy model for wood 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 2018b) provides both the annual wood consumption for specified categories of combustion installations (table K, categories 1-19, see Table 3-18), 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, 1A2gvi Other, 1A4ai Commercial/Institutional, 1A4bi Residential and 1A4ci Agriculture/forestry/fishing (EMIS 2019/1A Holzfeuerungen).

Table 3-18 Categories of wood combustion installations based on the Swiss wood energy statistics (SFOE 2018b).

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 50-500 kW w/o wood processing companies
Automatic pellet boilers 50-500 kW
Automatic chip boilers 50-500 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 CO₂, 3.2.4.4.3 for CH₄, and 3.2.4.4.4 for N₂O.

Activity data

Total activity data are based on the Swiss wood energy statistics (SFOE 2018b). 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 3-19 and EMIS 2019/1A Holzfeuerungen):

- Wood energy consumption in source categories 1A2f Brick and tile production, 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 3-19 Wood energy consumption in 1A Fuel combustion.

1A Wood combustion	Unit	1990	1995	2000	2005
Total	TJ	28'075	29'310	26'937	30'571
Open fireplaces	TJ	226	270	195	180
Closed fireplaces, log wood stoves	TJ	7'273	7'165	6'487	7'029
Pellet stoves	TJ	0	0	7	48
Log wood hearths	TJ	8'520	7'017	4'736	4'017
Log wood boilers	TJ	5'307	5'563	5'105	5'352
Log wood dual chamber boilers	TJ	1'964	1'777	977	479
Automatic chip boilers < 50 kW	TJ	239	433	550	753
Automatic pellet boilers < 50 kW	TJ	0	0	56	803
Automatic chip boilers 50-500 kW w/o wood proc. companies	TJ	687	1'323	1'774	2'665
Automatic pellet boilers 50-500 kW	TJ	0	0	2	93
Automatic chip boilers 50-500 kW within wood proc. companies	TJ	1'278	1'708	1'739	1'892
Automatic chip boilers > 500 kW w/o wood proc. companies	TJ	325	1'004	1'601	2'225
Automatic pellet boilers > 500 kW	TJ	0	0	0	9
Automatic chip boilers > 500 kW within wood proc. companies	TJ	1'277	1'987	2'177	2'461
Combined chip heat and power plants	TJ	0	3	186	127
Plants for renewable waste from wood products	TJ	979	1'060	1'345	2'439

1A Wood combustion	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Total	TJ	33'651	34'981	37'337	32'907	37'201	40'923	34'845	36'180	39'548	40'530
Open fireplaces	TJ	150	136	123	87	84	84	62	64	68	67
Closed fireplaces, log wood stoves	TJ	6'833	6'999	7'915	6'571	7'462	8'364	6'739	7'452	7'913	7'643
Pellet stoves	TJ	93	109	140	127	156	185	157	182	202	201
Log wood hearths	TJ	2'841	2'487	2'269	1'572	1'484	1'357	900	918	913	836
Log wood boilers	TJ	4'897	4'743	4'906	3'682	3'823	3'900	2'823	2'972	3'032	2'853
Log wood dual chamber boilers	TJ	339	288	272	194	190	182	125	119	112	88
Automatic chip boilers < 50 kW	TJ	834	860	1'008	799	867	946	740	787	798	742
Automatic pellet boilers < 50 kW	TJ	1'563	1'727	2'105	1'809	2'151	2'511	2'102	2'378	2'610	2'620
Automatic chip boilers 50-500 kW w/o wood proc. companies	TJ	3'179	3'240	3'724	3'197	3'755	4'251	3'491	4'017	4'403	4'391
Automatic pellet boilers 50-500 kW	TJ	359	429	534	509	622	727	696	875	1'050	1'175
Automatic chip boilers 50-500 kW within wood proc. companies	TJ	1'843	1'840	1'974	1'705	1'838	1'975	1'627	1'772	1'883	1'864
Automatic chip boilers > 500 kW w/o wood proc. companies	TJ	3'068	3'336	3'823	3'494	4'195	4'799	4'151	4'849	5'427	5'578
Automatic pellet boilers > 500 kW	TJ	80	84	92	139	161	191	181	203	236	233
Automatic chip boilers > 500 kW within wood proc. companies	TJ	2'340	2'348	2'626	2'244	2'399	2'562	2'120	2'236	2'345	2'241
Combined chip heat and power plants	TJ	2'467	3'422	2'756	3'900	5'010	5'421	5'325	3'792	3'936	4'858
Plants for renewable waste from wood products	TJ	2'764	2'933	3'070	2'878	3'005	3'468	3'607	3'564	4'621	5'140

3.2.4.6 Emissions from biomass (memo item)

CO₂ emissions from biomass do not count for the national total emissions and therefore are a memo item only. The CO₂ emissions from biomass as reported in the reporting tables are incomplete as the following CO₂ emissions 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 and 5D Wastewater treatment and discharge.

Table 3-20 provides an overview of latest effective CO₂ emissions from biomass and their reporting in the reporting tables (without land use, land-use change and forestry). For further information on the CO₂ emissions from biomass refer to the chapters of the respective source categories.

Table 3-20 Effective biomass CO₂ emissions in 2017 and their representation in the reporting tables.

Biomass CO ₂ emissions	Unit	2017	Note
1A1 Energy industries (without MSW incineration)	kt	401	Included in CRF
1A1 Energy generation from MSW Incineration	kt	2'287	Included in CRF
1A2 Manufacturing industries and construction	kt	1'464	Included in CRF
thereof use of waste derived fuels in cement production	kt	62	
thereof use of bio fuels (1A2gvii)	kt	15	
1A3 Transport	kt	340	Included in CRF
1A4 Other sectors (Commercial/institutional, residential)	kt	2'937	Included in CRF
1A5 Other	kt	0.46	Included in CRF
2H2 Food and beverages industry	kt	15	Not included in CRF
2G Other product use (Consumption of tobacco)	kt	11	Not included in CRF
5A Solid waste disposal on land	kt	42	Not included in CRF
5B Biological treatment of waste (composting and anaerobic digestion)	kt	177	Not included in CRF
5C Waste incineration (without MSW incineration)	kt	153	Included in CRF
5D Wastewater handling	kt	4	Not included in CRF
Total biomass combustion CO ₂ emissions included in CRF	kt	7'582	
Total energy related biomass combustion CO ₂ emissions included in CRF 1A	kt	7'429	See table "Summary 2" in CRF
Total biomass CO ₂ emissions in Switzerland in 2017	kt	7'831	

3.2.4.7 Uncertainty and time series consistency for source category 1A

Basic uncertainties of AD and EF CO₂ by fuel type

Table 3-21 Uncertainties of activity data, CO₂ emission factors and CO₂ 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	0.07	0.88
liquid fuels	0.69	0.08	0.69
solid fuels	5.00	5.06	7.12
gaseous fuels	5.00	0.99	5.10
other fuels	5.00	9.22	10.5
biomass	10.0	--	--

Liquid fuels

Uncertainty of the CO₂ emission factors: In 2013, a large measurement campaign was carried out to determine the CO₂ 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 3-22 as lower and upper values as well as relative uncertainties.

For mobile combustion, the 2006 IPCC Guidelines provide default uncertainties for the CO₂ 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 CO₂ 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 3-22 Uncertainties of aggregated results of measurements of the CO₂ 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 3-23 are based on a written message of SFOE to FOEN (SFOE 2012a). It lists two kinds of relevant sources of errors: errors of measurements and errors of the conversion from mass to energy units. For gasoline and diesel oil, the transformation of products represents a third source of errors. All these errors are multiplicative, therefore the relative uncertainties have to be summed up.

Table 3-23 Sources of errors contributing to the total uncertainty of the activity data of selected liquid fuels (SFOE 2012a).

Source of uncertainty	kerosene	gasoline	diesel oil	gas oil
	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%
Production transformation	0.00%	0.00%	0.20%	0.00%
Total Uncertainty	0.96%	0.69%	0.88%	0.69%

Gaseous fuels

Uncertainty of the CO₂ emission factor: The composition of the imported gas is analysed in detail at the import stations. From this information, the FOEN annually calculates the CO₂ 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 1.96 to extend the standard deviation to 95% uncertainty interval. This calculation has been carried out for 15 years within the period 1990 to 2017. The uncertainties fluctuate between 0.29% and 1.48% with a mean of 0.95%, which is used as the uncertainty of the CO₂ emission factor for gaseous fuels.

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 CO₂ 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 (medium 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 CO₂ emission factor: There are two factors influencing the uncertainty of CO₂ emissions from municipal solid waste incineration (1A1), 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 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). A field application of the radio carbon (¹⁴C) method was applied to calculate the ratio of biogenic versus fossil CO₂ emissions from five waste-to-energy plants. Gas samples for ¹⁴CO₂ analysis were taken at the plants during miscellaneous seasons. Six measuring campaigns of three weeks were carried out for three plants and three campaigns, again of three weeks, were carried out for two plants, leading to a total measurement time of 72 weeks. The campaigns provided a mean and 95% confidence interval of the biogenic fraction of 52.3%±3.8% (Table 3-24). The relative uncertainty was thus 7.1%. The results fit well to a former measurement campaign on three plants, which yielded 52.0%±3.7% for the biogenic fraction (Mohn et al. 2008). For the uncertainty analysis the latest result is used (Mohn et al. 2011).
- The emission factor for fossil CO₂ results from the multiplication of the carbon content and the fossil fraction. The uncertainty of the CO₂ emission factor is thus the addition of the corresponding uncertainties by error propagation: $[(5.9\%)^2 + (3.8\%)^2]^{0.5} = 7.0\%$.

Table 3-24 Fossil and biogenic fractions of municipal solid waste measured at five different incineration plants.

Plant	Shares		Uncertainty		Measurement campaigns (duration) weeks
	fossil	biogenic	absolute	relative	
	%	%	%	%	
Buchs	47.7	52.3	3.6	7.5	6 * 3 = 18
Winterthur	43.4	56.6	3.9	9.0	6 * 3 = 18
Linthgebiet	50.6	49.4	3.4	6.7	6 * 3 = 18
Linthgebiet	54.5	45.5	3.1	5.7	3 * 3 = 9
Zuchwil	45.9	54.1	3.7	8.1	3 * 3 = 9
Median / sum	47.7	52.3	1.8	3.8	72

Uncertainty of activity data: There is no country-specific estimate of the uncertainty for the consumption 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 $\pm 5\%$ for most developed countries.” In accordance with that statement, the value of 5% is used.

Biomass

Uncertainty of the CO₂ emission factor: For CO₂ 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). About 80% of the CO₂ emissions from biomass burning stem from industrial, institutional and residential (without fireplaces) combustion and about 20% from open and closed fireplaces (see Table 3-19). An average uncertainty of 10% is applied for biomass burning in all source categories.

Uncertainty of CH₄ and N₂O emission factors

Since the CO₂ emissions vastly dominate the GHG emissions of source category 1A (almost 99%), the uncertainty evaluation of the non-CO₂ emissions is carried out on a semi-quantitative level (see Table 3-25).

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 (current version see INFRAS 2017a), the uncertainties for the CH₄ and N₂O emission factors have been determined (see rows 1A3b gasoline and diesel oil in Table 3-25). The uncertainties of CH₄ and N₂O emissions of CNG (1A3b), which were not investigated in IFEU/INFRAS (2009), have been estimated qualitatively as “medium” according to Table 1-10. For **1A1, 1A2, 1A3a, 1A3c, 1A3d, 1A3e, 1A4a, 1A4b, 1A4c, 1A5** the uncertainties of CH₄ and N₂O emissions have similarly been estimated qualitatively (see Table 3-25).

Summary

Table 3-25 provides a summary of the uncertainties of 1A Fuel combustion as derived in the preceding sections. The uncertainty of the CO₂ emissions (“combined uncertainty”) are calculated from the uncertainties of the activity data and the emission factors by Approach 1 error propagation.

Table 3-25 Uncertainties of 1A Fuel combustion categories for activity data, emission factors and combined uncertainties. The latter are calculated by 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”⁵ from the combined and the activity data uncertainty. CH₄ and N₂O: semi-quantitative uncertainties are used (see Table 1-10).

1A Fuel Combustion Categories	Fuel type	Uncertainties				
		Activity data	CO ₂ em. factors	CO ₂ emissions	CH ₄ emissions	N ₂ O emissions
		%	%	%	--	--
1. Energy industries	liquid fuels	0.7	0.1	0.7	medium	medium
1. Energy industries	solid fuels	5.0	5.1	7.1	medium	medium
1. Energy industries	gaseous fuels	5.0	1.0	5.1	medium	medium
1. Energy industries	other fuels	5.0	9.2	10.5	medium	medium
2. Manufacturing industries and construction	liquid fuels	0.7	0.1	0.7	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	1.0	5.1	medium	medium
2. Manufacturing industries and construction	other fuels	5.0	9.2	10.5	medium	medium
3a. Transport; Domestic aviation	kerosene	1.0	0.2	1.0	high	high
3b. Transport; Road transportation	gasoline	0.7	0.1	0.7	37.0	50.0
3b. Transport; Road transportation	diesel oil	0.9	0.1	0.9	20.0	22.0
3b. Transport; Road transportation	gaseous fuels	5.0	1.0	5.1	medium	medium
3c. Transport; Railways	diesel oil	0.9	0.1	0.9	medium	medium
3d. Transport; Domestic navigation	liquid fuels	0.7	0.1	0.7	medium	high
3e. Transport; Other transportation	gaseous fuels	5.0	1.0	5.1	medium	medium
4a. Other sectors; Commercial/institutional	liquid fuels	0.7	0.1	0.7	medium	medium
4a. Other sectors; Commercial/institutional	gaseous fuels	5.0	1.0	5.1	medium	medium
4b. Other sectors; Residential	liquid fuels	0.7	0.1	0.7	medium	medium
4b. Other sectors; Residential	solid fuels	5.0	5.1	7.1	medium	medium
4b. Other sectors; Residential	gaseous fuels	5.0	1.0	5.1	medium	medium
4c. Other sectors; Agriculture/forestry/fishing	liquid fuels	0.7	0.1	0.7	medium	medium
4c. Other sectors; Agriculture/forestry/fishing	gaseous fuels	5.0	1.0	5.1	medium	medium
5. Other	liquid fuels	0.7	0.1	0.7	medium	high
1A Stationary sources	biomass	10.0	--	--	medium	medium
1A Mobile sources	biomass	10.0	--	--	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.

⁵ $U(EF) = \sqrt{U(EM)^2 - U(AD)^2}$

Comparison of emission estimates using different approaches

At the level of total energy-related CO₂ 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 2018). The differences in total CO₂ 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 2018) 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 CO₂ 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 CO₂ emission factors compare well with the IPCC default values (see Table 3-26).

Table 3-26 Comparison of default CO₂ 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

The CO₂ emission factor for gasoline is higher than the upper limit of the IPCC range. However, as the value from earlier measurements was confirmed and the new value is based on more than 100 fuel samples taken from July to December 2013, the value is considered to correctly represent national circumstances.

For natural gas, the CO₂ emission factor is annually assessed. A country-specific CO₂ 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 CO₂ EF used by the countries from which gas is imported: Germany (IEF: 55.5–56.0 t CO₂/TJ), the Netherlands (IEF: 56.5–56.8 t CO₂/TJ), Norway (IEF: 56.1 t CO₂/TJ), France (IEF: 56.0–57.0 t CO₂/TJ), Italy (IEF: 55.3 to 56.9 t CO₂/TJ) and Denmark (IEF: 56.9–57.5 t CO₂/TJ). It also lies within the range given by the IPCC (lower 54.3 t CO₂/TJ, upper 58.3 t CO₂/TJ, compared to the country-specific value of 56.3 t CO₂/TJ for 2017).

The CH₄ emission factors from combustion of wood were scrutinized and revised based on Nussbaumer and Hälgl (2015). The range of country-specific values is not entirely consistent with the upper and lower IPCC default values (Table 3-27). However, as the country-specific emission factors are based on an extensive measurement campaign, they are considered representative for Swiss circumstances.

Table 3-27 Comparison of default CH₄ emission factors from the 2006 IPCC Guidelines (IPCC 2006) with country-specific values.

CH ₄ emission factors	IPCC 2006			Switzerland
	lower	upper	default	CS
	kg CH ₄ /TJ			kg CH ₄ /TJ
Gas oil	10	100	30	1.3 - 240

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 3-28 Key categories of 1A1 Energy industries. Combined KCA results, level for 2017 and trend for 1990–2017, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
1A1	Energy industries: Gaseous fuels	CO ₂	L1, T1
1A1	Energy industries: Liquid fuels	CO ₂	L1, T1
1A1	Energy industries: Other fuels	CO ₂	L1, L2, T1, 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 is 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 2018). Emissions from industries producing heat and/or electricity (CHP) for their own use are included in category 1A2 Manufacturing Industries and Construction.

Table 3-29 Specification of source category 1A1 Energy Industries.

1A1	Source	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. Emissions of SO ₂ from Claus units in refineries.
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 3-30). 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 3-30 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 CO₂ 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 CH₄ emissions, a Tier 1 method was applied (using IPCC default emission factors), except for biomass, where country-specific emission factors are used. For N₂O IPCC default values are used (Tier 1), except for municipal solid waste and special waste incineration plants, where country-specific emission factors were used.

Emission factors (1A1a)

Table 3-31 presents the emission factors used in 1A1a. Emission factors for gas oil and natural gas (highlighted green in Table 3-31) are further explained in chp. 3.2.4.4.

Table 3-31 Emission factors for 1A1a Public Electricity and Heat Production in 2017.

1A1a Public electricity and heat production	CO ₂	CO ₂ bio.	CH ₄	N ₂ O	NO _x	NM VOC	SO ₂	CO
	t/TJ	t/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ
Gas oil	73.7	NA	3.0	0.6	33	2	9	6.3
Residual fuel oil	NO	NA	NO	NO	NO	NO	NO	NO
Petroleum coke	NO	NA	NO	NO	NO	NO	NO	NO
Natural gas	56.3	NA	1.0	0.1	18	2	0.5	10
Other (waste-to-energy), fossil	88.9	NA	NE	1.4	32	2.4	3.6	8.3
Other (waste-to-energy), biogenic	NA	91.9	NE	1.4				
Biomass (wood, renewable waste)	NA	99.9	1.2	4.0	114	2	12	93
Biogas (co-generation from landfills)	NA	56.3	20.0	0.1	131	NE	NE	219

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 CO₂, NO_x, CO, NM VOC and SO₂ are country-specific and based on measurements and expert estimates. Emission factors for CH₄ and N₂O are IPCC default values, with the exception of waste and biomass as fuel, where country specific emission factors are applied. Emission factors are documented in EMIS 2019/1A1a Kehrichtverbrennungsanlagen, EMIS 2019/1A1a Sondermüllverbrennungsanlagen and EMIS 2019/1A1a Kehrichtdeponien.

Source-specific CO₂ emission factors for municipal solid waste incineration plants

C-content of waste is calculated based on the net calorific value (NCV), which is deduced by a standard method and published on a yearly basis since 2009 by SFOE for each municipal solid waste incineration plant (MSWIP) and as a Swiss average (FOEN/SFOE/VBSA, 2018). In deviation from the general description of oxidation factors in 3.2.4.4.1, an oxidation factor of 0.99 is assumed here. The assumption is based on measurements in two MSWIPs in Zurich (AWEL 2009) and on a study in Austria (Zeschmar-Lahl 2004), where the MSWIP 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 MSWIP 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 (¹⁴C) in the flue gas for calibration have been made (Mohn et al. 2011). The CO₂ emission factor in MSWIPs fluctuates over the reporting period because of gradual changes in the net calorific values of the waste (Table 3-32).

Table 3-32 Emission factor CO₂ total, share of CO₂ 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
CO ₂ total (MSWIP)	t/TJ	92.80	91.86	91.09	91.49
Share of CO ₂ fossil (MSWIP)	1	0.497	0.505	0.513	0.505
NCV of waste (MSWIP)	TJ/t	0.0114	0.0119	0.0124	0.0121

1A1a Public electricity and heat production, Other fossil fuels	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
CO ₂ total (MSWIP)	t/TJ	92.20	92.50	92.32	92.25	92.62	92.76	92.43	92.28	92.01	91.92
Share of CO ₂ fossil (MSWIP)	1	0.493	0.489	0.486	0.482	0.478	0.478	0.478	0.478	0.478	0.478
NCV of waste (MSWIP)	TJ/t	0.0117	0.0116	0.0117	0.0117	0.0115	0.0114	0.0116	0.0117	0.0118	0.0119

Sodium bicarbonate and calcium carbonate are used in MSWIP 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 CO₂ 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 CO₂/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 2019/1A1a Sondermüllverbrennungsanlagen.

Source-specific CH₄ emission factors in municipal and special waste incineration plants

Emissions of CH₄ 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 N₂O and CH₄ emission factors for MSWIP (Mohn 2013). In this study, EMPA evaluated measurements that were performed in 2011 in five Swiss MSWIP with different Denox techniques (SCR, SNCR). For most of the measurements, CH₄ concentrations were below the detection limit of 0.3 ppm. The study concluded that "CH₄ emission concentrations were very low and below the background concentration of 1.8 ppm". CH₄ emissions are considered to be negligible for municipal waste incineration and are therefore reported as not estimated because they are considered insignificant. The same fact applies for special waste incineration.

Source-specific N₂O emission factors for municipal solid waste incineration

In 2013, a study evaluated N₂O 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 and 2016, weighted average N₂O emission factors have been calculated, based on the amounts of waste burnt in every plant. For the years in between, the N₂O emission factors were linearly interpolated. Since 2016, 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 N₂O emissions factors periodically, depending on data available; see documentation in EMIS 2019/1A1a Kehricht- und Sondermüllverbrennungsanlagen. The emission factor is therefore not constant over time.

Source-specific N₂O 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 3-33 N₂O emission factors of 1A1a Municipal solid (MSWIP) and special waste incineration (SWIP).

1A1a Public electricity and heat production, Other fossil fuels	Unit	1990	1995	2000	2005
N ₂ O (MSWIP)	kg/TJ	5.26	2.96	2.06	1.44
N ₂ O (SWIP)	kg/TJ	3.06	4.23	5.41	5.48

1A1a Public electricity and heat production, Other fossil fuels	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
N ₂ O (MSWIP)	kg/TJ	1.38	1.41	1.40	1.40	1.43	1.44	1.42	1.41	1.39	1.38
N ₂ O (SWIP)	kg/TJ	4.53	4.21	3.89	3.57	3.25	2.94	2.62	2.30	1.98	1.67

Activity data (1A1a)

Activity data for liquid, gaseous, solid fuels and wood are based on the Swiss overall energy statistics (SFOE 2018) and additional data sources as described in 3.2.4.3. Activity data for Other fuels are based on the amount of waste incinerated in MSWIPs and special waste incineration plants (SWIPs) (FOEN 2018i, see Table 3-35). Activity data for combined heat and power generation in landfills are taken from the Swiss renewable energy statistics (SFOE 2018a).

Please note that waste-to-energy activities in CRF Table 1.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 3-34 Activity data in 1A1a Public Electricity and Heat Production.

1A1a Public electricity and heat production	Unit	1990	1995	2000	2005
Total fuel consumption	TJ	40'359	39'141	49'875	56'959
Gas oil	TJ	980	554	790	1'300
Residual fuel oil	TJ	3'214	1'813	340	290
Petroleum coke	TJ	NO	NO	NO	NO
Other bituminous coal	TJ	530	46	NO	NO
Lignite	TJ	NO	NO	NO	NO
Natural gas	TJ	4'339	5'422	8'292	9'827
Other (waste-to-energy), fossil	TJ	16'605	16'870	22'482	24'711
Biomass	TJ	14'691	14'436	17'970	20'832
Other (waste-to-energy), biogenic	TJ	14'163	13'394	16'889	19'797
Biomass (wood, renewable waste)	TJ	301	466	547	844
Biogas (co-generation from landfills)	TJ	227	576	535	191

1A1a Public electricity and heat production	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Total fuel consumption	TJ	58'876	57'792	61'746	59'792	63'398	63'331	59'363	61'359	65'025	64'757
Gas oil	TJ	490	540	500	400	800	670	780	660	440	500
Residual fuel oil	TJ	180	130	40	10	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	8'468	8'073	9'926	7'512	8'213	8'449	5'072	7'060	8'956	7'927
Other (waste-to-energy), fossil	TJ	25'880	24'853	26'002	25'575	26'262	25'738	26'049	26'832	27'657	27'430
Biomass	TJ	23'859	24'196	25'277	26'295	28'123	28'473	27'461	26'807	27'972	28'899
Other (waste-to-energy), biogenic	TJ	21'464	21'249	22'275	22'272	23'051	22'489	23'112	23'716	24'765	24'886
Biomass (wood, renewable waste)	TJ	2'312	2'877	2'958	3'983	5'032	5'949	4'321	3'071	3'196	4'005
Biogas (co-generation from landfills)	TJ	83	70	45	40	40	35	28	19	11	8

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 1990ies.

Municipal solid waste incineration and special waste incineration

Figure 7-4 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 3-35 is the total amount of waste burned (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 3-35 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 burned.

1A1a iv Public electricity and heat production, Other	Unit	1990	1995	2000	2005
Total fuels	TJ	30'768	30'264	39'371	44'508
Municipal solid waste fossil	TJ	13'995	13'664	17'790	20'197
Municipal solid waste biogenic	TJ	14'163	13'394	16'889	19'797
Special waste	TJ	2'610	3'206	4'692	4'514
Total waste	kt	2'603	2'433	3'040	3'527
Municipal solid waste (fossil and biogenic)	kt	2'470	2'270	2'801	3'297
Special waste	kt	133	163	239	230

1A1a iv Public electricity and heat production, Other	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Total fuels	TJ	47'344	46'102	48'277	47'847	49'313	48'228	49'161	50'548	52'422	52'316
Municipal solid waste fossil	TJ	20'871	20'334	21'062	20'724	21'108	20'593	21'163	21'717	22'678	22'789
Municipal solid waste biogenic	TJ	21'464	21'249	22'275	22'272	23'051	22'489	23'112	23'716	24'765	24'886
Special waste	TJ	5'009	4'519	4'941	4'851	5'155	5'145	4'886	5'115	4'979	4'641
Total waste	kt	3'865	3'827	3'968	3'924	4'104	4'035	4'066	4'150	4'264	4'248
Municipal solid waste (fossil and biogenic)	kt	3'610	3'597	3'717	3'676	3'841	3'773	3'817	3'889	4'010	4'011
Special waste	kt	255	230	252	247	263	262	249	261	254	236

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 Guidelines 2006, vol.2, chp. 2), Switzerland applies a Tier 3 approach with country-specific emission factors for CO₂ emissions. The calculations are based on measurements and data from the refining industry as documented in the EMIS database (EMIS 2019/1A1b Heizkessel Raffinerien).

Emission factors (1A1b)

CO₂ 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 2013–2017 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 CO₂ 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 CO₂ emission factor of refinery gas is higher than the IPCC default value.

Table 3-36 Emission factors for 1A1b Petroleum refining in 2016.

1A1b Petroleum refining	CO ₂ t/TJ	CH ₄ kg/TJ	N ₂ O kg/TJ	NO _x kg/TJ	NMVOC kg/TJ	SO ₂ kg/TJ	CO kg/TJ
Residual fuel oil	C	C	C	C	C	C	C
Refinery gas	C	C	C	C	C	C	C
Petroleum coke	NO	NO	NO	NO	NO	NO	NO
Natural gas	C	C	C	C	C	C	C

Activity data (1A1b)

Activity data on fuel combustion for petroleum refining (1A1b) is provided by the Swiss overall energy statistics (SFOE 2018) 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 2018).

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).

Table 3-37 Activity data for 1A1b Petroleum refining.

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

1A1b Petroleum refining	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Total fuel consumption	TJ	15'118	14'473	14'176	13'169	11'242	13'834	14'173	7'232	6'355	6'298
Residual fuel oil	TJ	692	733	891	764	1'212	1'094	C	C	C	C
Refinery gas	TJ	11'978	11'706	11'282	10'720	8'249	11'055	C	C	C	C
Petroleum coke	TJ	2'449	2'035	2'003	1'685	1'781	1'685	C	C	NO	NO
Natural gas	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	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 Guidelines 2006, vol.2, chp. 2), emissions are estimated using a Tier 2 approach.

Emission factors (1A1c)

The CO₂ emission factor is based on literature (USEPA 1995) and CH₄, NO_x, CO and NMVOC emission factors are taken from the revised 1996 IPCC Guidelines (EMIS 2019/1A1c).

Table 3-38 Emission factors for 1A1c Manufacture of Solid Fuels and other energy industries in 2017. The CO₂ emission factor refers to CO₂ of biogenic origin.

1A1c Charcoal	Unit	CO ₂ biog.	CH ₄	NO _x	NMVOC	SO ₂	CO
Charcoal production	kg/TJ	16'900	1'000	10	1'700	NA	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 2019/1A1c. 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 3-39 Activity data for 1A1c Manufacture of Solid Fuels and other energy industries.

1A1c Charcoal	Unit	1990	1995	2000	2005
Charcoal production	TJ	1.25	1.43	2.20	3.37

1A1c Charcoal	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Charcoal production	TJ	3.64	3.60	3.30	3.42	3.73	2.94	3.94	3.43	3.90	3.76

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 2019. Major recalculations, which contribute significantly to the total differences in GHG emissions of sector 3 Energy between the latest and the previous submission are presented also in chp. 10.1.2.1.

- 1A1a: Activity data for natural gas in sector 1A1a has changed due to recalculation in gas losses of 1B2b for the year 2016.
- 1A1a: Activity data (wood, wood waste) of all wood combustion installations have been revised for 2014-2016 due to recalculations in the Swiss wood energy statistics (SFOE 2018b).
- 1A1a: Emissions from biogas usage in engines or boilers of gas produced by digestion in agricultural and industrial biogas plants were reported in source category 1A1a as well as 1A2gviii / 1A4ai. This led to a double counting of emissions. The processes for agricultural and industrial digestion have now been removed from source category 1A1a and are only reported in 1A2gviii and 1A4ai. This leads to a decrease of activity data and emissions for the years 1990-2016 in 1A1a.
- 1A1c: Activity data of 1A1c Charcoal production has been updated due to production figures from an additional charcoal pile for 2006–2016.

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 3-40 Key categories of 1A2 Manufacturing industries and construction. Combined KCA results, level for 2017 and trend for 1990–2017, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
1A2	Manufacturing industries and construction: Gaseous fuels	CO ₂	L1, L2, T1, T2
1A2	Manufacturing industries and construction: Liquid fuels	CO ₂	L1, T1
1A2	Manufacturing industries and construction: Other fuels	CO ₂	L1, T1
1A2	Manufacturing industries and construction: Solid fuels	CO ₂	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 CO₂ emissions of 1A2 from Liquid Fuels are dominated by the stationary sources, however, 36% (2017) of the CO₂ 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 Table 1.A(d) and described in chp. 3.2.3.

Table 3-41 Specification of source category 1A2 Manufacturing industries and construction in Switzerland.

1A2	Source	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, nitric acid, 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 CO₂ 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 and heating gas) 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, CH₄ emissions are calculated by a Tier 2 approach using country-specific emission factors. For CH₄ 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 N₂O 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.

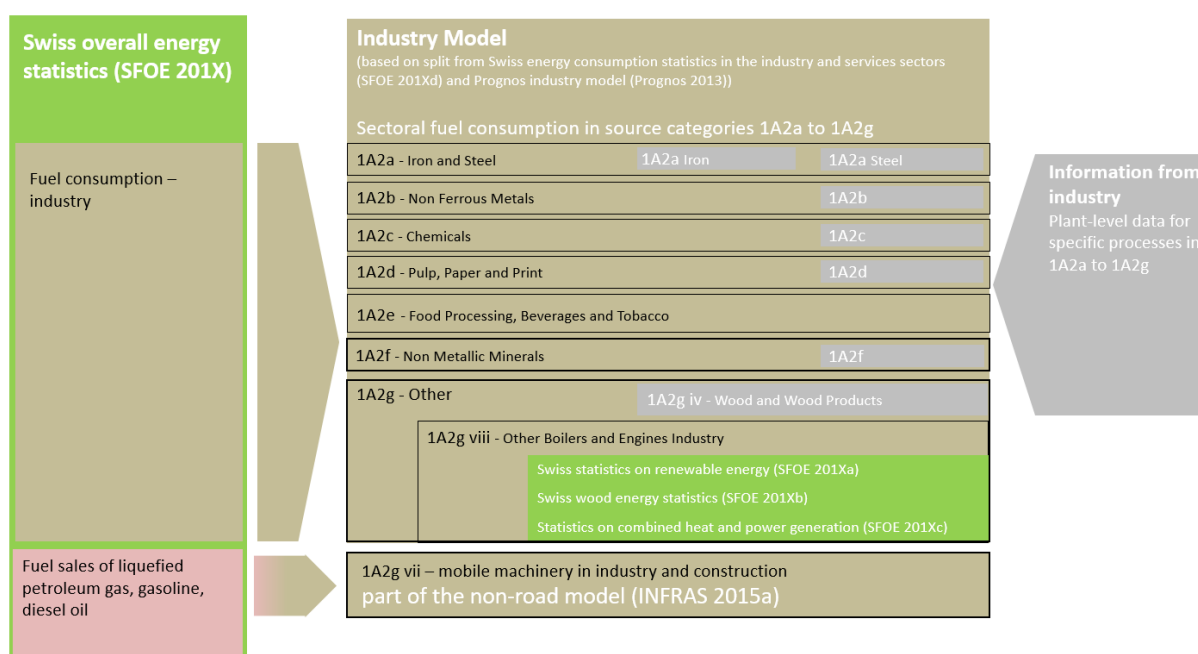


Figure 3-21 Schematic presentation of the data sources used for the industrial sectors 1A2a–1A2g. The references SFOE 201X, 201Xa, 201Xb and 201Xc refer to the 2018 edition of the corresponding energy statistics. For each fuel type, the Swiss overall energy statistics provide the total consumption for industry. The total consumption is then distributed to the different source categories based on information from industry surveys (SFOE 2018d) 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 2018, 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 2018d). 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 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 2018c).

Energy consumption statistics in the industry and services sectors

The energy consumption statistics in the industry and services sectors (SFOE 2018d) refer to representative surveys with about 12'000 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 old (1990–2012) and new (since 2013) survey method are therefore considered consistent.

Modelling of industry categories

The energy consumption statistics in the industry and services sectors (SFOE 2018d) 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 2019/1A2 Sektorgliederung Industrie).

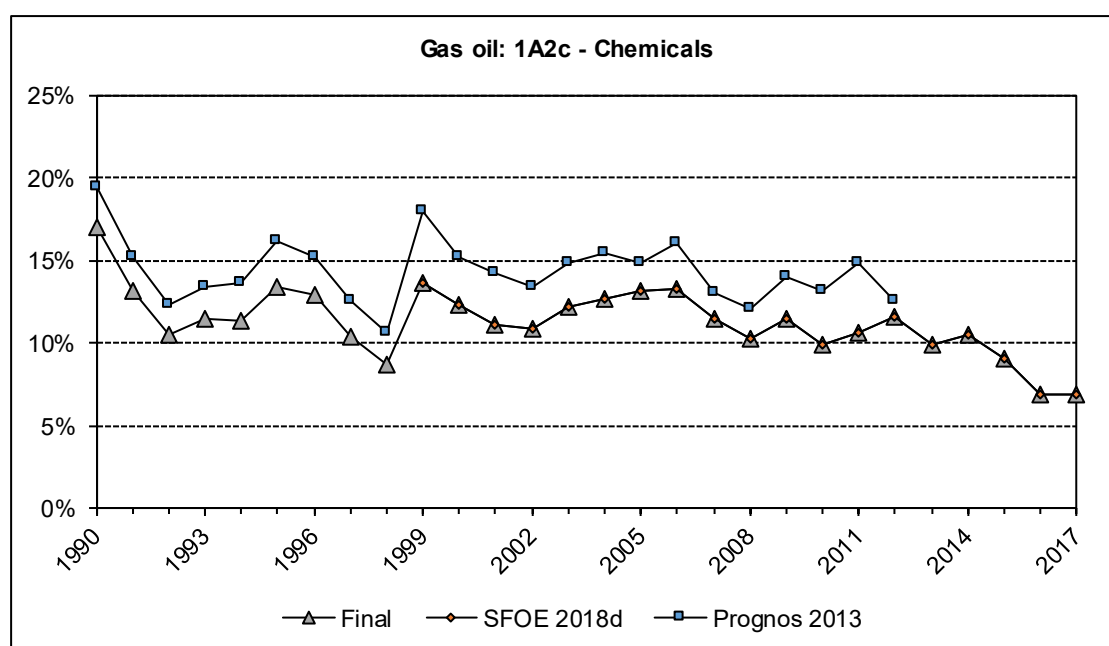


Figure 3-22 Illustrative example for combining time series with consistent overlap according to the 2006 IPCC Guidelines (IPCC 2006, Volume 1, chp. 5). The y-axis indicates the share of source category 1A2c of total gas oil consumption in the industry sector. The green line corresponds to the share finally used to calculate the fuel consumption in 1A2c and is based on the combination of the shares from the energy consumption statistics in the industry and services sectors (SFOE 2018d, red line from 1999 to 2017) and the bottom-up industry model (Prognos 2013, blue line from 1990 to 2012). Similar calculations are performed for each source category and fuel type.

Bottom-up industry data

Grey colored 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 CO₂ 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 2018d).

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 2018b) as well as on data from the Swiss renewable energy statistics (SFOE 2018a) and the statistics on combined heat and power generation in Switzerland (SFOE 2018c), 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 3-42 Emission factors for 1A2 Manufacturing industries and construction in 2017. Values that are highlighted in green are described in more detail in chp. 3.2.4.4.

1A2 Emission factors (mix of bottom-up and top-down approach (modelling)) for GHG	CO ₂ fossil	CO ₂ bio.	CH ₄	N ₂ O
	t/TJ	t/TJ	kg/TJ	kg/TJ
Gas oil	73.7		3	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)	0.2
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	56.3		1	0.1
Other fossil fuels (including solvents, plastics, waste tyres and rubber (see 1A2f))	70.9	4.7	2.3	3.4
Biomass (wood, biogas, biodiesel, bioethanol and other biogenic waste)		91.2	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 and heating gas used for steam production in a chemical plant in source category 1A2c. The emission factors of CO₂, CH₄ and N₂O are implied emission factors based on the fossil waste fuel mix. In addition, the CH₄ emission factor includes the total CH₄ emissions of the cement industry based on direct exhaust measurements at the chimneys of the cement plants (see documentation in EMIS 2019/1A2f Zementwerke_Feuerung), based on industry data and emission declarations according to the Ordinance on Air Pollution Control (Swiss Confederation 1985). Implied CH₄ 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 SO₂ for all fuels in source category 1A2 are provided in Annex A3.1.1. 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 SO₂ emission factors are country-specific and documented in SAEFL (2000).

In contrast to combustion in boilers, emission factors of precursors and SO₂ 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. In the same period, natural gas consumption has more than doubled. Regarding the fuels used within Swiss industry in 2017, natural gas consumption accounts for the largest share followed by biomass and gas oil.

Source category 1A2gviii Other comprising emissions from boilers and engines is the most important category within source category 1A2 Manufacturing Industries and construction in 2017. 1A2f Non-metallic minerals and 1A2c Chemicals are the second and third most important fuel consumers, respectively.

Table 3-43 Activity data for fuel consumption in 1A2 Manufacturing industries and construction.

Source	Unit	1990	1995	2000	2005
1A2 Manufacturing industries and constr. (stationary sources)	TJ	87'948	88'830	87'652	91'209
Gas oil	TJ	21'754	23'529	25'145	24'711
Residual fuel oil	TJ	18'870	13'678	5'675	4'613
Liquefied petroleum gas	TJ	4'354	4'458	5'627	4'309
Petroleum coke	TJ	1'400	1'260	551	1'093
Other bituminous coal	TJ	13'476	7'303	5'866	4'799
Lignite	TJ	265	153	124	742
Natural gas	TJ	18'711	27'898	31'373	34'372
Other fossil fuels	TJ	2'556	2'818	4'053	4'525
Biomass	TJ	6'562	7'733	9'237	12'046

Source	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1A2 Manufacturing industries and constr. (stationary sources)	TJ	93'239	87'549	90'276	83'921	85'232	87'118	81'725	80'233	81'256	81'518
Gas oil	TJ	21'386	21'005	20'686	16'771	17'157	17'902	12'340	12'636	12'726	11'371
Residual fuel oil	TJ	3'734	2'713	2'056	1'518	1'568	848	271	226	155	128
Liquefied petroleum gas	TJ	4'033	4'322	3'912	3'876	3'746	3'755	3'304	3'358	2'772	3'151
Petroleum coke	TJ	1'167	1'219	1'495	1'272	1'367	1'049	1'240	795	890	763
Other bituminous coal	TJ	4'445	4'263	4'348	3'868	3'794	3'910	2'403	1'946	1'517	1'634
Lignite	TJ	1'717	1'531	1'460	1'624	1'175	1'357	3'102	3'060	3'078	2'876
Natural gas	TJ	38'719	35'126	38'042	36'903	38'013	39'400	39'956	39'137	39'601	40'582
Other fossil fuels	TJ	4'975	4'958	5'183	5'307	4'883	5'186	5'270	5'252	5'926	5'912
Biomass	TJ	13'064	12'414	13'094	12'783	13'528	13'711	13'840	13'824	14'590	15'101

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 2019/1A2a-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 CO₂ 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 2018). Additionally, also limestone is used as flux in cupola furnaces yielding geogenic CO₂ 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 and gas oil and small amounts of petroleum coke are used.

Table 3-44 Activity data fuel consumption in 1A2a Iron and steel.

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

Source	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1A2a Iron and steel	TJ	4'501	3'457	4'102	4'145	3'962	3'850	4'007	4'287	4'170	4'660
Gas oil	TJ	307	279	315	271	172	139	86	136	134	126
Residual fuel oil	TJ	51	39	51	2	NO	NO	NO	NO	NO	NO
Liquefied petroleum gas	TJ	246	214	219	226	438	438	388	393	327	368
Petroleum coke	TJ	40	21	47	37	42	53	81	69	78	77
Other bituminous coal	TJ	482	316	346	377	341	321	325	313	303	321
Lignite	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Natural gas	TJ	3'374	2'588	3'125	3'233	2'969	2'898	3'128	3'376	3'328	3'769

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. Its last 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 2017 are mainly natural gas as well as gas oil and small amounts of residual fuel oil and 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 3-45 Activity data fuel consumption in 1A2b Non-ferrous metals.

Source	Unit	1990	1995	2000	2005
1A2b Non-ferrous metals	TJ	2'378	1'969	1'560	977
Gas oil	TJ	587	347	236	125
Residual fuel oil	TJ	NO	NO	NO	NO
Liquefied petroleum gas	TJ	27	17	15	7
Petroleum coke	TJ	NO	NO	NO	NO
Other bituminous coal	TJ	NO	NO	NO	NO
Lignite	TJ	NO	NO	NO	NO
Natural gas	TJ	1'764	1'605	1'309	845

Source	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1A2b Non-ferrous metals	TJ	1'042	1'006	1'218	1'177	1'746	1'593	1'917	1'792	1'683	1'647
Gas oil	TJ	112	167	112	76	153	128	90	78	76	80
Residual fuel oil	TJ	0	0	0	0	1	23	NO	44	NO	4
Liquefied petroleum gas	TJ	7	7	8	8	11	11	10	10	8	0
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	924	833	1'098	1'093	1'581	1'430	1'817	1'660	1'599	1'563

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, 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. 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 CO₂ emission factors of gasolio and heating 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 a new CO₂ emission factor. Due to changes in the cracker operation the composition of the heating gas has changed considerably.

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 are assumed for CH₄ and N₂O (see Table 3-42 and Table 3-14 (CH₄ EF of residual fuel oil)).

Table 3-46 Emission factors for 1A2c Chemicals are documented in the confidential NIR, which is available to reviewers on request.
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The fuels consumed in 2017 include mainly natural gas as well as minor amounts of gas oil. Fuel consumption in this source category has slightly decreased between 1990 and 2017. Consumption of gas oil and residual fuel oil have decreased in that period, while natural gas consumption has increased.

Table 3-47 Activity data fuel consumption in 1A2c Chemicals.

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

Source	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1A2c Chemicals	TJ	14'610	12'611	11'814	12'167	13'909	14'125	12'131	12'528	14'374	13'972
Gas oil	TJ	2'261	2'498	2'103	1'847	2'055	1'797	1'321	1'167	881	803
Residual fuel oil	TJ	79	91	66	0.2	0.2	1.2	NO	NO	NO	NO
Liquefied petroleum gas	TJ	9	9	8	7	10	10	9	9	8	8
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	12'261	10'014	9'637	10'312	11'845	12'317	10'800	11'352	13'485	13'160
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 half a dozen 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 GHG emissions were calculated using a country-specific CO₂ emission factor (EMIS 2019/1A2d Zellulose-Produktion) and default factors for CH₄ and N₂O (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 comprehensive information (statistical data) exists to distribute biomass consumption to the specific industry sectors within 1A2 as explained in chapter 3.2.4.5.2. Therefore, from 2009 onwards, GHG 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 2017 are mainly natural gas as well as gas oil. Since 1990, residual fuel oil and gas oil have decreased, while natural gas consumption increased.

Table 3-48 Activity data of fuel consumption in 1A2d Pulp, paper and print.

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

Source	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1A2d Pulp, paper and print	TJ	9'455	6'124	6'773	6'051	5'374	5'474	4'645	3'656	2'983	2'874
Gas oil	TJ	1'019	948	852	561	623	711	297	383	410	292
Residual fuel oil	TJ	1'887	1'084	279	4	3	0	22	19	9	9
Liquefied petroleum gas	TJ	60	62	61	62	67	67	60	60	50	57
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	5'164	4'030	5'581	5'424	4'681	4'696	4'266	3'194	2'513	2'516
Biomass	TJ	1'324	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 2018d) and Prognos (2013).

In 2017, the fuels used in this category were mainly natural gas as well as gas oil and small amounts of liquefied petroleum gas (Table 3-49). There was a slight increase in fuel consumption between 1990 and 2017. This is due to the increased production in this sector. The consumption of residual fuel oil and gas oil ceased and has decreased, respectively, whereas 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 comprehensive information (statistical data) exists to distribute biomass consumption to the specific industry sectors within 1A2 as explained in chapter 3.2.4.5.2. Therefore, activity data and GHG emissions from biomass are reported as "IE" in the CRF Table 1.A(a)s2.

Table 3-49 Activity data fuel consumption in 1A2e Food processing, beverages and tobacco.

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

Source	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1A2e Food processing, beverages and tobacco	TJ	10'975	12'558	13'161	11'374	11'310	13'079	12'442	11'574	10'976	11'404
Gas oil	TJ	3'376	3'687	3'778	3'197	3'237	3'681	2'395	2'522	2'503	2'182
Residual fuel oil	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Liquefied petroleum gas	TJ	535	736	659	675	935	935	828	838	699	785
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	7'064	8'135	8'723	7'502	7'138	8'463	9'220	8'214	7'774	8'438
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 in source category 1A2f. Therefore, all emissions from biomass used in these processes are reported in source category 1A2f. Fuel consumption in 2017 comprises mainly other fossil fuels, natural gas, lignite and biomass.

Between 1990 and 2017, 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 3-50.

Table 3-50 Activity data fuel consumption in 1A2f Non-metallic minerals.

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

Source	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1A2f Non-metallic minerals	TJ	17'902	17'102	18'196	17'801	16'956	17'119	17'677	16'484	16'518	16'536
Gas oil	TJ	1'299	1'260	1'269	1'238	1'097	1'174	1'204	1'098	1'020	1'118
Residual fuel oil	TJ	1'598	1'374	1'519	1'403	1'456	801	209	130	139	106
Liquefied petroleum gas	TJ	160	95	102	127	108	113	45	52	44	44
Petroleum coke	TJ	1'036	994	1'130	1'081	920	815	1'052	622	658	574
Other bituminous coal	TJ	3'912	3'940	3'992	3'474	3'403	3'478	1'973	1'498	1'089	1'210
Lignite	TJ	1'596	1'379	1'348	1'493	1'081	1'283	2'912	2'856	2'881	2'694
Natural gas	TJ	1'919	1'731	2'048	1'938	2'085	2'506	3'111	3'121	2'952	2'970
Other fossil fuels	TJ	4'975	4'958	5'183	5'307	4'883	5'186	5'270	5'252	5'926	5'912
Biomass	TJ	1'406	1'371	1'604	1'739	1'923	1'764	1'901	1'856	1'809	1'908

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 fossil and waste derived fuels used to generate the high temperatures needed for the calcination process.

Emission factors

The CH₄ emission factor includes the overall CH₄ emissions of the cement industry based on direct exhaust measurements at the chimneys of the cement plants. Therefore, these CH₄ emissions are reported under the fuel type other fossil fuels in the reporting tables.

Table 3-51 Emission factors for cement industry in 2017. Emission factors for CO₂ and N₂O are fuel specific (see Table 3-12, Table 3-16 and Table 3-52).

Cement industry (part of 1A2f)	CO ₂	N ₂ O	CH ₄	NO _x	NM VOC	SO ₂	CO
	t/TJ		g/t clinker				
Cement	fuel specific		6	930	59	270	1'900

The emission factors for CO₂ and N₂O for regular fossil fuels are the same as used elsewhere (Table 3-12, Table 3-16). Regarding waste derived fuels, the NCVs and CO₂ 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 Mauschwitz (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 N₂O is the same for all waste derived fuels and is taken from the 2006 IPCC guidelines (IPCC 2006, vol 2, chp.2 table 2.3 industrial wastes).

Table 3-52 NCVs, fossil fractions as well as CO₂ (fossil and biogenic) and N₂O 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 3-50).

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 ₂ O
		MJ/kg	%	kg CO ₂ /GJ	kg CO ₂ /GJ	kg CO ₂ /GJ	kg N ₂ O/GJ
Waste oil	Cemsuisse (2010a, 2017)	32.5 (2010) 31.0 (2017)	100.0 (2010) 92.7 (2017)	74.4 (2010) 73.2 (2017)	74.4 (2010) 67.9 (2017)	0.0 (2010) 5.3 (2017)	0.004
Waste coke from coke filters	Vock (2001) Hackl and Mauschwitz (2003)	23.7	100	97	97	0	0.004
Mixed industrial waste	Cemsuisse, FOEN	18.3	100	74	74	0	0.004
Other fossil waste fuels	Cemsuisse, FOEN	20.9	100	97	97	0	0.004
Solvents and residues from distillation	Cemsuisse (2010a, 2017)	23.6 (2010) 23.5 (2017)	99.1 (2010) 89.7 (2017)	74.0 (2010) 70.7 (2017)	73.3 (2010) 63.4 (2017)	0.7 (2010) 7.3 (2017)	0.004
Waste tyres and rubber	Hackl and Mauschwitz (2003) UBA (2006)	26.4	73.0	84.0	61.3	22.7	0.004
Plastics	Cemsuisse (2010a, 2017)	25.2 (2010) 23.6 (2017)	72.3 (2010) 76.6 (2017)	84.7 (2010) 84.5 (2017)	61.2 (2010) 64.7 (2017)	23.5 (2010) 19.8 (2017)	0.004
Mix of special waste with saw dust (CSS)*	Cemsuisse (2010a, 2017)	9.2 (2010) 9.1 (2017)	21.5 (2010) 27.0 (2017)	102.4 (2010) 112.2 (2017)	22.0 (2010) 30.3 (2017)	80.4 (2010) 81.9 (2017)	0.004
Sewage sludge (dried)*	Cemsuisse (2010a)	9.4	0.0	94.5	0.0	94.5	0.004
Wood waste*	Cemsuisse (2010a)	16.3	0.0	99.9	0.0	99.9	0.004
Animal meal*	Cemsuisse (2010a)	16.8	0.0	86.7	0.0	86.7	0.004
Agricultural waste / other biomass*	Cemsuisse, FOEN	12.7	0	110	0	110	0.004

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 2019/1A2f Zementwerke Feuerung).

In 2017, the Swiss cement industry used about slightly more waste derived fuels than standard fossil fuels. Fossil fuels used in cement industry are mainly lignite, other bituminous coal and petroleum coke. In addition, also fossil and biogenic waste derived fuels are used. Fossil wastes comprise plastics, solvents and residues from distillation, waste tyres and rubbers, and waste oil, whereas biogenic wastes contain mainly wood waste, animal residues and sewage sludge. The main fossil fuels used in 1990 were other bituminous coal, residual fuel oil and other fossil fuels.

Fuel consumption in cement plants has decreased between 1990 and 2017. 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 fossil fuels to the above mentioned mix of fuels, including biogenic fractions of waste derived 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 3-52).

Table 3-53 Activity data: Overview on fuel use in cement industry (part of 1A2f).

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

Cement industry (part of 1A2f)	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Cement, total incl. waste	TJ	11'954	11'816	12'388	12'187	11'462	11'866	12'339	11'348	11'583	11'476
Cement fossil without waste	TJ	6'389	6'127	6'278	5'859	5'406	5'512	5'847	4'917	4'544	4'354
Gas oil	TJ	NO	NO	5	1	0	87.8	75	87	50	56
Residual fuel oil	TJ	135	100	112	101	297	86	58	45	90	59
Petroleum coke	TJ	1'036	994	1'130	1'081	920	815	1'052	622	658	574
Other bituminous coal	TJ	3'618	3'650	3'662	3'167	3'097	3'203	1'713	1'267	826	938
Lignite	TJ	1'596	1'379	1'348	1'493	1'081	1'283	2'912	2'856	2'881	2'694
Natural gas	TJ	4	4	21	16	11	38	37	41	39	34
Cement, waste derived fuel	TJ	5'565	5'689	6'109	6'329	6'056	6'354	6'492	6'431	7'039	7'122
Other fossil fuels	TJ	4'237	4'394	4'580	4'685	4'225	4'599	4'596	4'582	5'234	5'219
Waste oil	TJ	866	1'278	1'253	1'170	839	876	923	1'142	1'567	1'311
Waste coke from coke filters	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	66
Mixed industrial waste	TJ	1	1	NO	NO	NO	NO	NO	NO	NO	NO
Other fossil waste fuels	TJ	105	137	45	55	36	25	19	12	11	6
Solvents and residues from distillation	TJ	1'476	1'032	1'189	1'264	1'294	1'414	1'273	1'292	1'534	1'398
Waste tyres and rubber	TJ	794	828	842	1'033	964	985	1'021	958	951	1'041
Plastics	TJ	995	1'119	1'252	1'163	1'092	1'299	1'360	1'177	1'171	1'398
Biomass	TJ	1'328	1'295	1'530	1'644	1'831	1'756	1'896	1'850	1'805	1'903
Mix of special waste with saw dust (CSS)	TJ	157	131	123	96	100	96	103	80	98	78
Sewage sludge (dried)	TJ	511	475	477	483	527	418	428	420	479	499
Wood waste	TJ	NO	61	292	409	586	732	886	896	811	840
Animal meal	TJ	658	621	624	614	572	479	457	412	409	470
Sawdust	TJ	NO	NO	6	24	17	32	21	42	8	6
Agricultural waste / other biomass	TJ	2	7	7	18	28	NO	NO	NO	NO	9

Lime (1A2f)

In Switzerland there is only one plant producing lime. Fossil fuels are used for the burning process (calcination) of limestone. Between 1994 and 2012, fuel consumption in lime production was dominated by residual fuel oil. However in 2013, the main kiln has been

switched to natural gas. Since 1995, no other bituminous coal is used anymore as it was replaced by residual fuel oil.

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 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)

In Switzerland, 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, but the natural gas consumption decreased. This can be explained by an increase in energy efficiency in the production process between 1990 and 2017.

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 2017.

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 CO₂ emission factors for wood and animal grease are based on a study of Cemsuisse (Cemsuisse 2010a), see Table 3-52, 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 2019/1A2f Ziegeleien).

For CH₄ and N₂O, 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 CH₄ and N₂O emission factors 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, are taken.

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 2017 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 are produced in two companies in Switzerland, where thermal energy is used for heating and drying processes.

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.

This source category accounts for about one third of the overall fuel consumption in 2017 of 1A2 Manufacturing industries and construction.

Emission factors (1A2g stationary)

The CO₂ emission factors for wood waste and animal grease in 1A2giv Wood and wood products are based on a study by Cemsuisse (2010a), see Table 3-52. For wood waste, the respective CH₄ and N₂O emission factors of the energy model for wood combustion, see chp. 3.2.4.5.2, 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 Wood and wood products, mainly wood waste as well as natural gas are used (Table 3-54). 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 2017. 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 2019/1A2giv).

1A2gviii Other Boilers and Engines Industry

Activity data for wood combustion is based on Swiss wood energy statistics (SFOE 2018b) whereas sewage and biogas consumption is based on data from the Swiss renewable energy statistics (SFOE 2018a) and the Statistics on combined heat and power generation in Switzerland (SFOE 2018c). Further information on wood energy consumption is provided in chapter 3.2.4.5.2.

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

Table 3-54 Activity data fuel consumption in 1A2g iv Wood and wood products and 1A2g viii Other (stationary).

Source	Unit	1990	1995	2000	2005
1A2g iv: Wood and wood products, 1A2g viii: Other (stationary)	TJ	20'340	26'601	28'947	31'651
Gas oil	TJ	6'276	10'716	12'796	13'925
Residual fuel oil	TJ	5'298	3'749	199	26
Liquefied petroleum gas	TJ	3'091	3'288	4'164	3'116
Petroleum coke	TJ	765	914	15	383
Other bituminous coal	TJ	205	140	12	88
Lignite	TJ	NO	NO	NO	5
Natural gas	TJ	261	2'005	4'946	5'689
Other fossil fuels	TJ	NO	NO	NO	NO
Biomass	TJ	4'445	5'790	6'814	8'419

Source	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1A2g iv: Wood and wood products, 1A2g viii: Other (stationary)	TJ	34'754	34'690	35'012	31'206	31'974	31'878	28'906	29'912	30'553	30'426
Gas oil	TJ	13'012	12'166	12'256	9'581	9'821	10'272	6'947	7'253	7'702	6'770
Residual fuel oil	TJ	119	124	142	109	109	22	40	33	8	9
Liquefied petroleum gas	TJ	3'016	3'200	2'855	2'771	2'176	2'180	1'965	1'995	1'635	1'890
Petroleum coke	TJ	91	203	318	154	405	181	108	104	155	113
Other bituminous coal	TJ	50	6	11	16	50	110	105	134	125	102
Lignite	TJ	121	152	111	131	95	75	189	204	197	182
Natural gas	TJ	8'012	7'796	7'828	7'400	7'713	7'090	7'614	8'220	7'950	8'166
Other fossil fuels	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Biomass	TJ	10'334	11'042	11'490	11'044	11'605	11'947	11'939	11'968	12'781	13'193

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 2019. Major recalculations, which contribute significantly to the total differences in GHG emissions of sector 3 Energy between the latest and the previous submission are presented also in chp. 10.1.2.1.

- 1A2: Activity data for natural gas in all the industry sectors 1A2a-g has changed for the year 2016.
- 1A2: Activity data for use of gas oil has changed in the industry sectors 1A2a-e and 1A2gviii by less than -1%.
- 1A2: Activity data for use of residual fuel oil in other boilers has changed due to necessary stock changes in the year 2010 and 2014.
- 1A2f: The CO₂ emission factors for four waste derived fuels used in the cement industry – i.e. waste oil, solvents, residues from distillation and plastics and CSS (mix of special waste with saw dust) were reassessed in 2017 (Cemsuisse 2018). Emission factors

between 2010 (the year of the last assessment) and 2017 are now interpolated, while constant values are used before the first and after the last year with available data.

- 1A2f: The CO₂ emission factors and the fossil fractions of most waste derived fuels (waste oil, waste tires and rubber, mix of special waste with sawdust (CSS), plastics, solvents and residues from distillation, animal meal, sewage sludge) were rounded to their significant digits (one decimal place in kg/GJ).
- 1A2f: The net calorific values of most waste derived fuels (waste oil, mixed industrial waste, other fossil waste fuels, solvents and residues from distillation, plastics, mix of special waste with saw dust (CSS), sewage sludge, wood waste, animal meal, agricultural waste / other biomass) were rounded to their significant digits (one decimal place in MJ/kg). This leads to small changes in AD of waste oil, sewage sludge, wood waste, solvents, plastics, animal meal, CSS.
- 1A2gviii: Activity data (wood, wood waste) of all wood combustion installations have been revised for the entire time series 1990- 2016 due to recalculations in the Swiss wood energy statistics (SFOE 2018b). Main recalculations include changes in automatic boilers.
- 1A2gviii: Emissions from biogas usage in engines of gas produced by digestion in industrial biogas plants were reported in source category 1A1a as well as 1A2gviii. This led to a double counting of emissions. The corresponding processes for industrial digestion have been removed from source category 1A1a and are now only reported in 1A2gviii. In connection with these adjustments calculations for biogas usage have been revised in the energy model. This leads to a small decrease of activity data and emissions for the years 1990-2016 in 1A2gviii.
- 1A2gviii: Emissions from sewage gas usage in engines or boilers of gas produced by digestion in wastewater treatment plants were reported in source category 5D as well as 1A2gviii. This led to a double counting of emissions. The emissions from sewage gas usage in engines have been removed from source category 5D and are now only reported in 1A2gviii. In connection with these adjustments, calculations for sewage gas usage have been revised in the energy model. This leads to an increase of activity data and emissions for the years 1990-2016 in 1A2gviii.
- 1A2gviii: Due to statistical stock changes of residual fuel oil consumption in the energy model (see Figure 3-14), stock numbers had to be adjusted for the years 2014 and 2015.

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

- 1A2gviii: The classification of the use of biogas and sewage gas in engines in industry and agriculture needs to be further revised.

3.2.7 Source category 1A4 – Other sectors (stationary 1A4 ai/bi/ci)

3.2.7.1 Source category description for 1A4 (stationary)

Table 3-55 Key categories of 1A4 Other sectors. Combined KCA results, level for 2017 and trend for 1990–2017, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
1A4a	Commercial: Gaseous fuels	CO ₂	L1, T1
1A4a	Commercial: Liquid fuels	CO ₂	L1, T1
1A4b	Residential: Biomass	CH ₄	T1
1A4b	Residential: Gaseous fuels	CO ₂	L1, L2, T1, T2
1A4b	Residential: Liquid fuels	CO ₂	L1, T1
1A4c	Agriculture and forestry: Liquid fuels	CO ₂	L1

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 CO₂ 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 dominating those of 1A4c. See chp.3.2.10.1.

Table 3-56 Specification of source category 1A4 Other sectors.

1A4	Source	Specification
1A4ai	Commercial/institutional: Stationary	Emissions from stationary combustion in commercial and institutional buildings.
1A4bi	Residential: Stationary	Emissions from stationary fuel combustion in households.
1A4ci	Agriculture/Forestry/Fishing: Stationary	Emissions from stationary fuel combustion of agriculture and grass drying.

3.2.7.2 Methodological issues for 1A4 (stationary)

Methodology (1A4 stationary)

CO₂ 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 2006 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 2006 IPCC defaults EFs for CH₄ emissions of liquid fuels and gas oil for boilers and N₂O emissions of all fuels and technologies. CH₄ emissions of gas oil used in engines, gaseous fuels and biogas are calculated by a Tier 2 approach using

country-specific emission factors. CH₄ 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 originate from fuel combustion for grass drying and wood combustion for heating in agriculture and forestry. For grass drying, information is provided by the grass drying association.

Emission factors (1A4 stationary)

Table 3-57 Emission factors for stationary combustion in 1A4ai Other sectors commercial/institutional in 2017. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

Source/fuel	CO ₂ fossil	CO ₂ biog.	CH ₄	N ₂ O	NO _x	CO	NM VOC	SO ₂
	t/TJ		kg/TJ					
1A4ai Other sectors: Commercial/institutional								
Gas oil (weighted average)	73.7	NA	10	0.6	33	6.4	6	9.2
Gas oil (heat only boilers)	73.7	NA	10	0.6	33	6.3	6	9.2
Gas oil (engines)	73.7	NA	2	0.6	40	30.0	8	9.2
Natural gas (weighted average)	56.3	NA	2.0	0.1	20.2	12.1	1.9	0.5
NG (heat only boilers)	56.3	NA	1	0.1	16.9	9.6	2	0.5
NG (turbines)	56.3	NA	2	0.1	60.0	15.0	0.1	0.5
NG (engines)	56.3	NA	20	0.1	78.0	56.3	1	0.5
Other bituminous coal	NO	NO	NO	NO	NO	NO	NO	NO
Lignite	NO	NO	NO	NO	NO	NO	NO	NO
Biomass (weighted average)	NA	94.1	18.9	3.5	102.5	607.4	28.5	9.5
Biomass (wood)	NA	99.9	21.7	4	115.6	699.1	32.5	10.8
Biomass (biogas)	NA	56.3	1	0.1	16.9	9.6	2.0	0.5

Table 3-58 Emission factors for stationary combustion in 1A4bi Other sectors residential in 2017. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

Source/fuel	CO ₂ fossil	CO ₂ biog.	CH ₄	N ₂ O	NO _x	CO	NM VOC	SO ₂
	t/TJ		kg/TJ					
1A4bi Other sectors: Residential								
Gas oil (weighted average)	73.7	NA	10	0.6	34.5	12	6	9.2
Gas oil (heat only boilers)	73.7	NA	10	0.6	34.5	12	6	9.2
Gas oil (engines)	73.7	NA	2	0.6	40	30	8	9.2
Natural gas (weighted average)	56.3	NA	1.2	0.1	16.0	13.0	4	0.5
NG (heat only boilers)	56.3	NA	1	0.1	15.9	13	4	0.5
NG (turbines)	56.3	NA	2	0.1	60	15	0.1	0.5
NG (engines)	56.3	NA	20	0.1	32.5	56.3	1	0.5
Other bituminous coal	92.7	NA	300	1.5	65	1'600	100	350
Lignite	NO	NO	NO	NO	NO	NO	NO	NO
Biomass (wood, charcoal)	NA	100.1	51.5	3.9	92.1	1'382	84.4	10.3

Table 3-59 Emission factors for stationary combustion in 1A4ci Agriculture/forestry/fishing in 2017. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A4ci Agriculture/forestry/fishing	Unit	CO ₂ fossil	CO ₂ biog.	CH ₄	N ₂ O
Grass drying (fossil, biogenic)	kg/TJ	61'647	96'974	5.6	0.9
Biomass (wood)	kg/TJ	NA	99'900	11	4

Charcoal and bonfires

Emission factors concerning CO₂, CH₄ and N₂O emissions of charcoal use in the residential source categories (1A4bi) are taken from the 2006 IPCC Guidelines (IPCC 2006). Default emission factors according to the guidelines are also applied for CH₄ and N₂O emissions resulting from bonfires. The CO₂ 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 (2016).

Table 3-60 Emission factors for use of charcoal and bonfires in 1A4bi Other sectors residential in 2017.

1A4bi Other sectors: residential stationary combustion	Unit	CO₂ biog.	CH₄	N₂O	NO_x	NMVOC	SO₂	CO
Use of charcoal	kg/TJ	112'000	200	1	50	600	11	6'000
Bonfires	kg/TJ	99'900	300	4	50	600	11	6'000

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 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 2018). 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 2019/1A4ci Grastrocknung). Since submission 2015, the actual fuel consumption for grass drying is available and used for emission calculations.

Table 3-61 Activity data in 1A4a Commercial/Institutional (stationary).

Source/Fuel	Unit	1990	1995	2000	2005
1A4a Other sectors: Commercial/institutional	TJ	78'254	85'584	81'910	87'967
Gas oil	TJ	57'622	58'811	53'013	54'937
Gas oil heat only boilers	TJ	57'599	58'635	52'662	54'620
Gas oil engines	TJ	24	175	351	318
Natural gas	TJ	17'648	22'955	24'539	27'721
NG heat only boilers	TJ	17'372	21'784	22'802	25'688
NG turbines	TJ	85	78	NO	28
NG engines	TJ	192	1'093	1'737	2'004
Other bituminous coal	TJ	NO	NO	NO	NO
Lignite	TJ	NO	NO	NO	NO
Biomass (total)	TJ	2'984	3'818	4'358	5'309
Biomass (wood)	TJ	2'924	3'769	4'296	5'181
Biomass (biogas)	TJ	59	49	62	128

Source/Fuel	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1A4a Other sectors: Commercial/institutional	TJ	79'141	77'105	83'366	69'037	75'900	80'649	64'079	70'142	73'488	71'444
Gas oil	TJ	47'585	45'699	48'778	38'900	41'814	44'328	34'191	36'406	37'592	35'485
Gas oil heat only boilers	TJ	47'416	45'545	48'660	38'796	41'720	44'242	34'109	36'324	37'510	35'403
Gas oil engines	TJ	169	154	119	105	94	86	82	82	82	82
Natural gas	TJ	25'257	24'761	27'469	24'057	27'025	28'455	22'187	25'070	26'419	26'392
NG heat only boilers	TJ	23'399	22'948	25'764	22'476	25'472	26'957	20'751	23'634	24'983	24'956
NG turbines	TJ	29	26	23	17	4.9	7.3	7.3	7.3	7.3	7.3
NG engines	TJ	1'829	1'787	1'681	1'564	1'548	1'490	1'429	1'429	1'429	1'429
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
Biomass (total)	TJ	6'299	6'645	7'119	6'080	7'061	7'866	7'701	8'666	9'476	9'566
Biomass (wood)	TJ	5'934	6'237	6'622	5'525	6'386	7'054	6'774	7'625	8'284	8'294
Biomass (biogas)	TJ	365	408	497	555	674	812	928	1'041	1'192	1'272

Table 3-62 Activity data in 1A4b Residential (stationary).

Source/Fuel	Unit	1990	1995	2000	2005
1A4b Other sectors: Residential	TJ	185'288	189'216	170'384	185'847
Gas oil	TJ	136'887	133'548	116'295	124'024
Gas oil heat only boilers	TJ	136'887	133'544	116'242	123'961
Gas oil engines	TJ	1	4	53	63
Natural gas	TJ	25'864	34'088	36'261	42'633
NG heat only boilers	TJ	25'804	33'830	35'822	42'103
NG turbines	TJ	NO	NO	NO	NO
NG engines	TJ	60	258	439	530
Other bituminous coal	TJ	630	460	130	400
Lignite	TJ	NO	NO	NO	NO
Biomass	TJ	21'907	21'120	17'698	18'790

Source/Fuel	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1A4b Other sectors: Residential	TJ	170'159	166'738	180'835	145'117	160'143	171'220	134'072	143'721	149'767	143'669
Gas oil	TJ	108'715	105'296	111'731	86'989	94'103	99'373	75'136	79'406	81'340	76'113
Gas oil heat only boilers	TJ	108'663	105'254	111'695	86'955	94'072	99'344	75'109	79'379	81'312	76'085
Gas oil engines	TJ	52	42	36	34	32	29	27	27	27	27
Natural gas	TJ	42'389	42'469	48'229	40'910	47'043	50'957	42'367	46'106	48'835	48'344
NG heat only boilers	TJ	41'848	41'931	47'723	40'440	46'577	50'509	41'937	45'676	48'405	47'914
NG turbines	TJ	3	NO	NO	NO	NO	NO	NO	NO	NO	NO
NG engines	TJ	537	538	506	470	466	448	430	430	430	430
Other bituminous coal	TJ	400	400	400	300	300	300	200	200	200	100
Lignite	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Biomass	TJ	18'656	18'573	20'474	16'917	18'697	20'590	16'369	18'009	19'392	19'112

Table 3-63 Activity data in 1A4ci Agriculture/forestry/fishing (stationary).

Source/Fuel	Unit	1990	1995	2000	2005
1A4c Agriculture/forestry/fishing	TJ	2'323	2'032	1'703	1'639
Grass drying (fossil, biogenic)	TJ	1'895	1'544	1'223	994
Biomass	TJ	428	488	479	645

Source/Fuel	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1A4c Agriculture/forestry/fishing	TJ	1'441	1'481	1'427	1'452	1'386	1'027	1'134	1'132	1'482	1'618
Grass drying (fossil, biogenic)	TJ	822	856	739	891	685	458	524	431	492	610
Biomass	TJ	619	625	688	561	701	570	610	701	990	1'009

Charcoal and bonfires

Besides the main energy sources, also charcoal use and bonfires are accounted for in source category 1A4bi. The energy source charcoal is only used for charcoal grills. The total charcoal consumption under 1A4bi is very small compared to other fuels used for heating purposes. The activity data are the sum of charcoal production under 1A1c and net imports provided by the Swiss overall energy statistics (SFOE 2018).

The total wood demand for bonfires is assumed to be constant over time (for further details see documentation in EMIS 2019/1A4bi Lagerfeuer).

Table 3-64 Activity data in 1A4bi Charcoal and bonfires.

1A4bi Other sectors: residential stationary combustion	Unit	1990	1995	2000	2005
Use of charcoal	TJ	311	291	292	313
Bonfires	TJ	160	160	160	160

1A4bi Other sectors: residential stationary combustion	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Use of charcoal	TJ	354	344	343	343	344	343	354	353	334	374
Bonfires	TJ	160	160	160	160	160	160	160	160	160	160

3.2.7.3 Uncertainties and time-series consistency for 1A4 (stationary)

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)

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)

The following recalculations were implemented in submission 2019. Major recalculations which contribute significantly to the total differences in GHG emissions of sector 3 Energy between the latest and the previous submission are presented also in chp. 10.1.2.1.

- 1A4: Activity data (wood, wood waste) of all wood combustion installations in source categories 1A4ai, 1A4bi and 1A4ci have been revised for the entire time series 1990-2016 due to recalculations in the Swiss wood energy statistics (SFOE 2018b). Main recalculations include changes in automatic boilers.
- 1A4a, 1A4b: Use of natural gas in source category 1A4bi has been corrected for the year 1990 (+400 GJ), leading to a corresponding reduction of natural gas use in source category 1A4ai. This is just a redistribution, no change of total natural gas consumption.
- 1A4ai: Emissions from biogas usage in engines or boilers of gas produced by digestion in agricultural biogas plants were reported in source category 1A1a as well as 1A4ai in the previous submission. This led to a double counting of emissions. The processes for agricultural digestion have now been removed from source category 1A1a and are only reported in 1A4ai. Further, calculations concerning use of biogas in the energy model have been revised. This leads to an increase of activity data and emissions for the years 1990-2003 and a decrease of activity data and emissions for the years 2005-2016 in 1A4ai.
- 1A4bi: Activity data of 1A4bi Charcoal use have been updated due to revised data in 1A1c Charcoal production for 2006–2016. In addition, the so far interpolated AD values of 1991 and 1992 have been replaced by effective import data of the Swiss overall energy statistics (SFOE 2018).

3.2.7.6 Category-specific planned improvements for 1A4 (stationary)

- 1A4ci: The classification of the use of biogas and sewage gas in engines in industry and agriculture needs to be further revised.

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 CO₂ emissions of 1A2 from Liquid Fuels are dominated by the stationary sources. Only 36% (2017) of the CO₂ emissions of Liquid Fuels from 1A2 stem from mobile sources 1A2gvii.

Table 3-65 Specification of source category 1A2 Manufacturing industries and construction (mobile).

Source	Specification
Mobile Combustion in manufacturing industries and construction	industry sector: forklifts and snow groomers etc. 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.

CO₂ emissions from lubricants of gasoline 2-stroke engines are calculated by using the IPCC default CO₂ 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, CH₄ and N₂O 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.

The mix of fossil and biofuels was recalculated for all of non-road vehicles (INFRAS 2018). This also affects industry and construction machinery (see chp. 3.2.8.5).

Emission factors (1A2gvii)

- The CO₂ emission factors applied for the time series 1990–2017 for diesel oil, gasoline, LPG and biofuels are country-specific and are given in Table 3-12.
- The CH₄ and N₂O emission factors are country-specific and are shown in Table 3-66 to Table 3-68 for diesel oil, gasoline and LPG engines for all emission standards.
- For SO₂, the emission factors are country-specific. See Table A – 13 in Annex 3.1.5 for diesel oil, gasoline, gas oil and LPG.
- 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 CH₄ emissions.
- The implied emission factors 2017 are shown in Table 3-69.

All emission factors (GHG, precursors, SO₂) can be downloaded by query from the public part of the non-road database INFRAS (2015a)⁶. They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels.

⁶ <https://www.bafu.admin.ch/bafu/en/home/topics/air/state/non-road-datenbank.html> [20.02.2019]

Table 3-66 Emission factors CH₄ and N₂O for industry and construction vehicles with diesel oil engines by emission standards including the year of inforcement.

Gas	Power class	PreEU-A <1996	PreEU-B 1996	EU-I 2002/03	EU-II 2002/04	EU-III-A 2006/08	EU-III-B 2011/12	EU-IV 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 ₂ O	0–3000	0.035	0.035	0.035	0.035	0.035	0.035	0.035

Table 3-67 Emission factors CH₄ and N₂O for industry and construction vehicles with gasoline engines by emission standards including the year of inforcement.

Gas	Power class	PreEU-A <1996	PreEU-B 1996	PreEU-C 2000	EU-I 2004	EU-II 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 ₂ O	0–3000	0.03	0.03	0.03	0.03	0.03

Table 3-68 Emission factors CH₄ and N₂O for industry and construction vehicles with LPG engines (for all years).

Gas	without catalyst	with catalyst
	g/kWh	
CH ₄	0.552	0.035
N ₂ O	0.05	0.05

Table 3-69 Implied emission factors 2017 for industry and construction vehicles.

1A2gvii Non-road vehicles and other machinery	CO ₂	CH ₄	N ₂ O	NO _x	NM VOC	SO ₂	CO
	t/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ
Gasoline	73.8	38.5	1.1	106	699	0.4	19'583
Diesel oil	73.3	0.6	3.3	307	26	0.5	134
Liquefied petroleum gas	65.5	0.7	2.4	103	9	NA	24
Biodiesel	73.3	0.5	2.8	262	23	0.4	115
Bioethanol	73.8	9.1	0.8	52	258	0.2	12'105

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 3-70 and in Annex A3.1.4. Detailed data can be downloaded from the online database of INFRAS (2015a).

Table 3-70 Activity data for industry and construction vehicles.

Source/Fuel	Unit	1990	1995	2000	2005
1A2gvii Non-road vehicles and other machinery	TJ	5'721	6'852	7'636	8'169
Gasoline	TJ	196	224	227	225
Diesel oil	TJ	5'359	6'380	7'106	7'626
Liquefied petroleum gas	TJ	165	248	294	290
Biodiesel	TJ	NO	NO	9	28
Bioethanol	TJ	NO	NO	NO	NO

Source/Fuel	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1A2gvii Non-road vehicles and other machinery	TJ	8'535	8'657	8'779	8'811	8'843	8'875	8'906	8'938	8'944	8'949
Gasoline	TJ	222	221	220	213	206	198	191	184	180	177
Diesel oil	TJ	8'003	8'129	8'254	8'283	8'312	8'341	8'370	8'399	8'380	8'361
Liquefied petroleum gas	TJ	277	273	269	260	252	243	235	226	215	203
Biodiesel	TJ	33	34	36	54	73	91	110	128	166	205
Bioethanol	TJ	0.003	0.004	0.005	0.26	0.51	0.76	1.02	1.27	1.96	2.65

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), see footnote 6 (p. 147). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels.

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 3-25.

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 3.2.4.8.

3.2.8.5 Category-specific recalculations for 1A2gvii (mobile)

No category-specific recalculations were carried out.

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 3-71 Key categories of 1A3 Transport. Combined KCA results, level for 2017 and trend for 1990–2017, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
1A3a	Civil aviation: Liquid fuels	CO ₂	T1
1A3b	Road transportation: Gasoline	CH ₄	T1
1A3b	Road transportation: Gasoline	CO ₂	L1, T1
1A3b	Road transportation: Gasoline	N ₂ O	T1, T2
1A3b	Road transportation: Diesel	CO ₂	L1, T1

Table 3-72 Specification of source category 1A3 Transport.

1A3	Source	Specification
1A3a	Domestic aviation	Large (jet, turboprop) and small (piston) aircrafts, helicopters
1A3b i	Road Transportation	Passenger cars
1A3b ii		Light duty trucks
1A3b iii		Heavy duty trucks and buses
1A3b iv		Motorcycles
1A3b v		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 (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 (Committee on Aviation Environmental Protection)). 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 and take-off cycle (LTO) 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/CORINAIR databases (EMEP/EEA 2016), 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 N₂O, the IPCC default emission factor of 2 kg/TJ is used. For the methane split of unburned hydrocarbons, the 10% methane share for the LTO, given in IPCC 2006 is used. For cruise emissions, no methane is reported.

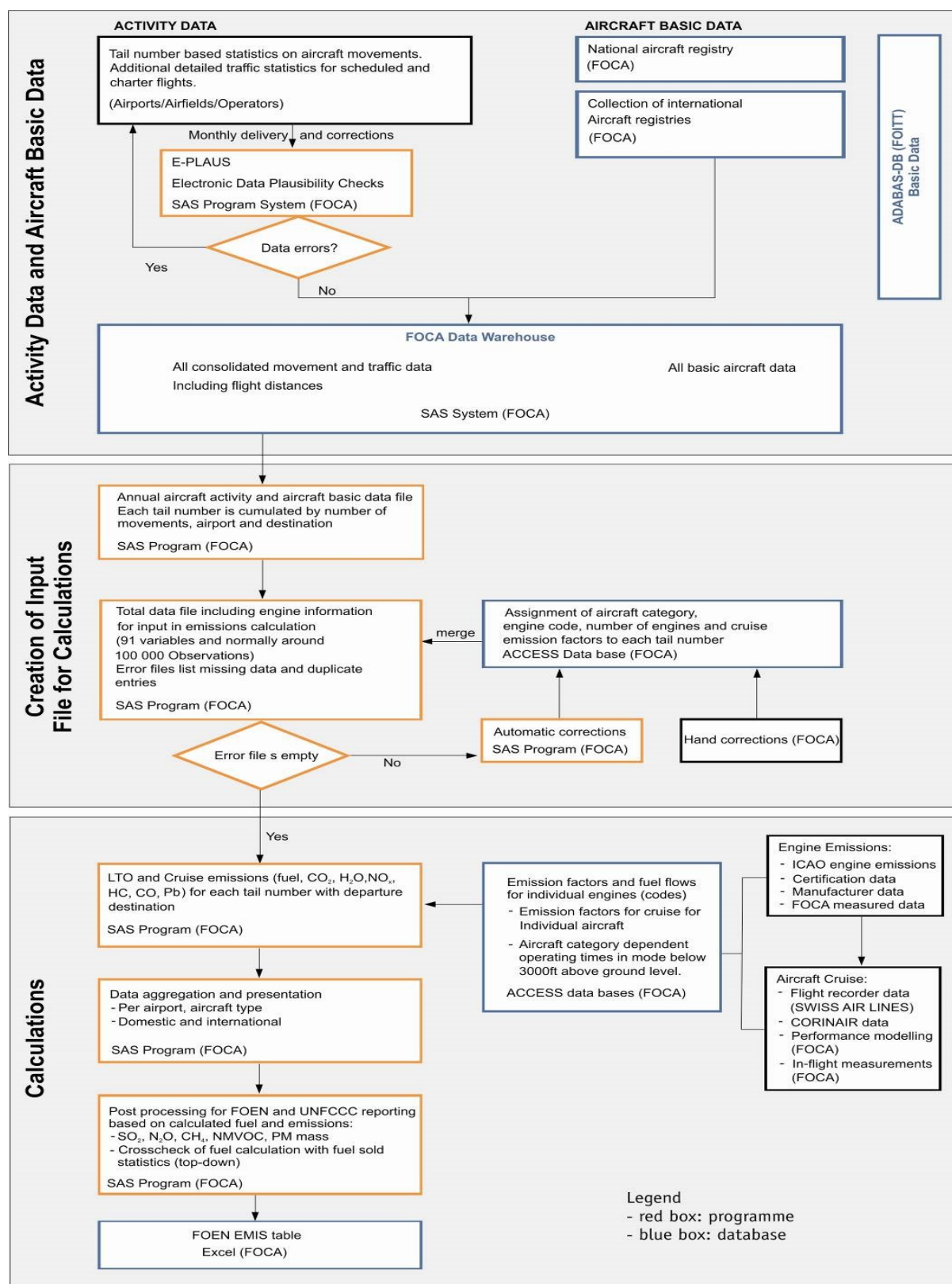


Figure 3-23 Modelling scheme (activity data, emission factors, emissions) for domestic aviation.

A complete emission modelling (LTO and cruise emissions for domestic and international flights) has been carried out by FOCA for 1990, 1995, 2000, 2002, 2004–2017. The results of

the emission modelling have been transmitted from FOCA to FOEN in an aggregated form (FOCA 2006a, 2007-2018). 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 A3.1.2, more detailed descriptions of the emission modelling may be found in FOCA (2006).

Emission factors (1A3a)

LTO

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 EMEP/CORINAIR (EMEP/EEA 2016) 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

- CO₂: the emission factor of 72.8 t/TJ is country-specific and is based on measurements and analyses of fuel samples (see Table 3-12 and Table 3-73)
- CH₄, NMVOC (country-specific; CORINAIR): VOC emissions (see Precursors below) are split into CH₄ and NMVOC by a constant share of 0.1 (CH₄) and 0.9 (NMVOC) for LTO. For cruise flights the VOC emissions do not consist of CH₄ emissions. The implied emission factor for CH₄ is shown in Table 3-73.
- The N₂O emission factor regarding jet kerosene is default given by the 2006 IPCC Guidelines (IPCC 2006). 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 1990–2017 (see Table 3-73).

Precursors

- 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 2017: 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 A 3.1.2 Table A – 6 Aircraft Engine Combinations).

FOCA determines the emission factors of different gases as given in Table 3-73.

Table 3-73 Implied emission factors of 1A3a in 2017. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A3a Aviation	Unit	CO ₂ fossil	CH ₄	N ₂ O	NO _x	NMVOC	SO ₂	CO
Kerosene, domestic, LTO	kg/TJ	72'800	11.4	2.0	233	102.3	20.8	2'605
Kerosene, domestic, CR	kg/TJ	72'800	NA	2.0	280	52.3	21.9	572
Kerosene, international, LTO	kg/TJ	72'800	3.2	2.0	309	28.6	23.2	293
Kerosene, international, CR	kg/TJ	72'800	NA	2.0	351	8.1	23.2	42

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 records 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 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 467'263 aircraft movements in the total of scheduled and charter traffic in 2017 as provided by FOCA 2018).

Non-scheduled, non-charter and general aviation (including 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 3-74 summarises the activity data for domestic aviation (1A3a). It also includes international aviation, which belongs to the memo items, international bunkers/aviation (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 2017, the modelled total fuel consumption in Switzerland was 3.2% higher than the fuel sold value, so the model showed a slight overestimation (see Table 3-5). The total fuel sold as reported in the Swiss overall energy statistics is considered the most robust value for reporting, so the modelled total fuel consumption is scaled downwards such that the sum of domestic and international fuel consumption becomes identical with the fuel sold. The scaling is only done on the international fuel for the following reasons: Eurocontrol calculations for Switzerland's international flights fuel consumption are usually a few percent lower than the FOCA result.

For domestic flights, the 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 3-74 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, 2008–2018).

1A3a/1D1 Civil aviation	1990	1995	2000	2005
	Fuel consumption in TJ			
Kerosene, domestic, LTO	1'050	935	773	518
Kerosene, domestic, CR	2'401	2'139	1'768	1'184
Kerosene, international, LTO (not part of national total)	4'277	5'097	6'507	4'878
Kerosene, international, CR (not part of national total)	37'608	44'821	57'219	42'896
Total Civil aviation	45'334	52'993	66'267	49'477
1990 = 100%	100%	117%	146%	109%

1A3a/1D1 Civil aviation	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	Fuel consumption in TJ									
Kerosene, domestic, LTO	514	499	464	509	504	494	525	387	421	384
Kerosene, domestic, CR	1'109	1'211	1'230	1'306	1'371	1'323	1'396	1'500	1'511	1'257
Kerosene, international, LTO (not part of national total)	5'755	5'468	5'643	6'041	6'226	6'208	6'142	6'459	6'529	6'728
Kerosene, international, CR (not part of national total)	52'269	49'958	52'691	56'420	57'677	58'501	58'864	60'874	64'073	66'096
Total Civil aviation	59'646	57'136	60'028	64'277	65'778	66'526	66'927	69'220	72'534	74'465
1990 = 100%	132%	126%	132%	142%	145%	147%	148%	153%	160%	164%

3.2.9.2.2 Road transportation (1A3b)

Methodology (1A3b)

Choice of method

- The CO₂ 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 CH₄ and the N₂O 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 2D3d as recommended in the reporting table's footnotes.
- CO₂ 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-CO₂ emissions are reported under 1A3b.

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 road transportation (1A3b) and a model for non-road transportation (mobile

sources in 1A2gvii, 1A3c, 1A3d, 1A4aii, 1A4bii, 1A4cii, 1A5b excl. military aviation; (FOEN 2015j, see also “non-road transportation model” in chp. 3.2.4.5.1). The general method of the road transportation model is described in the following paragraphs and Annex A3.1.3 (FOEN (2010i), Keller et al. (2017), Hausberger and Matzer (2017)).

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 mainly consumed abroad and often referred to as “fuel tourism”. Fuel tourism is not captured by the territorial road transportation model.

According to the reporting guidelines, emissions from road vehicles should be attributed to the country where the fuel is sold. The Swiss overall energy statistics (SFOE 2018) provide information on the total amounts of fuel sold, including the territorial consumption **and** fuel tourism. From the amounts of fuel sold, the consumptions modelled by the territorial road and non-road models – i.e. fuel used – are subtracted. The resulting differences to the amount of fuels sold represent the amount of fuel tourism plus statistical differences⁷. It is assumed that in the non-road model, no fuel tourism is happening.

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:

- CO₂ emissions are calculated by using fuel sales and country-specific CO₂ emission factors.
- CH₄ and N₂O emissions are calculated in three steps:
 - (i) From fuel used and country-specific CH₄ and N₂O emission factors, the territorial emissions are calculated.
 - (ii) 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 CH₄ and N₂O emission factors, which are deduced from the territorial road transportation model (including weighted averages over all vehicle categories), to form the CH₄ and N₂O emissions resulting from fuel tourism and statistical differences.
 - (iii) CH₄ and N₂O emissions from the territorial model plus CH₄ and N₂O from fuel tourism and statistical differences are added to the total CH₄ and N₂O emissions reported to the UNFCCC.
- Precursor and SO₂ emissions are calculated in the same manner as CH₄ and N₂O, using the specific emission factors.

Please note that the emissions resulting from fuel tourism are integrated in the reporting tables (CRF Table 1.A(a)s3) as follows:

- Gasoline emissions are implemented in 1A3bi Cars/Gasoline,
- natural gas emissions are implemented in 1A3bi Cars/Gaseous fuels,
- diesel oil emissions are implemented in 1A3biii Heavy duty trucks and buses/Diesel oil.

⁷ The amount of fuel tourism is regularly estimated in ex-post analysis, latest update by SFOE (2017f). 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 errors. Therefore, the difference between fuel sales and fuel used in the traffic model is indicated in the NIR as “fuel tourism and statistical differences”.

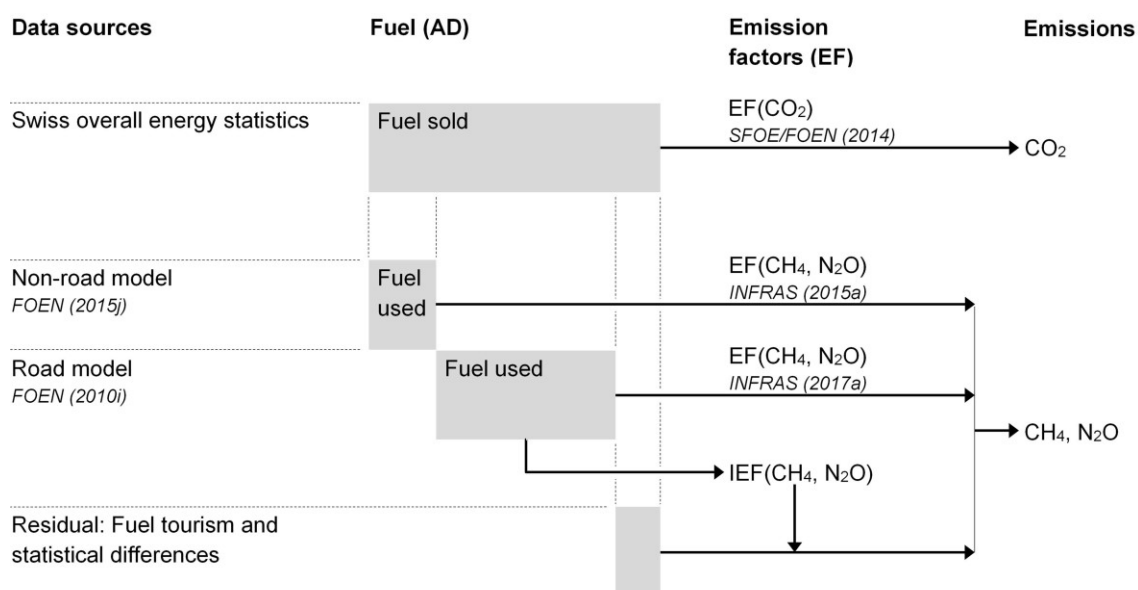


Figure 3-24 Connections between fuel sold and fuel used for road and non-road transportation. Fuel sold is provided by the Swiss overall energy statistics (minus Liechtenstein's gasoline and diesel oil consumption and bunker fuels for navigation). Fuel used results from the territorial road and non-road 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.

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), number of starts/stops and vehicle stock (cold start, evaporation emissions and running losses from gasoline passenger cars and light duty vehicles only) or fuel consumption per vehicle category.

Emission modelling consists of three parts:

hot emissions: $E_{hot} = VKT \cdot EF_{hot}$

start emissions: $E_{start} = N_{start} \cdot EF_{start}$

evaporative emissions: $E_{evap,i} = N_{evap,i} \cdot EF_{evap,i}$

with

- EF_{hot} , EF_{start} , EF_{evap} : Emission factors for ordinary driving conditions (hot motor), cold start and evaporative (VOC) emissions (after stops, running losses, diurnal losses)
- VKT : Vehicle km travelled
- N_{start} : Number of starts

- $N_{evap,i}$: Number of stops (i = "after stops") or number of vehicles (i = "running losses" and "diurnal losses")
- i runs over three evaporation categories: stops, running losses, diurnal losses
- Emissions factors are differentiated for all fuel types: Gasoline (4-stroke), gasoline (2-stroke), diesel oil, bioethanol, biodiesel, gas (CNG), biogas.

CO₂ 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 CO₂ emissions are reported in source category 2D1 Lubricant use. In contrast, CH₄ and N₂O emissions from lubricant use are reported in source category 1A3biv, since the emission factors are deduced from measurements on motorcycles including 2-stroke engines.

Note that cold start emissions for N₂O are not accounted for in the model described. During the in-country review in 2016, the ERT identified a potential underestimation. Switzerland therefore estimated N₂O cold start excess emissions for PC and LDV by means of emission factors of the Copert model, as recommended by the ERT. The corresponding emission factors per Euro class are documented in the EMEP/EEA air pollutant emission inventory guidebook - 2016 on p. 78 ff. (EMEP/EEA 2016). The procedure was repeated for the current submission by modelling the base year and the latest year (1990, 2017). For the years 1991–2016 the emissions were interpolated linearly between 1990 and 2017. The ERT confirmed that this approach complies with the 2006 IPCC Guidelines. In a forthcoming update of the road transport emission model, cold start emission factors for N₂O will be integrated.

In submission 2018, a number of smaller modifications have been carried out for the modelling of road transportation (see INFRAS 2018). The methodology remained unchanged, the modifications are related to the emission factors (e.g. NO_x, to account for realistic exhaust emission factors after manipulation in diesel cars became public in 2015) and activity data.

Emission factors (1A3b)

CO₂

- The country-specific CO₂ emission factors are described in chp.3.2.4.4.2. Values are shown in Table 3-12 (gasoline, diesel oil, biofuels) and in Table 3-13 (natural gas, biogas). The values in 2017 are also shown in Table 3-75.
- The same emission factors are also applied for the calculation of the emissions resulting from fuel tourism and statistical differences.
- Emission factor for gasoline 2-stroke: For the gasoline part of the fuel, the CO₂ emission factor for gasoline according to Table 3-12 is applied. For the lubricant part of the fuel, the IPCC default CO₂ emission factor for lubricants is applied (see Table 4-35). 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).

CH₄

- Country-specific emission factors are applied. For details including data sources see below ("*Country-specific emission factors*"). Note that updated emission factors are applied for the current submission.
- CH₄ emissions from fuel tourism: From the territorial model, implied emission factors for CH₄ 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 3.2.9.4).
- For biofuels, no country-specific EFs for CH₄ are available. Therefore, emissions have been estimated using the EFs for alternative fuel vehicles provided in table 3.2.4 on page 3.23 of Volume 2 of the 2006 IPCC Guidelines (IPCC 2006).

N₂O

- N₂O emissions from territorial traffic under warm operating condition: Country-specific emission factors are used, details see below (INFRAS 2017a).
- Cold start emission factors are not included in the Handbook of Emissions Factors and are therefore taken from the COPERT model for gasoline PC and for LDV for the base and the latest year (1990 and 2017; EMEP/EEA 2016, chapter on 1A3b). Values in-between are linearly interpolated. Example 2017: 9 mg/start for PC and 17 mg/start for LDV. For the on-going update of the road transportation model, N₂O cold start emission will be implemented consistently with all other cold start emissions since it is planned to integrate N₂O cold start emission factors in the next version of the "Handbook of Emission Factors for Road Transport" (the update is on-going, the results will be available in one of the next submissions, see planned improvements chp. 3.2.9.6)
- N₂O emissions from fuel tourism: The same approach as for CH₄ is applied (see paragraph above) by means of mean emission factors (country-specific).
- For biofuels no country-specific EFs for N₂O are available. Therefore, emissions have been estimated using the EFs for alternative fuel vehicles provided in table 3.2.4 on page 3.23 of Volume 2 of the 2006 IPCC Guidelines (IPCC 2006). The value of 101 mg/km from the 2006 IPCC Guidelines was used for urban buses running on CNG only. For the bi-fuel passenger cars, it is assumed that they use gasoline mainly during the start but otherwise run on CNG; therefore the respective CNG emission factor for light duty vehicles of 27 mg/km from the same source was applied.

Country-specific emission factors

Emission factors for other gases are country-specific, derived from "emission functions" which are determined from a compilation of measurements from various European countries with programs 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 and latest in 2017. These emission factors are compiled in a "Handbook of Emission Factors for Road Transport" (HBEFA, see INFRAS 2017a). The latest version 3.3 – which was used for an update of the emissions in the current submission, resulting in a recalculation of the complete time series – is presented on the website <http://www.hbefa.net/> and documented in Keller et al. (2017) and Hausberger and Matzer (2017). Further descriptions can also be found in the former

publication FOEN (2010i). The emission factors refer to the so-called “traffic situations”, which represents characteristic patterns of driving behaviour and further technical and topographic features. 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. Corrective factors are provided to account for future technologies. Further details are shown in Annex A3.1.3.

Implied emission factors for GHG, precursors and SO₂

The following Table 3-75 presents mean emission factors for GHG, precursors and SO₂ in 2017. 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 (mandatory use of catalytic converters for gasoline cars and lower limits for sulphur content in diesel fuels). Early models of catalytic converters have been substantial sources of N₂O, leading to an emission increase until 1998. Recent converter technologies have overcome this problem resulting in a decrease of the (mean) emission factor. Note that for submission 2019, a consistency error in CO₂ emission factors for gas/biogas was corrected, now there is no difference of the emission factors between the vehicle categories.

Table 3-75 Implied emission factors in 2017 for road transportation. For more details see Annex A3.1.3.

1A3b Road Transportation Gasoline / Bioethanol	CO₂	CH₄	N₂O	NO_x	NMVOC	SO₂	CO
	kg/TJ						
Passenger cars	73'800	3.7	0.6	32	61	0.38	508
Light duty vehicles	73'800	8.0	2.0	118	128	0.38	1789
Heavy duty vehicles	NO	NO	NO	NO	NO	NO	NO
Motorcycles	73'800	45	1.4	144	295	0.38	3901
Fuel tourism and statistical differences	73'800	5.0	0.6	37	74	0.38	629

1A3b Road Transportation Diesel / Biodiesel	CO₂	CH₄	N₂O	NO_x	NMVOC	SO₂	CO
	kg/TJ						
Passenger cars	73'300	0.18	2.0	269	7.2	0.47	38
Light duty vehicles	73'300	0.15	1.9	291	6.1	0.47	39
Heavy duty vehicles	73'300	0.15	3.6	232	5.9	0.47	67
Motorcycles	NO	NO	NO	NO	NO	NO	NO
Fuel tourism and statistical differences	73'300	0.17	2.5	260	6.7	0.47	47

1A3b Road Transportation Gas / Biogas	CO₂	CH₄	N₂O	NO_x	NMVOC	SO₂	CO
	kg/TJ						
Passenger cars	56'300	5.6	NA	28	0.49	NA	196
Light duty vehicles	56'300	4.54	NA	13	0.39	NA	498
Heavy duty vehicles	56'300	10.0	NA	132	0.87	NA	84
Motorcycles	NO	NO	NO	NO	NO	NO	NO
Fuel tourism and statistical differences	56'300	7.9	NA	83	0.7	NA	148.7

Activity data (1A3b)

Energy-related activity data (basis for modelling the CO₂ emissions)

The Swiss overall energy statistics (SFOE 2018) 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.

The consumption of biofuels is based on the Swiss overall energy statistics (SFOE 2018), the Swiss renewable energy statistics (SFOE 2018a) and the Federal Customs Administrations (FCA 2018). Note that the NCV of biogas used in 1A3b is kept constant for the whole period 1997-2017. The value is 45.7 GJ/t. It corresponds to the value of the years 1995, 2013, 2014, but deviates slightly (max. 3%) from the values of the other years (see NCV time series for natural gas and biogas in Table 3-10).

Table 3-76 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 road transportation are given as two different contributions in the rows "on road fuel consumption (model)" and "fuel tourism and statistical differences".
- The emissions from natural gas combustion for road transportation originate from activity data of two vehicle categories: CNG/passenger cars and urban buses running purely on CNG. Data source is FCA (2018).
- Consumption of biofuels for road transportation (biodiesel, bioethanol and biogas) starts in Switzerland in 1997.

Table 3-76 Split of fuel sales between territorial “on-road consumption (model)”, “non-road consumption (models)” and “fuel tourism and statistical differences” (residual value to sales amounts) for gasoline, diesel oil, natural gas (CNG) 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
PJ					
Gasoline					
on-road consumption (model)	1A3b	144.2	141.1	148.4	134.8
fuel tourism and statistical differences	1A3b	9.2	7.8	17.5	15.2
non-road consumption (models)	1A2gvii; 1A3dii; 1A4aii,bii,cii; 1A5b	2.4	2.4	2.3	2.1
Gasoline sold in Switzerland		155.8	151.3	168.2	152.1
Diesel oil					
on-road consumption (model)	1A3b	38.3	41.3	46.0	60.2
fuel tourism and statistical differences	1A3b	-2.5	-5.8	-4.4	-1.6
non-road consumption (models)	1A2gvii; 1A3c,dii; 1A4cii; 1A5b	11.0	12.4	13.5	13.9
Diesel oil sold in Switzerland		46.7	47.8	55.2	72.6
Natural gas					
on-road consumption (model)	1A3b	NO	NO	NO	0.1
fuel tourism and statistical differences	1A3b	NO	NO	NO	0.1
non-road consumption (models)		NO	NO	NO	NO
Natural gas sold in on- and non-road categories in Switzerland		NO	NO	NO	0.2
Liquefied petroleum gas					
on-road consumption (model)	1A3b	NO	NO	NO	NO
non-road consumption (models)	1A2gvii	0.2	0.2	0.3	0.3
LPG sold in on- and non-road categories in Switzerland		0.2	0.2	0.3	0.3
Biodiesel					
on-road consumption (model)	1A3b	NO	NO	0.1	0.4
non-road consumption (models)	1A2gvii; 1A3c,dii; 1A4cii; 1A5b	NO	NO	0.02	0.05
Biodiesel sold in Switzerland		NO	NO	0.1	0.5
Bioethanol					
on-road consumption (model)	1A3b	NO	NO	NO	0.02
non-road consumption (models)	1A2gvii; 1A3dii; 1A4bii; cii; 1A5b	NO	NO	NO	NO
Bioethanol sold in Switzerland		NO	NO	NO	0.02
Biogas					
on-road consumption (model)	1A3b	NO	NO	NO	0.0
non-road consumption (models)		NO	NO	NO	NO
Biogas sold in Switzerland		NO	NO	NO	NO

Activity data for on-road and non-road categories	Source category	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
PJ											
Gasoline											
on-road consumption (model)	1A3b	122.3	119.0	115.3	111.6	107.8	104.0	100.7	97.1	94.4	90.7
fuel tourism and statistical differences	1A3b	18.5	18.0	16.8	15.3	14.6	12.9	11.4	6.8	6.3	6.8
non-road consumption (models)	1A2gvii; 1A3dii; 1A4aii,bii,cii; 1A5b	2.0	1.9	1.9	1.9	1.8	1.8	1.7	1.7	1.7	1.6
Gasoline sold in Switzerland		142.8	139.0	134.0	128.9	124.3	118.6	113.9	105.6	102.3	99.2
Diesel oil											
on-road consumption (model)	1A3b	72.0	75.8	80.2	84.8	89.5	94.7	98.7	102.1	104.5	106.6
fuel tourism and statistical differences	1A3b	6.2	3.8	2.8	0.9	2.4	2.0	0.9	-4.0	-5.2	-7.5
non-road consumption (models)	1A2gvii; 1A3c,dii; 1A4cii; 1A5b	14.4	14.6	14.8	14.8	14.8	14.8	14.8	14.8	14.7	14.7
Diesel oil sold in Switzerland		92.7	94.1	97.8	100.5	106.6	111.5	114.4	112.8	114.1	113.7
Natural gas											
on-road consumption (model)	1A3b	0.5	0.6	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6
fuel tourism and statistical differences	1A3b	0.3	0.2	0.3	0.4	0.3	0.3	0.3	0.3	0.2	0.2
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		0.7	0.8	1.0	1.1	1.0	1.0	1.0	0.9	0.8	0.8
Liquefied petroleum gas											
on-road consumption (model)	1A3b	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
non-road consumption (models)	1A2gvii	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
LPG sold in on- and non-road categories in Switzerland		0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
Biodiesel											
on-road consumption (model)	1A3b	0.4	0.3	0.3	0.3	0.3	0.2	0.5	1.2	2.1	3.4
non-road consumption (models)	1A2gvii; 1A3c,dii; 1A4cii; 1A5b	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.4
Biodiesel sold in Switzerland		0.4	0.3	0.4	0.4	0.4	0.4	0.7	1.5	2.4	3.8
Bioethanol											
on-road consumption (model)	1A3b	0.1	0.0	0.05	0.1	0.1	0.1	0.2	0.6	0.8	1.1
non-road consumption (models)	1A2gvii; 1A3dii; 1A4bii; cii; 1A5b	0.0000	0.0000	0.0000	0.002	0.004	0.01	0.01	0.01	0.02	0.02
Bioethanol sold in Switzerland		0.1	0.0	0.1	0.1	0.1	0.1	0.2	0.6	0.8	1.1
Biogas											
on-road consumption (model)	1A3b	0.06	0.09	0.11	0.1	0.1	0.1	0.1	0.1	0.1	0.1
non-road consumption (models)		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Biogas sold in Switzerland		0.06	0.09	0.11	0.09	0.1	0.1	0.1	0.1	0.1	0.1

Mileage-related activity data (basis for modelling of the non-CO₂ emissions by means of a traffic model)

The activity data are derived from different data sources:

- Vehicle stock: The federal vehicle registration database MOFIS (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 ordinary vehicle stock numbers are published by the Swiss Federal Statistical Office (SFSO 2018e). With the help of a fleet turnover model, the vehicle categories are 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 transport performance, i.e. the mileage per vehicle category is an input from Swiss Federal Statistical Office (SFSO 2018f, 2018g). It is based on periodical surveys/Mikrozensus (ARE 2002, ARE/SFSO 2005, ARE/SFSO 2012). By means of the vehicle stock data (see paragraph above), the specific mileage per vehicle category can be derived (SFOE 2017e, SFOE 2017f, INFRAS 2017).
- Numbers of starts/stops: Derived from vehicles stock, with data on trip length distributions and parking time distributions (ARE/SFSO 2005, ARE/SFSO 2012).

The transport performance is attributed to “traffic situations” (characteristic patterns of driving behaviour) which serve as a key to select the appropriate emission factor and 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 2010). 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 3-77 shows the time series of the mileage per vehicle category. The total mileage has constantly been growing since 1995. 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 3-78 that shows the specific fuel consumption per vehicle-km. Average consumption and the specific consumption for most of the vehicle categories has decreased in the period 1990–2017.

Table 3-77 Mileages in millions of vehicle kilometres. PC: passenger cars, LDV: light duty vehicles, HDV: heavy duty vehicles).

Veh. category	1990	1995	2000	2005
	million vehicle-km			
PC	42'649	41'324	45'613	48'040
LDV	2'600	2'746	2'957	3'228
HDV	1'992	2'107	2'273	2'120
Coaches	108	110	99	106
Urban Bus	174	192	200	229
2-Wheelers	2'025	1'563	1'700	1'785
Sum	49'548	48'042	52'841	55'507
(1990=100%)	100%	97%	107%	112%

Veh. category	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	million vehicle-km									
PC	49'467	50'373	50'949	51'575	52'582	53'493	54'313	55'114	55'726	55'765
LDV	3'415	3'432	3'502	3'635	3'776	3'874	3'998	4'129	4'290	4'221
HDV	2'218	2'164	2'226	2'258	2'229	2'243	2'236	2'235	2'235	2'283
Coaches	114	116	118	122	124	125	128	131	151	133
Urban Bus	228	238	244	250	254	262	267	272	259	285
2-Wheelers	1'850	1'847	1'852	1'894	1'934	1'957	1'992	2'027	2'054	2'051
Sum	57'292	58'171	58'891	59'734	60'899	61'953	62'933	63'908	64'716	64'739
(1990=100%)	114%	116%	117%	119%	121%	123%	125%	127%	129%	131%

Table 3-78 Specific fuel consumption of road transport, excluding fuel tourism and statistical differences. Numbers include additional fuel consumption by cold starts.

Veh. cat.	Fuel	1990	1995	2000	2005
		MJ/veh-km			
PC	Gasoline	3.37	3.44	3.35	3.23
	Diesel	3.60	3.61	3.49	3.02
	CNG	NO	NO	NO	NO
LDV	Gasoline	3.32	3.30	3.29	3.31
	Diesel	3.93	3.92	3.81	3.53
HDV	Diesel	11.3	11.2	10.7	11.0
Coach	Diesel	12.4	12.2	11.8	11.7
Urban Bus	Diesel	15.8	15.9	15.5	15.1
	CNG	NO	NO	NO	NO
2-Wheeler	Gasoline	1.24	1.33	1.25	1.33
Average		3.68	3.80	3.68	3.51
		100%	103%	100%	95%

Veh. cat.	Fuel	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
		MJ/veh-km									
PC	Gasoline	3.12	3.09	3.05	3.02	2.98	2.93	2.89	2.85	2.81	2.77
	Diesel	2.89	2.87	2.85	2.83	2.81	2.80	2.78	2.75	2.71	2.69
	CNG	2.10	2.15	2.10	2.06	2.07	1.99	2.01	1.94	1.99	1.90
LDV	Gasoline	3.33	3.32	3.30	3.29	3.26	3.22	3.17	3.11	3.06	3.02
	Diesel	3.44	3.44	3.44	3.43	3.40	3.37	3.33	3.26	3.20	3.18
HDV	Diesel	10.9	10.9	10.9	10.9	10.9	10.9	10.8	10.7	10.6	10.6
Coach	Diesel	11.6	11.6	11.6	11.7	10.9	10.9	10.8	10.7	11.7	11.7
Urban Bus	Diesel	14.7	14.6	14.5	14.4	14.3	14.3	14.3	14.1	14.0	14.1
	CNG	15.3	15.7	15.5	15.2	15.3	14.7	14.7	14.2	14.7	14.3
2-Wheeler	Gasoline	1.31	1.31	1.31	1.33	1.34	1.32	1.35	1.37	1.35	1.38
Average		3.40	3.35	3.33	3.30	3.25	3.21	3.17	3.12	3.08	3.06
		94%	93%	92%	91%	90%	89%	88%	87%	86%	85%

For modelling of evaporative emissions, the stock, the mileage and the number of stops of gasoline passenger cars and light duty vehicles are used. For modelling of cold start emissions, also start numbers of passenger cars and light duty vehicles are used for activity data. The corresponding numbers are summarised in Table 3-79. Vehicle stock figures correspond to registration data. The starts per vehicle are based on specific surveys (ARE/SFSO 2005, 2012).

Table 3-79 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
	stock in 1000 veh. (gasoline/bioeth.)			
PC	2'831	3'041	3'296	3'224
LDV	167	164	148	114
2-Wheelers	764	688	712	746
	starts per veh. per day			
PC	2.61	2.53	2.46	2.40
LDV	1.97	1.97	1.96	1.96

Veh. Category	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	stock in 1000 veh. (gasoline/bioeth.)									
PC	3'044	2'959	2'922	2'892	2'846	2'795	2'747	2'698	2'663	2'614
LDV	92	85	81	77	73	68	65	62	60	58
2-Wheelers	770	767	766	775	780	793	802	804	803	790
	starts per veh. per day									
PC	2.37	2.35	2.34	2.34	2.33	2.33	2.32	2.33	2.33	2.32
LDV	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96

Further details are given in Annex A3.1.3.

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 CO₂ (based on decision tree Fig. 3.4.1 in IPCC 2006)
- Tier 3 for CH₄, N₂O and precursors/SO₂ (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 CO₂ emission factor applied for the time series 1990–2017 for diesel oil is country-specific and is given in Table 3-12.
- The CH₄ and N₂O emission factors of diesel locomotives are shown in Table 3-80.
- For SO₂ the emission factors are country-specific. See also Table A – 13 (row diesel 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 CH₄ emissions.
- Implied emission factors 2017 are shown in Table 3-81.

All emission factors (GHG, precursors, SO₂) 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 footnote 6, p. 147).

Table 3-80 CH₄ and N₂O 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 ₂ O	all	0.035	0.035	0.035	0.035	0.035

Table 3-81 Implied emission factors 2017 for rail vehicles. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A3c Railways	Unit	CO ₂ fossil	CO ₂ biogen	CH ₄	N ₂ O	NO _x	NMVOC	SO ₂	CO
Diesel oil	kg/TJ	73'300	NA	1.3	3.6	998	116	0.47	532
Biodiesel	kg/TJ	NA	73'300	1.1	3.0	853	99	0.40	455

Activity data (1A3c)

Activity data for non-road (1A3c) 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 3-82 and in Annex A3.1.4.

Table 3-82 Activity data (diesel oil consumption) for railways.

1A3c Railways	Unit	1990	1995	2000	2005
Diesel oil	TJ	390	441	455	472
Biodiesel	TJ	NO	NO	0.6	1.7
Total Railways	TJ	390	441	456	474
1990 = 100%		100%	113%	117%	121%

1A3c Railways	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Diesel oil	TJ	484	488	492	471	451	431	410	390	388	387
Biodiesel	TJ	2.0	2.0	2.1	2.9	3.7	4.4	5.2	5.9	7.7	9.4
Total Railways	TJ	486	490	494	474	455	435	416	396	396	396
1990 = 100%		125%	126%	127%	122%	117%	112%	107%	102%	102%	102%

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 footnote 6, p. 147).

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 3 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.)

The mix of fossil and biofuels was recalculated for all of mobile (road and non-road) sources (INFRAS 2017, 2018).

CO₂ emissions from lubricants of gasoline 2-stroke engines are calculated by using the IPCC default CO₂ 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, CH₄ and N₂O emissions from lubricant use are reported in source category 1A3d, since the emission factors are deduced from measurements including 2-stroke engines.

The mix of fossil and biofuels was recalculated for all non-road vehicles (INFRAS 2018). This also affects navigation (see chp. 3.2.9.5).

Emission factors (1A3d)

- The CO₂ emission factor applied for the time series 1990–2017 for diesel oil, gasoline and gas oil are country-specific and are given in Table 3-12.

- The CH₄ and N₂O emission factors are country-specific and are shown below in Table 3-83 to Table 3-85 for all fuel types and emission standards.
- For SO₂ the emission factors are country-specific. See also Table A – 13 in Annex A3.1.5 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 CH₄ emissions.
- The implied emission factors 2017 are shown in Table 3-86.

All emission factors (GHG, precursors, SO₂) 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 footnote 6, p. 147).

Table 3-83 CH₄ and N₂O 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 ₂ O	all	0.035	0.035	0.035	0.035	0.035

Table 3-84 CH₄ and N₂O 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 ₂ O	0–300	0.01	0.01	0.01	0.03	0.03	0.03

Table 3-85 CH₄ and N₂O 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 ₂ O	0.035	0.035	0.035

Table 3-86 Implied emission factors 2017 for navigation. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A3d Navigation	Unit	CO ₂ fossil	CO ₂ biog.	CH ₄	N ₂ O	NO _x	NM VOC	SO ₂	CO
Gasoline	kg/TJ	73'800	NA	20.9	1.9	541	385	0.38	7'939
Diesel oil	kg/TJ	73'300	NA	1.7	3.4	878	267	0.47	522
Gas oil	kg/TJ	73'700	NA	0.2	0.7	26	1.6	9	6.9
Biodiesel	kg/TJ	NA	73'300	1.4	2.9	751	228	0.40	446
Bioethanol	kg/TJ	NA	73'800	12.4	1.3	348	236	0.24	5'010

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 3-87 and in Annex A3.1.4.

Table 3-87 Fuel consumption of (domestic) navigation.

1A3d Navigation	Unit	1990	1995	2000	2005
Gasoline	TJ	701	654	616	565
Diesel oil	TJ	738	724	792	800
Gas oil	TJ	110	139	147	150
Biodiesel	TJ	NO	NO	1.0	2.9
Bioethanol	TJ	NO	NO	NO	NO
Total Navigation	TJ	1'550	1'517	1'556	1'518
1990 = 100%		100%	98%	100%	98%

1A3d Navigation	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Gasoline	TJ	841	854	868	870	872	874	876	878	873	867
Diesel oil	TJ	547	541	535	530	526	522	518	514	512	511
Gas oil	TJ	155	157	159	157	156	154	153	151	150	149
Biodiesel	TJ	3.4	3.6	3.8	5.7	7.6	9.5	11.5	13.4	17.3	21.2
Bioethanol	TJ	0.0	0.0	0.0	0.8	1.6	2.3	3.1	3.9	6.3	8.6
Total Navigation	TJ	1'546	1'556	1'565	1'564	1'563	1'562	1'561	1'560	1'559	1'557
1990 = 100%		100%	100%	101%	101%	101%	101%	101%	101%	101%	100%

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 footnote 6, p. 147).

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 CO₂, CH₄, N₂O, NO_x, CO, NMVOC and SO₂ 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 CO₂ emission factor applied for the time series 1990–2017 for natural gas is country-specific and is given in Table 3-12.
- The CH₄ emission factor corresponds to the one used for gas turbines in Switzerland (SAEFL 2000) as suggested by expert judgement. The CH₄ 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 CH₄ emissions of the gas turbine.
- For N₂O emission factors the IPCC 2006 default value (Table 3-16) is used as displayed in Table 3-88.
- For SO₂ the emission factors are country-specific. The emission factor 2017 is shown in Table 3-88. See also Table A – 13 in Annex A3.1.5 row natural gas.
- The emission factors for precursors are country-specific and are given in SAEFL (2000); see also EMIS 2019/1A3e “Gasturbinen; Erdgas”.
- The emission factors 2017 are shown in Table 3-88.

Table 3-88 Emission factors of 1A3ei Pipeline transportation / compressor station located in Ruswil in 2017. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A3e Other transportation	Unit	CO ₂ fossil	CH ₄	N ₂ O	NO _x	NMVOC	SO ₂	CO
Gas	kg/TJ	56'300	2.0	0.10	60	0.10	0.50	15

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 2018; Table 17).

Table 3-89 Activity data of 1A3e.

1A3ei Pipeline transport	Unit	1990	1995	2000	2005
Natural gas	TJ	560	310	340	1'070
1990=100%		100%	55%	61%	191%

1A3ei Pipeline transport	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Natural gas	TJ	1'460	950	830	840	810	410	830	760	340	470
1990=100%		261%	170%	148%	150%	145%	73%	148%	136%	61%	84%

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 3-25.

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 passenger (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/100 passenger km is in line with expectations for 1990 passenger fleets.
- The implied emission factors were calculated for 2017 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 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 VFR (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 percents.

- 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 and Switzerland's emission factors

- CO₂ (see also Table 3-26): 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.
- CH₄: 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 22.5 kg/TJ and 3.7 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, whereas Switzerland's range is on a lower level (0.18-1.2 kg/TJ).
- N₂O: 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 4.2 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, whereas Switzerland's range is lower (0.2-2.0 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 been carried out between 2015 and 2017, several experts from the federal administration have conducted the project. The results have undergone extensive plausibility checks and comparisons with earlier estimates.

The emission factors CH₄ and N₂O used for the modelling of 1A3b Road Transportation are taken from the handbook of emission factors (INFRAS 2017b), which is also applied in Germany, Austria, Netherlands, and Sweden. The Swiss emission factors for CH₄ and N₂O used in 1A3b 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 (COPERT⁸). Nevertheless, the use of the implied Swiss emission factors seemed to be the consistent approach. It must be noted, that this comparison was carried

⁸ see European Environment Agency <http://www.eea.europa.eu/publications/TEC05> [19.02.2019]

out with version 3.1 of the “Handbook of Emission Factors for Road Transport”, whereas the current emissions are based on version 3.3. A similar verification with the updated emission factors of version 3.3 of the Handbook (INFRAS 2017a) is not yet possible since the modelling results for implied emission factors of the neighbouring countries are not yet available.

For gasoline, the activity data is easily verified due to the fact, that 98.3% of the gasoline sold 2017 in Switzerland is consumed by 1A3b Road Transportation itself. Therefore, the amount of gasoline reported in the Swiss overall energy statistics is a strong control and verification parameter for the activity data of 1A3b.

3.2.9.5 Category-specific recalculations for 1A3

The following recalculations were implemented in submission 2019. Major recalculations, which contribute significantly to the total differences in emissions of sector 3 Energy between the latest and the previous submission are presented also in chp. 10.1.2.1.

- 1A3b: In the road sector, the ex post analysis 2016 (SFOE 2017e, SFOE 2017f) now forms the basis for the time series up to 2016. For the years starting 2017 (forecast with current data), the same data basis continues to apply as for Submission 2018, i.e. the FOEN pilot study on greenhouse gas emissions up to 2050 (INFRAS 2017).
- The ex post analysis 2016 contains the following new features:
 - New driving performance for 2016 (slightly higher overall than in the pilot study on greenhouse gas emissions).
 - Specific consumption of passenger cars adjusted in 2016.
 - Time series of fuel sales, thus also adjusted proportions of biofuels, especially 2016.
 - Retrospective adjustments to the fleet composition of motorcycles.
 - CO₂ emission factors of the transport model were not linked to so called central emission factors in the EMIS database. This has now been corrected and results in very small recalculations in the years where emission factors are interpolated.

These adjustments lead to 0-0.2% higher energy consumption in the road model without fuel tourism and statistical difference in 1A3bviii and to

- negligible higher CO₂ fossil emissions of 1-50t and a maximum of 560t in 2016
- 1-8% higher CO₂ biog. emissions in 1997-2016
- 0-8% higher CH₄ emissions
- 1A3b: New calculated N₂O emission factors for processes concerning starting engines: a mistake was corrected in the database and N₂O emissions from processes in road transportation using natural gas are judged to be not occurring anymore. These changes lead to 0-4% lower N₂O emissions.
- 1A3b: Due to recalculations in diesel consumption in Liechtenstein, the total of diesel sold in Switzerland has changed slightly (<1%) for the year 2016. This leads also to recalculation in 1A3bviii of -7%.

3.2.9.6 Category-specific planned improvements for 1A3

No category-specific improvements are planned.

3.2.10 Source category 1A4 - Other sectors (mobile)

3.2.10.1 Source category description for 1A4 Other sectors (mobile)

Key categories 1A4

See key categories mentioned in chp. 3.2.7.1, which are vastly dominated by the emissions of the stationary sources except CO₂ from the combustion of Liquid Fuels in 1A4c Agriculture/Forestry/Fishing (level approach 1).

Table 3-90 Specification of source category 1A4 Other sectors (mobile 1A4a ii/b ii/c ii).

1A4	Source	Specification
1A4a ii	Commercial/ institutional	Emission from non-road vehicles (professional gardening) and motorised equipment
1A4b ii	Residential	Emissions from mobile machinery (hobby, gardening) and motorised equipment
1A4c ii	Agriculture/forestry	Emissions from non-road vehicles and machinery in agriculture and forestry

3.2.10.2 Methodological issues for 1A4 Other sectors (mobile)

Methodology (1A4 Other sectors, mobile)

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.

CO₂ emissions from lubricants of gasoline 2-stroke engines are calculated by using the IPCC default CO₂ 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, CH₄ and N₂O emissions from lubricant use in 2-stroke engines are reported in the corresponding source category in 1A4 (mobile), since the emission factors are based on measurements including 2-stroke engines.

Emission factors (1A4 Other sectors, mobile)

In the categories 1A4a ii and 1A4b ii only gasoline is being used as fuel. In category 1A4c ii mainly diesel oil is consumed (more than 80%, see Table 3-92) and only a small amount of gasoline e.g. chainsaws (less than 20%).

- The CO₂ emission factors applied for the time series 1990–2017 are country-specific and are given in Table 3-12.
- The CH₄ and N₂O emission factors are country-specific and are shown in Table 3-66 and Table 3-67 for diesel oil and gasoline engines for all emission standards.

- For SO₂ the emission factors are country-specific. See also Table A – 13 in Annex A3.1.5 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 CH₄ emissions.
- Implied emission factors 2017 are shown in Table 3-91.

All emission factors (GHG, precursors, SO₂) 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 footnote 6, p. 147).

Table 3-91 Implied emission factors 2017 for 1A4 Other sectors (1A4aii – 1A4cii mobile). Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A4 Non-road machinery	Unit	CO ₂ fossil	CO ₂ biog.	CH ₄	N ₂ O	NO _x	NMVOC	SO ₂	CO
1A4a ii Gardening professional									
Gasoline	kg/TJ	73'800	NA	88	1.1	185	1'412	0.4	26'504
Bioethanol	kg/TJ	NA	73'800	17	1.0	86	487	0.2	15'561
1A4b ii Gardening									
Gasoline	kg/TJ	73'800	NA	47	1.4	157	965	0.4	25'117
Bioethanol	kg/TJ	NA	73'800	17	1.0	94	477	0.2	15'621
1A4c ii Forestry and agriculture									
Gasoline	kg/TJ	73'800	NA	84	1.1	175	1'477	0.4	24'066
Diesel oil	kg/TJ	73'300	NA	1.4	3.0	459	54	0.5	269
Biodiesel	kg/TJ	NA	73'300	1.2	2.6	393	46	0.4	230
Bioethanol	kg/TJ	NA	73'800	20.9	0.9	82	595	0.2	14'768

Activity data (1A4 Other sectors, mobile)

Activity data are described in chp. 3.2.4.5.1 (non-road transportation model) and are shown in Table 3-92 and in Annex A3.1.4.

Table 3-92 Activity data for non-road vehicles and machinery in 1A4 Other sectors (mobile).

1A4 Non-road machinery	Unit	1990	1995	2000	2005
1A4a ii Gardening professional					
Gasoline	TJ	191	245	295	295
Bioethanol	TJ	NO	NO	NO	NO
1A4b ii Gardening					
Gasoline	TJ	142	155	165	166
Bioethanol	TJ	NO	NO	NO	NO
1A4c ii Forestry and agriculture					
Gasoline	TJ	1'160	1'070	963	824
Diesel oil	TJ	4'269	4'604	4'920	4'802
Biodiesel	TJ	NO	NO	6	17
Bioethanol	TJ	NO	NO	NO	NO
Total 1A4 non-road machinery	TJ	5'761	6'073	6'349	6'103
Relative values 1A4 (1990 = 100%)		100%	105%	110%	106%

1A4 Non-road machinery	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1A4a ii Gardening professional											
Gasoline	TJ	290	289	287	280	273	266	260	253	251	250
Bioethanol	TJ	0.002	0.003	0.004	0.24	0.48	0.72	0.95	1.2	1.9	2.6
1A4b ii Gardening											
Gasoline	TJ	164	163	163	162	160	159	158	156	155	154
Bioethanol	TJ	0.002	0.003	0.003	0.21	0.43	0.64	0.85	1.1	1.7	2.3
1A4c ii Forestry and agriculture											
Gasoline	TJ	743	716	689	665	641	616	592	568	551	535
Diesel oil	TJ	4'850	4'866	4'882	4'876	4'870	4'864	4'859	4'853	4'835	4'817
Biodiesel	TJ	20	20	21	32	42	53	63	74	96	118
Bioethanol	TJ	0.01	0.01	0.01	0.66	1.3	2.0	2.6	3.3	4.8	6.4
Total 1A4 non-road machinery	TJ	6'066	6'054	6'042	6'015	5'989	5'962	5'936	5'909	5'898	5'886
Relative values 1A4 (1990 = 100%)		105%	105%	105%	104%	104%	103%	103%	103%	102%	102%

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 footnote 6, p. 147).

3.2.10.3 Uncertainties and time-series consistency for 1A4 Other sectors, mobile

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 3-25.

3.2.10.4 Category-specific QA/QC and verification for 1A4 Other sectors, 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.

3.2.10.5 Category-specific recalculations for 1A4 Other sectors, mobile

No category-specific recalculations were carried out.

3.2.10.6 Category-specific planned improvements for 1A4 Other sectors, mobile

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 3-93 Specification of Swiss source category 1A5 Other.

1A5	Source	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.

Emission factors (1A5bi Other, military aviation)

- The CO₂ emission factor applied for the time series 1990–2017 for kerosene is country-specific and is given in Table 3-12.
- CH₄: Because there is no split in LTO and cruise flights in military aviation, the CH₄ 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.
- N₂O: the emission factor is set equal to the emission factor of 1A3a Civil aviation (FOCA 2017), where the 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 information from the Federal Department of Defence, Civil Protection and Sport (DDPS) concerning fuel consumption per aircraft type in the year 2016-2017 (DDPS 2018b). These emission factors stay constant for the whole timeseries from 1990 onwards.
- SO₂: the emission factor is taken from the EMEP/EEA Guidebook (EMEP/EEA 2016, Table 3.11, row “Switzerland/CCD”⁹) and is assumed to be constant over the period 1990–2017.
- Implied emission factors 2017 are shown in Table 3-94.

⁹ CCD: climb/cruise/descent

Table 3-94 Implied emission factors 1A5bi military aviation in 2017. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A5bi Military aviation	Unit	CO ₂ fossil	CH ₄	N ₂ O	NO _x	NM VOC	SO ₂	CO
Jet kerosene	kg/TJ	72'800	0.50	2.0	232	33	23	235

Activity data (1A5bi Other, military aviation)

The fuel consumption 1990–2017 is known on an annual basis (DDPS 2018a). 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 IPCC Guidelines (2006, chp. 3.6.1.4).

Table 3-95 Activity data (fuel consumption) for military aviation.

1A5 Other Military aviation	1990	1995	2000	2005
	fuel consumption in TJ			
Jet kerosene	2'733	1'955	1'794	1'624

1A5 Other Military aviation	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	fuel consumption in TJ									
Jet kerosene	1'505	1'529	1'592	1'420	1'527	1'542	1'615	1'567	1'627	1'469

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 the decision tree Fig. 3.3.1 in chp. 3. Mobile Combustion in IPCC (2006).

CO₂ emissions from lubricants of gasoline 2-stroke engines are calculated by using the IPCC default CO₂ 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, CH₄ and N₂O 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 CO₂ emission factors applied for the time series 1990–2017 for diesel oil, gasoline and biofuels are country-specific as shown in Table 3-12.
- The CH₄ and N₂O emission factors are country-specific and are shown in Table 3-66 to Table 3-68 for diesel oil and gasoline engines for all emission standards.
- For SO₂ the emission factors are country-specific. See Table A – 13 in Annex A3.1.5, 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 CH₄ emissions.
- Implied emission factors are shown in Table 3-96.

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 footnote 6, p. 147).

Table 3-96 Implied emission factors 1A5bii military non-road vehicles 2017. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A5bii Military non-road	Unit	CO ₂ fossil	CO ₂ biog.	CH ₄	N ₂ O	NO _x	NMVOC	SO ₂	CO
Gasoline	kg/TJ	73'800	NA	41.9	1.5	133	774	0.38	24199
Diesel	kg/TJ	73'300	NA	0.81	3.0	402	33	0.47	172
Biodiesel	kg/TJ	NA	73'300	0.69	2.6	343	28	0.40	147
Bioethanol	kg/TJ	NA	73'800	10.8	1.0	72	301	0.24	15371

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 3-97 and in Annex A3.1.4.

Table 3-97 Activity data (fuel consumption) for military non-road vehicles.

1A5bii Military non-road	1990	1995	2000	2005
	fuel consumption in TJ			
Military non-road	239	248	252	257
Gasoline	19	19	19	19
Diesel	220	228	233	238
Biodiesel	NO	NO	0.30	0.86
Bioethanol	NO	NO	NO	NO

1A5bii Military non-road	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	fuel consumption in TJ									
Military non-road	268	272	275	275	275	275	275	275	274	273
Gasoline	18	18	18	18	18	17	17	17	17	16
Diesel	249	252	256	256	255	255	254	254	252	250
Biodiesel	1.0	1.1	1.1	1.7	2.2	2.8	3.3	3.9	5.0	6.1
Bioethanol	0.0002	0.0003	0.0004	0.02	0.05	0.07	0.09	0.11	0.18	0.25

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 footnote 6, p. 147).

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 3-25.

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)

The following recalculations were implemented in submission 2019. Major recalculations, which contribute significantly to the total differences in emissions of sector 3 Energy between the latest and the previous submission are presented also in chp. 10.1.2.1.

- 1A5b: The emission factor of CH₄ from military aviation has been revised for the years 1990-2016 based on the Tier 1 emission factor from the IPCC Guidelines 2006.

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 3-98 Key categories (KCA incl. LULUCF) of 1B Fugitive emissions from fuels.

Code	IPCC Category	GHG	Identification Criteria
1B2	Oil and natural gas energy production	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 3-99 Specification of source category fugitive emissions from 1B2a Oil in Switzerland.

1B2	Source	Specification
1B2a ⁱⁱⁱ	Fugitive emissions oil: Transport	Emissions only stem from pipeline transport
1B2a ^{iv}	Fugitive emissions oil: Refining / storage	Emissions from oil refining process
1B2a ^v	Fugitive emissions oil: Distribution of oil products	Distribution of oil products (from gasoline storage tanks and gasoline stations) (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 1 (1B2aiii Fugitive emissions oil: Transport) and a Tier 2 (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 2016, Figure 3-1).

For source 1B2a fugitive emissions from oil, fugitive emissions of CH₄ are reported, which occur only in 1B2aiii Transport and 1B2aiv Refining/storage. Indirect CO₂ emissions resulting from NMVOC emissions in source category 1B2a are reported in chp. 9. For CO complete oxidation is assumed and therefore there are no indirect CO₂ emissions from CO.

Emission factors (1B2a)

For oil transport (1B2aiii), the default emission factors from the 2006 IPCC Guidelines for pipeline transportation are used to calculate emissions. Values provided in Table 3-100 are converted using a crude oil density of 0.82 t/m³.

For oil refining and storage (1B2aiv), country-specific emission factors for CH₄ and NMVOC are used. The emission factors for CH₄ are delineated from an emission estimation project in one of the refineries in 1992 called CRISTAL (Raffinerie de Cressier 1992). The estimation 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 2019/1B2aiv). This emission factor is used for all the years until 1995. For the years 2007-2017 total NMVOC emissions from 1A1b, 1B2aiv and 1B2c correspond to those reported in the E-PRTR database from the two refineries. Therefore emission factors in 1B2aiv are adapted to reach the total NMVOC emission reported in E-PRTR. Between the years 1995 and 2017 the emission factors are interpolated linearly. The ratio between CH₄ and NMVOC stays 1:10 for all the years.

The emission factors for SO₂ 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 for oil distribution from tanks and gasoline stations 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 2019/1B2av Benzinumschlag Tanklager and EMIS 2019/1B2av 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 3-100 Emission factors for fugitive emissions of source category 1B2a Oil in 2017.

Source/fuel	Unit	CO ₂	CH ₄	N ₂ O	NO _x	NMVOC	SO ₂	CO
1B2a Oil								
Exploration	g/t	NO	NO	NO	NO	NO	NO	NO
Production	g/t	NO	NO	NO	NO	NO	NO	NO
Transport (crude oil in pipeline)	g/t	NA	6.59	NA	NA	65.9	NA	NA
Refining/Storage	g/t	NA	11	NA	NA	112	38	NA
Distribution of oil products: Gasoline storage tank	g/GJ	NA	NA	NA	NA	6.7	NA	NA
Distribution of oil products: Gasoline station	g/GJ	NA	NA	NA	NA	9.3	NA	NA

Activity data (1B2a)

For oil transport (1B2aⁱⁱⁱ) and oil refining and storage (1B2a^{iv}), activity data (crude oil use in the refineries) are based on annual statistics of the Swiss petroleum association (EV 2018). The annual amount of processed crude oil in Claus units is based on the Swiss overall energy statistics (SFOE 2018).

For oil distribution from storage tanks and gasoline stations (1B2a^v), gasoline sales based on the Swiss overall energy statistics (SFOE 2018), corrected for consumption of Liechtenstein, are used as activity data.

Table 3-101 Activity data for fugitive emissions from 1B2a Oil.

1B2a Oil products	Unit	1990	1995	2000	2005
Crude oil import (pipeline)	kt	3'127	4'657	4'649	4'877
Gasoline transport	TJ	156'516	151'672	168'353	152'182

1B2a Oil products	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Crude oil import (pipeline)	kt	5'133	4'833	4'546	4'452	3'455	4'935	4'975	2'836	3'006	2'889
Gasoline transport	TJ	142'904	139'067	134'129	128'941	124'386	118'717	113'954	105'664	102'367	99'223

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 2019. Major recalculations which contribute significantly to the total differences in emissions of sector 3 Energy between the latest and the previous submission are presented also in chp. 10.1.2.1.

- 1B2a: The NMVOC and CH₄ emissions of leakage losses in refineries have been modified the way that the total NMVOC emissions from refineries (i.e. 1A1b + 1B2 excluding pipeline transport) from 2007 onwards are the same as those reported in the E-PRTR database. The emission factors are now interpolated linearly from 1995 to 2007. For the years before 1995 the emission factors are taken from a study carried out at that time and have not been changed. The ratio CH₄:NMVOC remains 1:10 over the entire period.

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 3-102 Specification of source category fugitive emissions from 1B2b Natural gas in Switzerland.

1B2	Source	Specification
1B2b	Fugitive emissions attributed to natural gas	Emissions from gas network

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. 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 are only available for the years 1990–1994 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, CO₂, CH₄ 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 CO₂ emissions resulting from NMVOC emissions in this source category are reported in chp. 9. For CO complete oxidation is assumed and therefore there are no indirect CO₂ emissions from CO.

Emission factors (1B2b)

For natural gas production, CO₂, CH₄ and NMVOC default emission factors are taken from the 2006 IPCC Guidelines (IPCC 2006) as documented in the internal emission database documentation (EMIS 2019/1B2b Diffuse Emissionen Erdgas).

Emission factors for transmission, distribution and other leakages (source categories 1B2biv, 1B2bv, and 1B2bvi) are calculated based on the weighted average CO₂, CH₄, 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 2019/1B2b Diffuse Emissionen Erdgas).

Table 3-103 Emission factors for fugitive emissions of source category 1B2b Natural gas in 2017.

1B2b Natural gas	CO ₂ g/GJ	CH ₄ g/GJ	N ₂ O g/GJ	NO _x g/GJ	NMVOC g/GJ	SO ₂ g/GJ	CO g/GJ
1B2b ii Production	NO	NO	NO	NO	NO	NO	NO
1B2b iv Transmission	645	17'867	NA	NA	1'400	NA	NA
1B2b v Distribution	645	17'867	NA	NA	1'400	NA	NA
1B2b vi Other Leakage	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 2018).

For gas transmission (1B2biv), distribution (1B2bv), and other leakage (1B2bvi), the activity data have been reassessed in a recent study by Quantis (2014) and updated in 2016 (EMIS 2019/1B2b Diffuse Emissionen Erdgas). The activity data represent the amount of natural gas lost from the gas network and are shown in Table 3-104.

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 2019/1B2b 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 CH₄ emissions from gas transmission and distribution decreased due to gradual replacement of cast-iron pipes with polyethylene pipes.

Table 3-104 Activity data (amount of gas lost) for fugitive emissions from 1B2b Natural gas

1B2b Natural Gas	Unit	1990	1995	2000	2005
1B2b Natural gas	GJ	868'472	847'902	687'838	545'527
1B2b ii Production	GJ	130'000	NO	NO	NO
1B2b iv Transmission	GJ	28'226	30'874	32'571	33'491
1B2b v Distribution	GJ	710'246	817'028	655'267	512'036
1B2b vi Other Leakage	GJ	NO	NO	NO	NO

1B2b Natural Gas	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1B2b Natural Gas		506'306	493'783	484'013	476'426	470'028	434'845	424'435	423'719	425'928	426'781
1B2b ii Production	GJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B2b iv Transmission	GJ	34'572	34'586	34'595	34'569	34'483	34'852	35'125	35'468	35'743	35'813
1B2b v Distribution	GJ	471'734	459'197	449'418	441'857	435'545	399'993	389'310	388'251	390'185	390'968
1B2b vi Other Leakage	GJ	NO	NO	35'444	28'114	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 CH₄ 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 2019/1B2b Diffuse Emissionen Erdgas).

3.3.4.5 Category-specific recalculations for 1B2b

The following recalculations were implemented in submission 2019. Major recalculations which contribute significantly to the total differences in emissions of sector 3 Energy between the latest and the previous submission are presented also in chp. 10.1.2.1.

- 1B2biv, 1B2bv and 1B2bvi: Recalculation of the EF for CO₂ emissions of transmission and storage, distribution and other leakages of natural gas for 1990-2016. For the calculation of the EF the share of CO₂ provided by the Swiss Gas and Water Industry Association (SGWA) has erroneously been interpreted as referring to mass instead of referring to volume in previous submissions. Correcting this issue, the EF for CO₂ has now further been based on the complete data provided by the Swiss Gas and Water Industry Association (SGWA), while previously only the data from one single year has been considered.
- 1B2b: The calorific value is rounded less strongly in the calculation model, therefore a slight shift occurred in the calculation of activity data and emission factors of CH₄ and NMVOC.

3.3.4.6 Category-specific planned improvements for 1B2b

- 1B2b: In collaboration with the Swiss Gas and Water Industry Association (SGWA), fugitive emissions from the gas network will be re-assessed and updated in the greenhouse gas inventory as appropriate.

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 (1B2c i Flaring). Since 2015, there is only one refinery in operation. In addition, CO₂ emissions from H₂ production in one of the two refineries are also reported under 1B2c.

Table 3-105 Specification of source category 1B2c Venting and flaring in Switzerland.

1B2	Source	Specification
1B2 c	Fugitive emissions attributed to venting and flaring.	The combustion of excess gas at the oil refinery (flaring) only. Emissions from H ₂ production Emissions from gas production (1990-1994 only)

3.3.5.2 Methodological issues for 1B2c

Methodology (1B2c)

According to the decision tree for crude oil transport, refining and upgrading, Switzerland follows a Tier 2 method for emissions 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 emission calculations country-specific emission factors and activity data are available from the refining industry. For source category 1B2ci Flaring, Oil, emissions of CO₂ as well as CH₄, N₂O, NO_x, CO and NMVOC are considered.

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 CO₂ as well as CH₄, N₂O and NMVOC are considered.

One of the refining plants produces H₂. Until 2017, butane was used for the production of H₂, leading to process emissions of CO₂. 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.

Since the CO₂ emission factors assume an oxidation of 100%, no indirect emissions need to be accounted for. Therefore, from this source category no indirect emissions are reported in chp. 9.

Emission factors (1B2c)

Emission factors are based on data from the refining industry as documented in the internal emission database documentation (EMIS 2019/1B2c Raffinerie Abfackelung). Since 2005 (with the exception of 2012), the refining industry provides annual data on the emissions from flaring under the Federal Act on the Reduction of CO₂ Emissions (Swiss Confederation 2011) based on daily measurements of CO₂ emission factors of the flared gases. From these data annual emission factors are derived. Since 2005, the evolution of the other emission factors (CH₄, N₂O, NO_x, CO and NMVOC) is assumed to vary proportionally to the CO₂ 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.

Emission factors for butane production are confidential. Data are available to reviewers on request.

Table 3-106 Emission factors for 1B2c Venting and flaring in 2017.

Source/fuel	Unit	CO ₂	CH ₄	N ₂ O	NO _x	NMVOC	SO ₂	CO
1B2ci Flaring Oil	g/t	C	C	C	C	C	C	C
1B2cii Flaring from gas production	g/GJ	NO	NO	NO	NA	NO	NA	NA
1B2ci: H ₂ production refinery (butane)	g/GJ	C	NA	NA	NA	NA	NA	NA
1B2ci: H ₂ production refinery (natural gas)	g/GJ	C	NA	NA	NA	NA	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. The Swiss petroleum association provides data on the use of crude oil on an annual basis (EV 2018). 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 H₂ production in one of the refining plants, annual data on butane consumption are provided by the industry since 2005, when the H₂ production unit was installed. Data are confidential and they are available to reviewers on request.

Table 3-107 Activity data for 1B2c Venting/flaring.

1B2c Venting and flaring	Unit	1990	1995	2000	2005
1B2ci Flaring Oil: Crude oil used	kt	3'127	4'657	4'649	4'877
1B2cii Flaring Gas	GJ	130'000	NO	NO	NO
1B2ci H2 production in refinery (butane and natural gas)	GJ	NO	NO	NO	C

1B2c Venting and flaring	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1B2ci Flaring Oil: Crude oil used	kt	5'133	4'833	4'546	4'452	3'455	4'935	C	C	C	C
1B2cii Flaring Gas	GJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B2ci H2 production in refinery (butane and natural gas)	GJ	C	C	C	C	C	C	C	C	C	C

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

The following recalculations were implemented in submission 2019. Recalculations cause a change in emission levels in 1990 or 2016 by less than 1 kt CO₂.

- Emission factor for flaring in refineries changed due to less rounding. This results in 20-30% higher or lower CH₄ emissions for 1B2c.

3.3.5.6 Category-specific planned improvements for 1B2c

No category-specific improvements are planned.

3.4 Source category 1C – CO₂ transport and storage

CO₂ transport and storage is not occurring in Switzerland.

4 Industrial processes and product use (IPPU)

Responsibilities for sector Industrial Processes and product use (IPPU)	
Method updates & authors	Sabine Schenker (FOEN), Cornelia Stettler (Carbotech; F-gases)
EMIS database operation	Sabine Schenker (FOEN), Anouk-Aimée Bass (FOEN, F-gases)
Annual updates (NIR text, tables, figures)	Beat Rihm (Meteotest), Cornelia Stettler (Carbotech; F-gases), Dominik Eggli (Meteotest)
Quality control (annual updates)	Felix Weber (INFRAS), Adrian Schilt (FOEN), Regine Röthlisberger (FOEN), Daniela Zumstein (Carbotech; F-gases)
Internal review	Regine Röthlisberger (FOEN), Sabine Schenker (FOEN), Adrian Schilt (FOEN, F-gases), Stefan Reimann (EMPA, 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. CO₂ 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 sector (chp. 7).

Indirect emissions of CO₂ from fossil CO and NMVOC as well as of N₂O from NO_x and NH₃ emissions are included in CRF Table6 and reported in chapter 9. Since the CO₂ 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 2C1 and 2B8) are not accounted for calculation of the indirect CO₂ emissions. Biogenic NMVOC and CO emissions occur in source category 2H2 Food and beverages and 2G4 tobacco consumption and are not reported as indirect CO₂ 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). For reviewers there is an additional version of chapter 4 Industrial processes and product use available, including all confidential data and information.

Figure 4-1 shows the evolution of GHG emissions in sector 2 between 1990 and 2016.

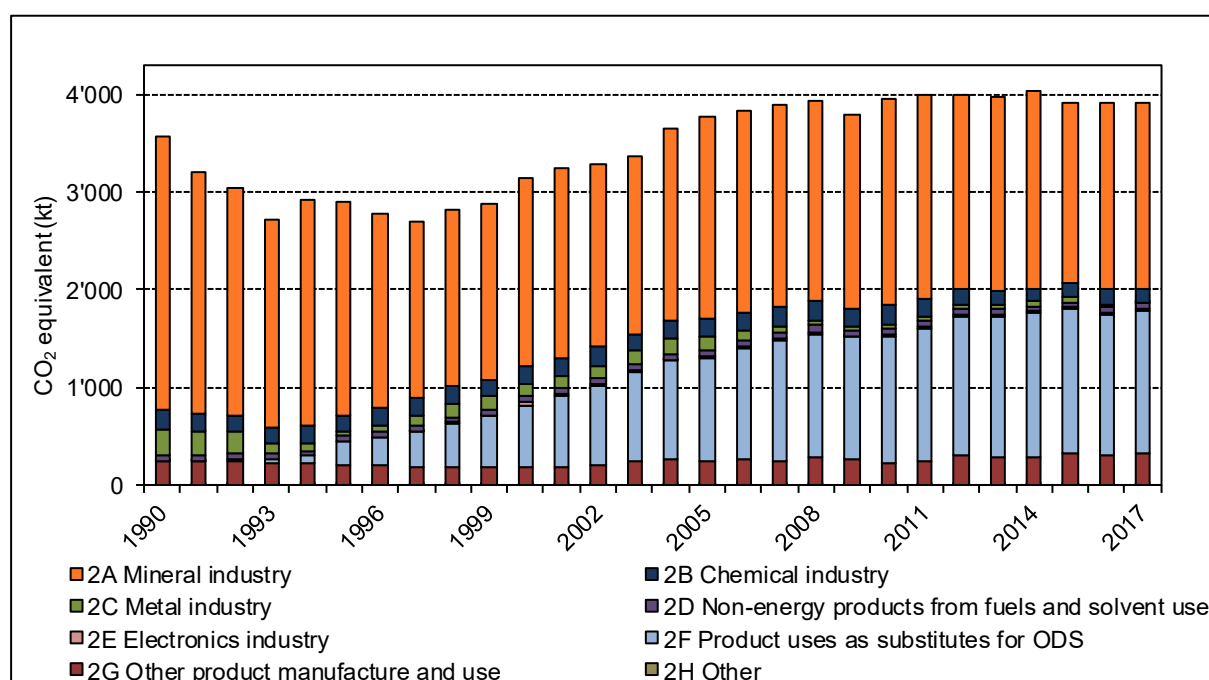


Figure 4-1 Switzerland's greenhouse gas emissions of sector 2 Industrial processes and product use.

2A Mineral industry remains the dominant source of sector 2 accounting for around half of the GHG emissions in 2017 although absolute emissions have decreased since 1990. 2B Chemical industry accounts for a small share and shows a decreasing trend since 1990. 2C Metal industry shows a strong decreasing trend and accounts only for a small share in 2016. 2D Non-energy products also only have a minor contribution in 2017.

2F Product uses as substitutes for ozone depleting substances (ODSs) is of increasing importance: The emissions have increased since 1990 and account for almost half of total GHG emissions in sector 2 in 2017. This is primarily due to the replacement of CFCs and other ODSs by HFCs in many technical applications. 2G Other product manufacture and use shows no clear trend since 1990. 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 CO₂ and F-gases in 2017 whereas N₂O and CH₄ have 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 kt CO₂ equivalent.

Gas	1990	1995	2000	2005
	CO ₂ equivalent (kt)			
CO ₂	3'149	2'415	2'197	2'370
CH ₄	1.8	1.8	1.7	2.6
N ₂ O	172	141	117	102
F-gases	254	353	828	1'296
Sum	3'576	2'911	3'143	3'771

Gas	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	CO ₂ equivalent (kt)									
CO ₂	2'286	2'205	2'365	2'319	2'195	2'197	2'251	2'083	2'156	2'129
CH ₄	2.9	1.9	2.7	2.8	2.8	2.1	2.1	2.2	2.7	2.9
N ₂ O	109	99	102	94	93	63	40	40	38	39
F-gases	1'535	1'490	1'498	1'579	1'700	1'713	1'752	1'795	1'717	1'740
Sum	3'933	3'796	3'968	3'995	3'990	3'975	4'046	3'919	3'914	3'910

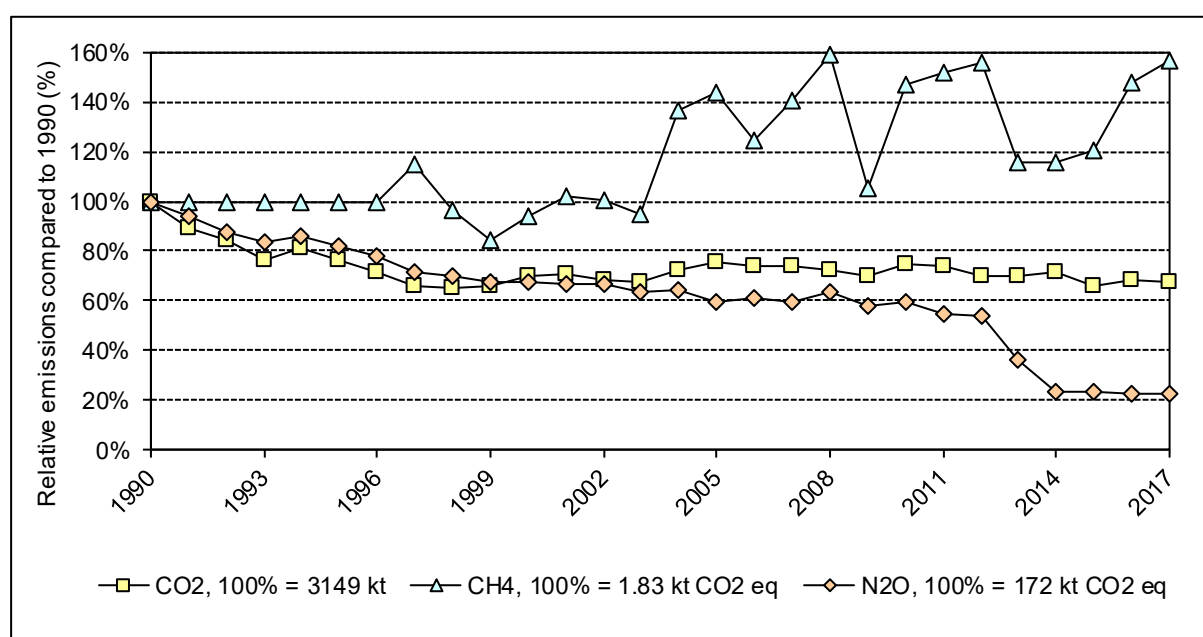


Figure 4-2 Relative trends of the greenhouse gas emissions (without F-gases, see Figure 4-3) of sector 2 Industrial processes and product use. The base year 1990 represents 100%.

Figure 4-2 shows that the emissions of CO₂ decreased between 1990 and 1998 and since then, they remain at a constant level. Emissions of N₂O from sector 2 Industrial processes and product use have also decreased since 1990 and remain at a constant level since 2014. Emissions of CH₄ have increased in the same time period with considerable interannual fluctuation. However, absolute emissions are small compared to CO₂ and N₂O.

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 smelting process

of aluminium production (chp. 4.4.2.2) and from the use of SF₆ 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, emissions remain at a constant level. Most relevant and main source of F-gases emissions in 2017 is the use of HFC in refrigeration and air conditioning.

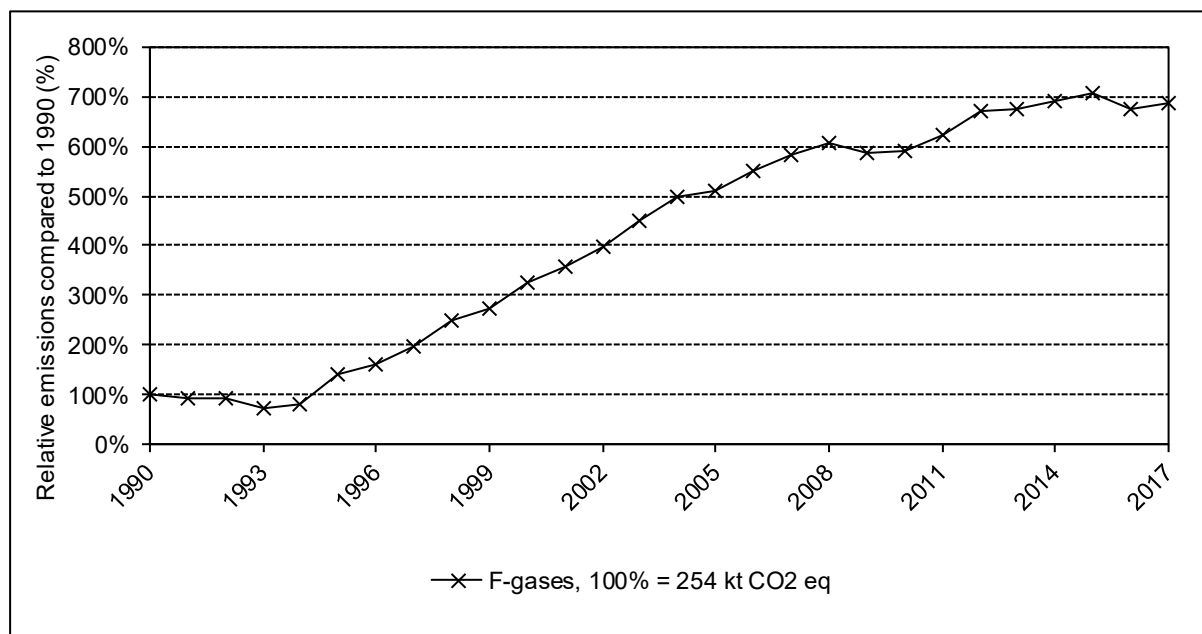


Figure 4-3 Relative trends of the F-gases of sector 2 Industrial processes and product use. The base year 1990 represents 100%.

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 2017 and trend for 1990–2017, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
2A1	Cement production	CO ₂	L1, L2, T1

Table 4-3 Specification of source category 2A Mineral industry in Switzerland.

2A	Source	Specification
2A1	Cement production	Geogenic CO ₂ emissions from calcination process in cement production; Emissions of CO ₂ , NO _x , CO, NMVOC and SO ₂ from blasting operations
2A2	Lime production	Geogenic CO ₂ emissions from calcination process in lime production; Emissions of CO ₂ , NO _x , 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 Geogenic CO ₂ emissions from use of carbonates for sulphur oxide removal in municipal solid waste incineration plants and cellulose production (ceased in 2008) Geogenic CO ₂ emissions from use of limestone in iron-foundries (cupola furnaces) Geogenic CO ₂ emissions from use of sodium bicarbonate Emissions of CO ₂ , NO _x , 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 CO₂ 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 (CaCO₃), is heated (calcined) to produce lime (CaO) and CO₂ as by-product. The CaO reacts subsequently with minerals in the raw materials and yields clinker. During this reaction step no further CO₂ 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 CO₂ and precursor greenhouse gases such as NO_x, CO, NMVOC and SO₂.

Indirect CO₂ emissions resulting from NMVOC and CO emissions in this source category are only included in CRF Table6 and reported in chp. 9.

Methodology

Calcination process

The geogenic CO₂ 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 (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 EMEP/EEA Guidebook 2016 (EMEP/EEA 2016, chp. 2A1, Fig. 3.1) using country-specific emission factors. The CO₂ 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 amount of used explosives is reported to be 0.13 kg/t cement¹⁰ (EMIS 2018/2A1 Zementwerke übriger Betrieb).

Total emissions reported for the production of cement are the sum of emissions from calcination process and blasting operations. The share of CO₂ emissions from blasting operations in limestone quarries is well below one tenth of a per cent of the geogenic CO₂ emissions from the calcination process.

Emission factors

Calcination process

The emission factor of CO₂ 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 CO₂/t clinker used in the Swiss ETS corresponds to the value provided by the Cement Sustainability Initiative (CSI) in its report "CO₂ and Energy Accounting and Reporting Standard for the Cement Industry – The Cement CO₂ 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 – 66%, while MgO contents were around 2%. 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 it was decided to revise the EF in order to establish a consistent time series from 1990 – 2015 and also achieve consistency between the Swiss ETS and the greenhouse gas inventory (CSI 2011).

¹⁰ The CO₂ emission factor for the use of blasting agents amounts to 600 kg CO₂/t of blasting agent. For the average amount on blasting agent used per kg cement measurement data for the year 2002 were taken. Measurement data were available for four Swiss cement plants, covering more than 60% of the Swiss cement production. Therefore, this information is considered representative for cement plants in Switzerland.

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 CO₂/t clinker). The emission factor of CKD is estimated based on plant-specific data available for 2013–2016 that are provided by the cement industry association (cemuisse). From this data, an average emission factor of CO₂ from CKD is calculated (0.35 kg CO₂/t clinker).

Based on these emission factors a total country-specific emission factor per ton of clinker is calculated. The emission factor is assumed constant for the entire time period.

Table 4-4 CO₂ emission factor for calcination in 2A1 Cement Production 1990 to 2017.

2A1 Cement production	Unit	1990 - 2017
Calcination, CO ₂	kg/t clinker	536.7

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 2018/2A1 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 CO₂, NO_x, CO, NMVOC and SO₂ from blasting operations in g/t clinker from source category 2A1 Cement Production in 2017.

2A1 Cement production	Unit	CO ₂	NO _x	CO	NMVOC	SO ₂
Blasting operations	g/t clinker	34.1	3.3	3.3	8.6	0.1

Activity data

Since 1990, data on annual clinker production are provided by the industry association cemuisse as documented in the EMIS database (EMIS 2019/2A1_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
Clinker production	kt	4'808	3'706	3'214	3'442

2A1 Cement production	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Clinker production	kt	3'461	3'443	3'642	3'587	3'368	3'415	3'502	3'195	3'296	3'279

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 NMVOC and CO emissions in this source category are only included in CRF Table6 and reported 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 2006 IPCC guidelines (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 EMEP/EEA Guidebook 2016 (EMEP/EEA 2016, 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 rest 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 2019/2A2 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 CO₂ emission factor for calcination process in lime production in kg/t lime for 1990–2017 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 2019/2A2 Kalkproduktion, übriger Betrieb. The values are confidential and they are available to reviewers on request.

Table 4-8 CO₂ emission factor for the calcination process in lime production in kg/t lime and emission factors for CO₂, NO_x, CO, NMVOC and SO₂ from blasting operations in g/t lime in 2017.

2A2 Lime production	Unit	CO₂	NO_x	CO	NMVOC	SO₂
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 2019/2A2 Kalkproduktion, Rohmaterial and EMIS 2019/2A2 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 CO₂ 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 CO₂ emissions from glass production, a Tier 2 method according to the decision tree Fig. 2.3 of 2006 IPCC Guidelines (vol. 3, chp. 2.4 Glass production) is used. For glass production in Switzerland this results in the following formula:

$$\text{CO}_2 \text{ Emissions} = M_{\text{Glass type}} \cdot EF_{\text{Glass type}} \cdot (1 - \text{cullet ratio})$$

The cullet ratio describes the share of recycled glass material which is used in the production. The melting of cullet causes no geogenic CO₂ emissions.

From 2005 onwards, the geogenic CO₂ 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 (1990–2017) and glass wool (1990–2017) 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 CO₂ 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 CO₂ emission factor for glass production in g/t glass and g/t carbonate containing raw material (IPCC 2006).

2A3 Glass production	Unit	CO₂ geogenic	
Glass wool (fibre glass insulation)	g/t	250'000	
Glass (speciality tableware)	g/t	100'000	
		1990–2004	2005–2017
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 CO₂ 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.

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.

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 2019/2A3 Hohlglass Produktion, EMIS 2018/2A3 Glas übrige Produktion and EMIS 2019/2A3 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
Container glass					
Production	kt	C	C	C	C
Cullet ratio	%	C	C	C	NA
Soda use	kt	NA	NA	NA	C
Dolomite use	kt	NA	NA	NA	C
Limestone use	kt	NA	NA	NA	C
Glass (speciality tableware)					
Production	kt	C	C	C	C
Cullet ratio	%	C	C	C	C
Glass wool					
Production	kt	24	24	31	37
Cullet ratio	%	21	45	69	65

2A3 Glass production	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
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	44	33	36	41	39	33	32	31	32	36
Cullet ratio	%	69	69	71	72	61	67	67	67	67	69

4.2.2.4 Other process uses of carbonates (2A4)

Source category 2A4 Other process uses of carbonates comprises geogenic CO₂ emissions from production of fine ceramics (2A4a), bricks and tiles (2A4a) and rockwool (2A4d), from use of carbonates for sulphur oxide removal in municipal solid waste incineration plants (2A4d) and cellulose production (ceased in 2008) (2A4d), from use of limestone in iron-foundries (cupola furnaces) (2A4d) and from use of sodium bicarbonate (2A4d) as well as emissions of CO₂, NO_x, CO, NMVOC and SO₂ from blasting operations in plaster production (2A4d).

Indirect CO₂ emissions resulting from NMVOC and CO emissions in this source category are only included in CRF Table6 and reported 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 2019/2A4a Feinkeramik Produktion.

Methodology

The geogenic CO₂ emissions from fine ceramics production are determined by a Tier 2 method according to the decision tree Fig. 2.4 of 2006 IPCC Guidelines (IPCC 2006, vol. 3, chp. 2.5 Other process uses of carbonates).

For fine ceramics production in Switzerland, this results in the following formula:

$$\text{CO}_2 \text{ Emissions} = (M_{\text{Limestone}} \cdot EF_{\text{Limestone}}) + (M_{\text{Dolomite}} \cdot EF_{\text{Dolomite}}) + (M_{\text{Soda Ash}} \cdot EF_{\text{Soda Ash}})$$

Emission factors

The CO₂ 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 CO₂ 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		1990–2017					
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
Brick and tile production	g/t	117'000	100'000	110'000	103'000	112'000	113'000

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 CO₂ 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 2019/2A4a 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 CO₂ Emissions, Swiss Confederation 2011 and Ordinance for the Reduction of CO₂ 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 2006 IPCC Guidelines (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 CO₂ (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 CO₂ emission factor of 117 kg CO₂/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 CO₂ 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). 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) in Switzerland in kt.

2A4a Ceramics	Unit	1990	1995	2000	2005
Fine ceramics production	kt	C	C	C	C
Limestone use	kt	C	C	C	C
Dolomite use	kt	C	C	C	C
Soda use	kt	C	C	C	C
Brick and tile production	kt	1'271	1'115	959	1'086
2A4d Other					
Rock wool production	kt	C	C	C	C
Carbonate use in waste incineration plants	kt	0.7	0.8	0.8	0.6
Limestone use in cellulose	kt	8.5	9.4	9.3	8.3
Limestone use in iron foundries	kt	6.2	4.1	3.8	2.3
Other use of carbonates	kt	5.9	5.4	7.0	7.3
Plaster production	kt	319	304	288	327

2A4a Ceramics	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
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	865	701	879	800	792	785	765	726	660	622
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	NO	NO	NO	NO	1.9	6.5	6.6	6.8
Limestone use in cellulose	kt	6.5	0.0	NO	NO	NO	NO	NO	NO	NO	NO
Limestone use in iron foundries	kt	2.7	1.1	1.0	1.1	0.9	0.9	0.8	0.7	0.7	0.7
Other use of carbonates	kt	7.4	6.6	6.9	6.4	7.6	6.1	7.5	6.7	6.8	6.5
Plaster production	kt	295	293	335	293	271	213	166	140	148	146

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).

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 2019/2A4d Steinwolle Produktion).

Methodology

Since 2013, rock wool manufacturers are legally obliged to report geogenic CO₂ 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 CO₂ 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 CO₂ emission factor is based on measurements of the oxides (CaO, MgO, Na₂O, K₂O, 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 CO₂ 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 CO₂ emission factors are confidential. They are available to reviewers on request.

Table 4-15 Geogenic CO₂ emission factors used for rock wool production and other carbonate uses, CO₂ fossil, NO_x, CO, NMVOC and SO₂ emission factors for plaster production in g/t carbonate containing raw material and g/t product, respectively for 2017.

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
Limestone use in iron foundries	g/t	439'710	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	14.4	0.24

Table 4-16 In the confidential NIR, the respective table with geogenic CO₂ 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 CO₂ 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 ($\text{CaMg}(\text{CO}_3)_2$), 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 as documented in the EMIS database (EMIS 2019/1A2a 2A4d Eisengiessereien Kupolöfen).

Limestone is also used to neutralize acid waste water 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 2006 IPCC guidelines (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 2006 IPCC guidelines (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 (2006 IPCC Guidelines, 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 2019/1A2d 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 2019/1A1a Kehrichtverbrennungsanlagen).

The amount of limestone used as flux in iron foundries (cupola furnaces) is estimated by the Swiss foundry association 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 2019/1A2a Eisengiessereien Kupolöfen).

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 2019/2A4d 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 EMEP/EEA Guidebook 2016 (EMEP/EEA 2016).

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 2019/2A4d 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 2019/2A4d Gips-Produktion übriger Betrieb (see Table 4-14).

4.2.3 Uncertainties and time-series consistency

The uncertainty for CO₂ emissions in 2A1 Cement production, which is a key category regarding level and trend, amounts to 4.5%. The uncertainty of CO₂ emissions was calculated following the steps in Table 3.2 in 2006 IPCC Guidelines (IPCC 2006, vol. 1, chp. 3, p. 3.30–3.31). 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 2018m, 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 CO₂ 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 2019.

Major recalculations which contribute significantly to the total differences in GHG emissions of sector 2 IPPU between latest and previous submission are also presented in chp.

10.1.2.2.

- 2A3: The emission factor of CO₂ geogenic of 2A3 Container glass production has been corrected for 2016.
- 2A4a: The emission factor of CO₂ geogenic of 2A4a Fine ceramics production has been revised for 2015 and 2016 based on updated effective amounts of carbonate containing glazes.
- 2A4a: The activity data of 2A4a Brick and tile production has been corrected for 2016 resulting in a revised emission factor of CO₂ geogenic for 2016 as well.

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

Source category 2B Chemical industry is not a key category.

Table 4-17 Specification of source category 2B Chemical industry in Switzerland.

2B	Source	Specification
2B1	Ammonia production	Emissions of CO ₂ and NMVOC are reported in 2B8b Ethylene production
2B2	Nitric acid production	Emissions of N ₂ O and NO _x from the production of nitric acid
2B5	Carbide production	Emissions of CO ₂ , CH ₄ and SO ₂ from the production of silicon carbide
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; CO ₂ emissions from limestone pit and niacin production; NMVOC emissions from PVC production (ceased in 1996); SO ₂ emissions from sulphuric acid production

4.3.2 Methodological issues

4.3.2.1 Ammonia production (2B1)

Ammonia (NH₃) is produced in one single plant in Switzerland by catalytic reaction of nitrogen and synthetic hydrogen (see Figure 4-4). Ammonia is not produced in an isolated reaction plant but is part of an integrated production chain (see Figure 4-5).

The starting production process is the thermal cracking of liquefied petroleum gas (LPG) and light virgin naphtha yielding ethylene (ethene, C₂H₄), 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 (CO₂ and NMVOC) to every single product such as, e.g., ethylene, acetylene (ethyne, C₂H₂), cyanic acid or ammonia. Therefore, all CO₂ 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, CO₂ and NMVOC emissions are reported as included elsewhere (IE). All information on the ammonia production and the cracking process is documented in EMIS 2019/2B1 Ammoniak-Produktion and EMIS 2019/2B8b Ethen-Produktion, respectively.

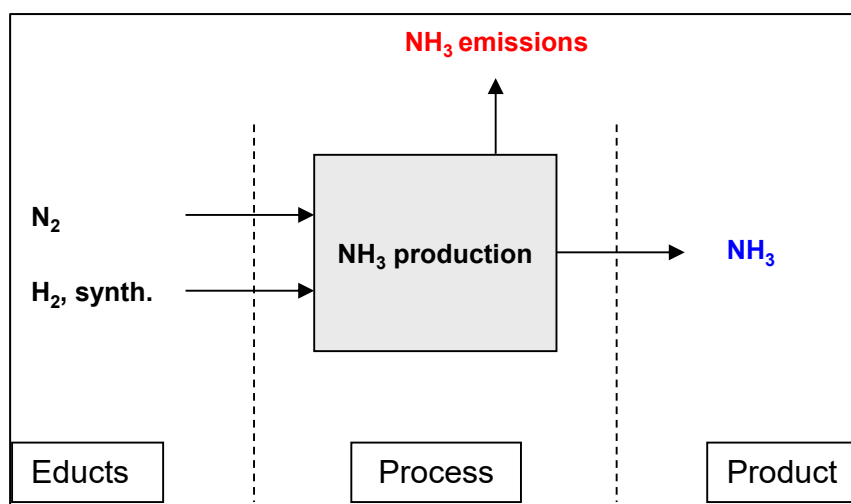


Figure 4-4 Process flow chart for the production of ammonia (NH₃) from nitrogen (N₂) and hydrogen (H₂, synth.). Hydrogen is derived from the thermal cracking process in the same plant (see Figure 4-5).

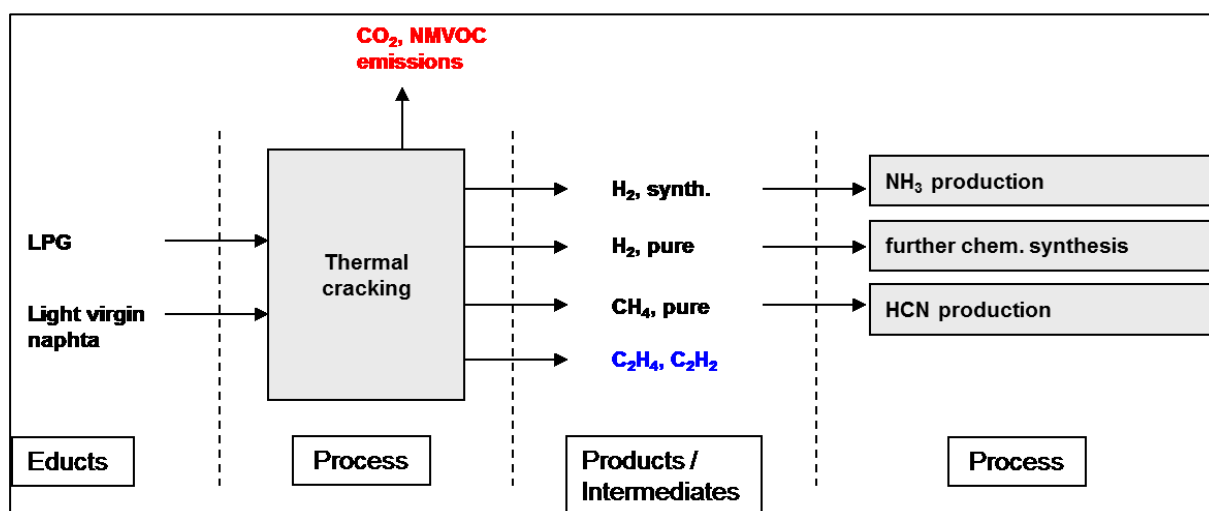


Figure 4-5 Process flow chart for the production of ethylene (C₂H₄) and acetylene (C₂H₂) by thermal cracking of liquefied petroleum gas (LPG) and light virgin naphtha. The intermediate product H₂, synth. is used as educt in the ammonia production in the same plant (see Figure 4-4).

Table 4-18 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 is one single plant producing nitric acid (HNO₃). Nitric acid is produced by catalytic oxidation of ammonia (NH₃) with air. At temperatures of 800°C nitric monoxide (NO) is formed. During cooling, nitrogen monoxide reacts with excess oxygen to form nitrogen dioxide (NO₂). The nitrogen dioxide reacts with water to form 60% nitric acid (HNO₃). Today, two types of processes are used for nitric acid production: single pressure or dual pressure plants. In Switzerland a dual pressure plant is 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 is done by selective catalytic reduction (SCR, installed in 1988), which reduces NO_x to N_2 and O_2 (the SCR in this plant is 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 the IPCC 2006 guidelines (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 since 2013, 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 (2016) (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 $\pm 20\%$ (minimum $\pm 0.5 \text{ mg/m}^3$). On repeated enquires the plant confirmed that since a denitrification system and an automatic control system for the ammonia addition was 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 from 2013 onwards.

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 duplicated. This modification together with the new catalyst in the production line slightly reduced the NO_x emission factor. The values are documented in EMIS 2019/2B2 Salpetersäure Produktion.

Table 4-19 Emission factors for N₂O and NO_x for nitric acid production in Switzerland in kg/t nitric acid for 1990-2017 and 2017, respectively. Data refer to 100% nitric acid.

2B2 Nitric acid production	Unit	N ₂ O	NO _x
	kg/t	C	C

Activity data

Activity data on annual production of nitric acid (100%) are provided annually by the Swiss production plant for the entire time period 1990–2017. 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 2019/2B2 Salpetersäure Produktion).

Table 4-20 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. The Swiss silicon carbide is produced in an electric furnace at temperatures above 2000°C using the Acheson process. The starting materials are quartz sand (SiO₂), petroleum coke and anthracite (C) which yield silicon carbide (SiC) and carbon monoxide (CO). The CO is converted to CO₂ 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 (CH₄) as an unintended by-product. There is no abatement techniques installed which could capture the CO₂ or CH₄ emissions.

Methodology

According to decision tree Fig. 3.5 of the IPCC 2006 guidelines (vol. 3, chp. 3.6 Carbide production), the CO₂ and CH₄ emissions from silicon carbide production are determined by a Tier 2 method. The SO₂ emissions are calculated by a Tier 2 method according to the decision tree Fig. 3.1 in EMEP/EEA (2016) (chp. 2B Chemical industry) using plant-specific emission factors.

Emission factors

The CO₂, CH₄ and SO₂ emission factors are confidential and available to reviewers on request. The values are partly based on measurements from the single silicon carbide production plant and are documented in EMIS 2019/2B5 Graphit und Siliziumkarbid Produktion.

Table 4-21 In the confidential NIR, a respective table with emission factors of fossil CO₂ in kg/t silicon carbide are provided. Data are available to reviewers on request.

Table 4-22 Emission factors for CO₂, CH₄ and SO₂ for carbide production in kg/t silicon carbide in Switzerland for 2017.

2B5 Carbide production	Unit	CO₂	CH₄	SO₂
2B5a Silicon carbide	kg/t	C	C	C

Activity data

Activity data on annual production of silicon carbide are provided annually from 1997 onwards by the Swiss production plant. For the time period 1990–1996 activity data are based on industry data for 1990 and 1995 and interpolated values in between.

The data are confidential but available to reviewers on request (see EMIS 2019/2B5 Graphit und Siliziumkarbid Produktion).

Table 4-23 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, C₂H₄) is produced by a single plant in Switzerland by thermal cracking of liquefied petroleum gas (LPG) and virgin naphtha. Ethylene is not produced in an isolated process but is co-processed together with several other products such as H₂, CH₄, and C₂H₂ (see flow chart in Figure 4-5 in chp. 4.3.2.1). From the thermal cracking process, emissions of CO₂ and NMVOC are released. They are both allocated entirely to the production of ethylene, which is the first product within the integrated production chain. CH₄ emissions to atmosphere do not occur since CH₄ is completely used as an educt in the downstream production of cyanic acid (HCN) in the same facility (see Figure 4-5 and for further information see EMIS 2019/2B8b Ethen-Produktion). Therefore, CH₄ emissions are reported as NA for ethylene production and only CO₂ and NMVOC emissions are reported.

The CO₂ 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 no longer included in the calculation of the indirect CO₂ emissions from sector 2 IPPU in order to avoid double counting.

Methodology

According to decision trees Fig. 3.8 of the IPCC 2006 guidelines (vol. 3, chp. 3.9 Petrochemical and carbon black production) and Fig. 3.1 of EMEP/EEA (2016) (chp. 2B Chemical industry), the CO₂ and NMVOC emissions, respectively, from ethylene production

are determined by a Tier 2 method using plant-specific emission factors (EMIS 2019/2B8b Ethylene production).

Emission factors

The CO₂ 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 a constant value, i.e. the mean value of the years 2000–2009 was assumed.

The emission factors for ethylene production are considered confidential; however, they are available to reviewers on request.

Table 4-24 Emission factors for CO₂ and NMVOC in ethylene production, NMVOC in acetic acid production, CO₂ in limestone pit and niacin production and SO₂ in sulphuric acid production for 2017 in kg/t product.

	Unit	CO ₂	NMVOC	SO ₂
2B8 Petrochemical and carbon black production				
2B8b Ethylene	kg/t	C	C	NA
2B10 Other				
Acetic acid production	kg/t	NA	C	NA
Limestone pit	kg/t	C	NA	NA
Niacin production	kg/t	C	NA	NA
Sulphuric acid production	kg/t	NA	NA	C

Table 4-25 CO₂ 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 4-26 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
2B8 Petrochemical and carbon black production					
2B8b Ethylene	kt	C	C	C	C
2B10 Other					
Acetic acid production	kt	30	27	24	8
Limestone pit	kt	C	C	C	C
Niacin production	kt	C	C	C	C
PVC production	kt	43	43	NO	NO
Sulphuric acid production	kt	C	C	C	C

	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
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	28	20	18	12	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 occur.

Indirect CO_2 emissions resulting from NMVOC and CO emissions in this source category are only included in CRF Table6 and reported 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 the IPCC 2006 guidelines (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 EMEP/EEA (2016) (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 2019/2B10 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 CH₄, 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 4-27 In the confidential NIR, the respective table with emission factors for CO₂ and CH₄ 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 2019/2B10 Essigsäure-Produktion (see Table 4-26).

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 CO₂ emissions.

Methodology

According to decision tree Fig. 2.4 of the IPCC 2006 guidelines (vol. 3, chp. 2.5 Other process uses of carbonates), the CO₂ emissions from the limestone pit are determined by Tier 2 method using plant-specific emission factors..

Emission factors

The CO₂ 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 2019/2B10 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)

CO₂ emissions from niacin production of the single manufacturer in Switzerland are reported since submission 2014. CO₂ is released in the last reaction step of the niacin production.

Methodology

In order to determine emissions of CO₂ from niacin production, a country-specific method analogous to a Tier 2 method according to the IPCC 2006 guidelines (vol. 3) is used.

Emission factors

The CO₂ emission factor is plant-specific based on monitoring reports of the Swiss ETS and is assumed to be constant as documented in the EMIS database (EMIS 2019/2B10 Niacin-Produktion). The emission factor is considered confidential but available to reviewers on request.

Activity data

Activity data of annual niacin production were provided by the Swiss production plant for the entire time period as documented in EMIS 2019/2B10 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 (H₂SO₄) is produced by one plant only in Switzerland. From this production process SO₂ is emitted. Until 1996, also PVC was produced in Switzerland releasing NMVOC emissions.

Indirect CO₂ emissions resulting from NMVOC and CO emissions in this source category are only included in CRF Table6 and reported in chp. 9.

Methodology

In order to determine SO₂ and NMVOC emissions from sulphuric acid and PVC production, respectively, a Tier 2 method according to the decision tree Fig. 3.1 of EMEP/EEA (2016) (chp. 2B Chemical industry) with plant-specific emission factors is used.

Emission factors

The emission factor for SO₂ 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 2019/2B10 Schwefelsäure-Produktion).

The SO₂ 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 2019/2B10 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 2019/2B10 Schwefelsäure-Produktion and EMIS 2019/2B10 PVC-Produktion (see Table 4-26). The activity data for sulphuric acid production are confidential but available to reviewers on request.

4.3.3 Uncertainties and time-series consistency

The uncertainties for CO₂ in source category 2B are estimated to be medium, (see Table 1-10 Semi-quantitative uncertainties for non-key categories) resulting in a relative uncertainty of 10%. For CH₄ a combined uncertainty of 20% is estimated.

For N₂O emissions from 2B2 Nitric acid production, the uncertainty is assumed to be 7.5% since the Swiss ETS requires that an uncertainty of 7.5% is not exceeded for continuous N₂O measurements.

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 2019. Major recalculations which contribute significantly to the total differences in GHG emissions of sector 2 IPPU between latest and previous submission are also presented in chp. 10.1.2.2.

- 2B5: The emission factor of CO₂ fossil from 2B5 Silicon carbide production has been revised for 2016 based on corrected data from the production plant.

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 4-28 Key categories of 2C Metal industry. Combined KCA results, level for 2017 and trend for 1990–2017, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
2C3	Aluminium production	CO ₂	T1
2C3	Aluminium production	PFC	T1

Table 4-29 Specification of source category 2C Metal industry in Switzerland.

2C	Source	Specification
2C1	Iron and steel production	Emissions of CO ₂ , NO _x , CO, NMVOC and SO ₂ from the production of iron and steel
2C2	Ferroalloys production	Production is not occurring in Switzerland
2C3	Aluminium production	Emissions of PFC, CO ₂ , NO _x , CO, NMVOC, and SO ₂ from the production of primary aluminium (ceased in 2006)
2C4	Magnesium production	Emissions from use of SF ₆ in magnesium foundries (emissions from use of SF ₆ in aluminium foundries included)
2C7	Other	Emissions of CO and NMVOC from non-ferrous metal foundries Emissions of CO ₂ , NO _x , 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 CO₂ 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 SO₂ 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 CO₂ emissions from other bituminous coal occur. Other bituminous coal acts first of all as fuel but also as carburization material and reductant. Therefore it was decided to report those CO₂ 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 2018). Geogenic CO₂ emissions from use of limestone in cupola furnaces are reported in 2A4d Other process uses of carbonates.

The CO₂ 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 no longer included in the calculation of the indirect CO₂ emissions from sector 2 IPPU in order to avoid a double counting.

Methodology

For determination of CO₂ emission from iron and 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 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 CO₂ 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 CH₄ emissions occur in the EAF process.

Emissions of all precursors are determined by a Tier 2 method based on the decision tree Fig. 3.1 in chapter 2C1 in EMEP/EEA (2016) using country-specific emission factors (EMIS 2019/2C1).

Emission factors

The emission factors for iron and steel production in Switzerland are country-specific and are based on measurements from industry and expert estimates documented in the EMIS database (EMIS 2019/2C1 Eisengiessereien Elektroschmelzofen/übriger Betrieb, EMIS 2019/2C1 Stahl-Produktion Elektroschmelzöfen and EMIS 2018/2C1 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 CO₂ emission factor results. The reported CO₂ emission factor for Swiss steel industry is the production-weighted average. Consequently, there are no indirect CO₂ emissions to be accounted for in chp. 9 Indirect CO₂ and N₂O emissions for source category 2C1.

The plant-specific data are confidential but available to reviewers on request.

Table 4-30 CO₂ emission factor of electric arc furnaces in 2C1 Steel production in kg/t.

2C1 Steel production	Unit	1990	1995	2000	2005
CO ₂	kg/t	8.3	8.0	7.7	8.8

2C1 Steel production	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
CO ₂	kg/t	6.8	6.8	7.6	7.1	7.9	8.5	8.2	8.6	8.8	9.2

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, NMVOC, SO₂, and CO 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 factors from iron production in foundries are provided by the Swiss foundry association (GVS).

Table 4-31 Emission factors for NO_x, CO and NMVOC in iron production, for CO₂, NO_x, CO, NMVOC and SO₂ in steel production, for CO and NMVOC in non-ferrous metal production and for CO₂, NO_x, CO and SO₂ in battery recycling for 2016.

2C Metal industry	Unit	CO ₂	NO _x	CO	NMVOC	SO ₂
2C1 Iron production	kg/t	IE	0.01	4.1	4	NA
2C1 Steel production	kg/t	9.2	0.14	0.7	0.1	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).

Table 4-32 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
2C1 Iron production	kt	170	130	120	67
2C1 Steel production	kt	1'108	716	1'022	1'159
2C3 Aluminium production	kt	87	21	36	45
2C7a Non-ferrous metals	kt	55	60	70	33
2C7c Battery recycling	kt	C	C	C	C

2C Metal industry	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
2C1 Iron production	kt	78	49	53	61	46	45	43	37	34	35
2C1 Steel production	kt	1'315	935	1'218	1'322	1'252	1'231	1'315	1'296	1'238	1'270
2C3 Aluminium production	kt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2C7a Non-ferrous metals	kt	21	15	20	12	18	7	7.4	6.8	6.6	6.1
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 the 2006 IPCC Guidelines (IPCC 2006, vol. 3, chp. 4.4, fig. 4.11), CO₂ 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 2006 IPCC 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 SF₆ imports to be related to the aluminium industry, referring to cleaning processes in foundries. The 2006 IPCC Guidelines mention use of SF₆ 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 CO₂ of 1.6 tonnes per tonne of aluminium is country-specific. It is based on measurements and data from industry and expert estimates, documented in the EMIS database (EMIS 2019/2C3 Aluminium Produktion). CO₂ 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, there are no indirect CO₂ emissions to be accounted for in chp. 9 Indirect CO₂ and N₂O emissions from CO emissions of primary aluminium production. But as the NMVOC emissions originate solely from the production of the electrodes at the plants they have to be considered for the calculation of the indirect CO₂ emissions in chp. 9. Indirect CO₂ emissions are not included in CO₂ emissions in the CRF table 2, but exclusively reported in CRF table 6.

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 EFs in kg per tonne of 0.17, 0.06 and 0.04, respectively, for those three years (Alcan 2003). This was reported to be lower than the European averages, by factors of 3.9, 4.7 and 5.1, respectively. For other years no measurements have been made; thus, European Union (EU) average EFs have been used, multiplied by a factor of 0.25 (Alcan 2002). Figure 4-6 shows the resulting development of the EF for PFC over time. The European average has been decreasing over 60% from 0.68 kg PFC per t Aluminium to 0.16 kg PFC per t Aluminium between 1990 and 2000.

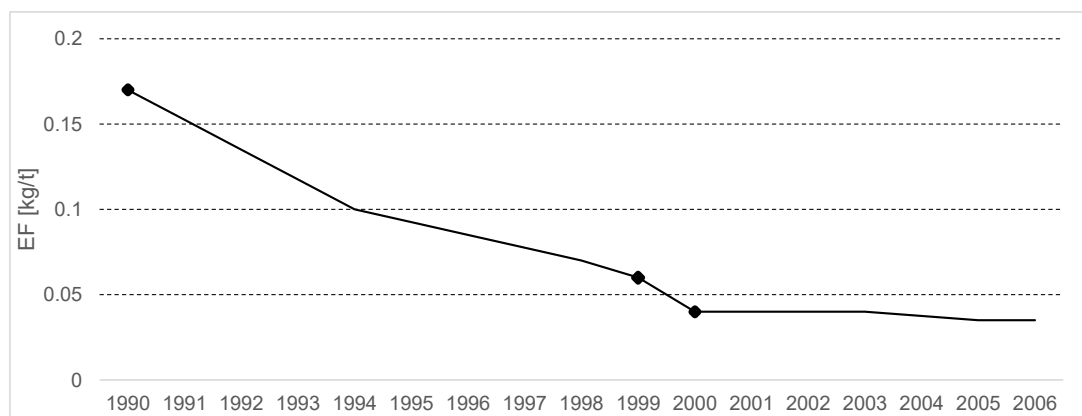


Figure 4-6 Extrapolation of PFC emission factor based on measurements in 1990, 1999 and 2000. The path for the reduction between measurements and the stagnation after the last measurements reflects the observed development of average EFs in the European Union.

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 EFs 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 4-33 PFC emission factors for aluminium production in Switzerland. Aluminium production in Switzerland ceased in 2006.

Gas	Unit	1990	1995	2000	2005
CF ₄	kg/t	0.1530	0.0833	0.0360	0.0315
C ₂ F ₆	kg/t	0.0170	0.0093	0.0040	0.0035

Gas	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
CF ₄	kg/t	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
C ₂ F ₆	kg/t	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

There are no measurements of SF₆ emissions available from aluminium foundries to identify the fraction of SF₆ destroyed or transformed in the cleaning process. For SF₆ 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 2006 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 4-32.

Activity data on SF₆ used in aluminium foundries (2C3) is derived from import data from FOEN statistics. Import companies indicated in the year 2003 a portion of SF₆ 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). It is assumed that the total imported amount is emitted within one year. In 2011, a study was carried out among members of the Swiss Foundry Association (GVS), confirming that SF₆ 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 SF₆ is assumed from 2003 until the final elimination of SF₆ 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 SF₆ in magnesium foundries (2C4)

SF₆ was used in Swiss magnesium foundries in the time periode 1997 to 2016. There have been two magnesium foundries known to be using SF₆. 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 is using SF₆.

The import of SF₆ for magnesium foundries is prohibited in Switzerland since 2017.

Methodology

SF₆ 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 SF₆ emissions available to identify the fraction of SF₆ destroyed or transformed in the process. For SF₆ 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 SF₆ 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). It is assumed that the total imported amount is emitted within one year. The import of SF₆ 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 SF₆ 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. The recycling is done by applying the Sumitomo process. The batteries are first pyrolysed 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 CO₂ emissions resulting from CO and NMVOC emissions in this source category are only included in CRF Table6 and reported in chp. 9.

Methodology

To determine emissions of CO₂, NO_x, CO and SO₂ from battery recycling and of CO and NMVOC from non-ferrous metal foundries, Tier 2 methods according to EMEP/EEA Guidebook 2016 (EMEP/EEA 2016, chp. 2C7c and 2C7a) with country-specific emission factors are used.

Emission factors

The emission factors of CO₂, NO_x, SO₂, CO from battery recycling between 1990 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 reported for the first time in submission 2017. They are assumed constant for the entire time period (EMIS 2019/2C7 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 (2019/2C7 Buntmetallgiessereien Elektroöfen) (see Table 4-31). 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 and the foundry association as documented in the EMIS database (EMIS 2019/2C7 Batterie-Recycling and 2019/2C7 Buntmetallgiessereien Elektroöfen).

Activity data are confidential. They are available to reviewers on request.

4.4.3 Uncertainties and time-series consistency

The uncertainty of CO₂ emissions in 2C1 Iron and steel production amounts to 5.4%.

Production data of the steel industry have a high confidence and its uncertainty is estimated at 2%. The uncertainty for the CO₂ emission factor is estimated at 5%.

For the emission of CO₂ 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 CO₂ and PFC are estimated to be 20% and 6.4%, respectively. The uncertainty in the activity data is estimated to be 5% for CO₂ emissions and 6.4% for PFC emissions.

For the emissions of SF₆ from the use in 2C4 Magnesium the combined uncertainty is estimated at 27.7%.

The uncertainty of CO₂ 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

No recalculations were implemented in submission 2019.

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

Source category 2D – Non-energy products from fuels and solvent use is not a key category.

Table 4-34 Specification of source category 2D Non-energy products from fuels and solvent use in Switzerland.

2D	Source	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

CO₂ 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 CH₄ and N₂O emissions from lubricant use in two-stroke engines are reported in sector 1 Energy since these emissions are included in the CH₄ and N₂O emission factors of the respective two-stroke engines (1A2gvii, 1A3biv, 1A3dii, 1A4aii, 1A4bii, 1A4cii and 1A5b).

CO₂ emissions from oxidation of all other lubricants and paraffin wax are calculated by a Tier 1 method according to the 2006 IPCC Guidelines (IPCC 2006, vol. 3, chp. 5.2 and 5.3) applying the IPCC default oxidation fraction of 0.2.

Emission factors

The CO₂ emission factor for lubricants used in 2-stroke vehicles is based on the default emission factor and the net calorific value from 2006 IPCC Guidelines (vol. 2, chp. 2 Stationary combustion, Table 2.2 and chp.1, Table 1.2, respectively), see Table 4-35 and EMIS 2019/2 D 1_Schmiermittel-Verbrauch B2T. Non-CO₂ 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 CO₂ 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 2019/2D1 Lubricant use and EMIS 2019/2D2 Paraffin wax use.

Table 4-35 CO₂ emission factor of 2D1 Lubricant use and 2D2 Paraffin wax use for 2017 in kg/t.

	Unit	CO ₂
2D1 Lubricant use		
in two-stroke engines	kg/t	2'948
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 the Swiss petroleum association (EV 2018). The consumption of lubricants of Liechtenstein, which forms a customs union with Switzerland, is subtracted from the consumption reported by the Swiss petroleum association. The resulting amount is further differentiated between application in two-stroke engines and unspecified use. The amount of lubricants corresponds to 2% of total gasoline consumption of all two-stroke engines based on the road and non-road transportation models (INFRAS 2017a, INFRAS 2015a).

Table 4-36 Use of lubricants in Switzerland.

	Unit	1990	1995	2000	2005
2D1 Lubricant use					
in two-stroke engines	kt	0.6	0.4	0.5	0.4
unspecified	kt	79	61	62	72
2D2 Paraffin wax use	kt	11	10	12	10

	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
2D1 Lubricant use											
in two-stroke engines	kt	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.3	0.2
unspecified	kt	65	51	55	53	51	53	53	51	51	50
2D2 Paraffin wax use	kt	9	6	5	5	3	4	4	4	3	4

4.5.2.2 Other (2D3)

Solvent use (2D3a)

Since the 2006 IPCC Guidelines (vol. 3, chp. 5.5) refer to the EMEP/EEA Guidebook 2016 regarding methodologies for estimating NMVOC emissions from solvent use, the respective NFR codes are indicated as reference as well. In the following sections, 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. The source categories paint application in construction, paint application on wood, industrial and non-industrial paint application, production of fine chemicals and cleaning of parts in metal processing account for the largest share of NMVOC emissions from 2D3a in 2017. Indirect CO₂ emissions resulting from NMVOC emissions in this source category are only included in CRF Table 6 and reported in chp. 9.

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 CO₂ emissions from post-combustion of NMVOC are estimated based on industry data and expert estimates (Carbotech 2019a).

Post-combustion of NMVOC (2D3a)

Methodology

The CO₂ 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 2019a). Post-combustion facilities are applied in source categories industrial paint applications (NFR code 2D3d), metal degreasing (NFR code 2D3e) and chemical products (NFR code 2D3g). For submission 2019, the source category allocation of all post-combustion plants has been verified. 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

Emission factors are derived from the composition of solvents. For installations with no information on the solvent composition, mean source category-specific values are applied.

Table 4-37 CO₂ 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
Coating applications (2D3d NFR)	t/t NMVOC	2.57	2.45	2.45	2.57
Degreasing (2D3e NFR)	t/t NMVOC	2.44	2.63	2.63	2.63
Chemical products, manufacture and processing (2D3g NFR)	t/t NMVOC	1.88	1.67	1.88	1.90

2D3a Solvent use	Unit	CO ₂									
Post-combustion of NMVOC		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Coating applications (2D3d NFR)	t/t NMVOC	2.57	2.57	2.56	2.56	2.56	2.56	2.56	2.01	2.01	2.01
Degreasing (2D3e NFR)	t/t NMVOC	2.63	2.64	2.65	2.65	2.65	2.65	2.41	2.38	2.36	2.36
Chemical products, manufacture and processing (2D3g NFR)	t/t NMVOC	1.93	1.94	2.21	2.24	2.31	2.31	2.34	2.30	2.29	2.30

Activity data

Activity data are provided by the industry. For the ten most important installations, activity data are provided annually.

Table 4-38 Activity data of NMVOC post-combustion in 2D3a Solvent use.

2D3a Solvent use	Unit	1990	1995	2000	2005
Post-combustion of NMVOC					
Coating applications (2D3d NFR)	t NMVOC	443	720	773	942
Degreasing (2D3e NFR)	t NMVOC	5.2	754	754	576
Chemical products, manufacture and processing (2D3g NFR)	t NMVOC	1'170	4'472	6'037	8'454

2D3a Solvent use	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Post-combustion of NMVOC											
Coating applications (2D3d NFR)	t NMVOC	942	942	1'170	1'174	1'171	1'147	1'117	1'297	1'297	1'339
Degreasing (2D3e NFR)	t NMVOC	1'289	1'294	903	1'008	988	988	678	669	868	837
Chemical products, manufacture and processing (2D3g NFR)	t NMVOC	7'448	7'323	5'520	5'366	4'925	5'135	5'298	5'054	4'545	5'291

Coating applications (2D3d NFR)

Methodology

For the determination of NMVOC emissions from coating applications a Tier 2 method according to the EMEP/EEA Guidebook 2016 is used based on the consumption of paints, lacquers, thinners etc. and their solvent content.

Emission factors

Emission factors for NMVOC are derived from the solvent contents of the paints and thinners based on data from the Swiss association for coating and paint applications (VSLF) and retailers as documented in the EMIS database (EMIS 2019/2D3d NFR). The emission factors

for all commercial and industrial coating applications declined significantly between 1990 and 2004 as a result of both a reduction of the solvent content and replacing of solvent based paint by water based paint due to increasingly strict NMVOC regulations by the EU directive (EC 2004). In addition, powder coatings, which are far more efficient, replaced in this time period the conventional paint (rough estimate: 1 t of powder coating replaces 3 t of conventional paint). But since then, their mean solvent content has remained about constant. For paint application, wood and paint application, car repair, even a slight increase in solvent content has been observed in the last few years. Source category 2D3d Paint application, households has been updated substantially based on a comprehensive study including all major Swiss DIY (do it yourself) companies resulting in revised emission factor values from 1999 onwards.

Table 4-39 NMVOC emission factors of coating applications, degreasing, dry cleaning, chemical products, manufacture and processing in 2D3a Solvent use for 2017.

2D3a Solvent use	Unit	NMVOC
Coating applications (2D3d NFR)		
Paint application, construction	kg/t paint	61
Paint application, households	kg/t paint	65
Paint application, industrial	kg/t paint	282
Paint application, wood	kg/t paint	319
Paint application, car repair	kg/t paint	550
Degreasing (2D3e NFR)		
Cleaning of electronic components	kg/t solvent	500
Degreasing of metal	kg/t solvent	460
Other industrial cleaning	kg/t solvent	610
Dry cleaning (2D3f NFR)	kg/t solvent	900
Chemical products, manufacture and processing (2D3g NFR)		
Fine chemicals production	t/production index	3.5
Glue production	kg/t glue	0.8
Handling and storing of solvents	t/production index	1.7
Ink production	kg/t ink	8.4
Paint production	kg/t paint	3.3
Pharmaceutical production	kg/t pharmaceutical	7.5
Polyester processing	kg/t polyester	50
Polystyrene processing	kg/t polystyrene	15
Polyurethane processing	kg/t polyurethane	3.4
PVC processing	kg/t PVC	4.0
Rubber processing	kg/tyres	0.14

Activity data

The activity data correspond to the annual consumption of paints which are estimated according to information from VSLF and relevant retailers for paint applications in households (EMIS 2019/2D3d NFR). Source category 2D3d Paint application, households has been updated substantially based on a comprehensive study including all major Swiss DIY companies resulting in revised activity data from 1999 onwards. Between 1990 and 1998, the total consumption of paint decreased considerably, increased continuously from 2004 onwards and dropped again after 2013. This trend results from the opposing trends in the different source categories:

- 2D3d NFR Paint application, construction: The paint consumption in construction shows a substantial reduction compared to 1990 levels. The increasing tendency in paint application between 2001 and 2013 and the drop afterwards can be explained to a certain extent by the evolution in the construction activity in Switzerland. Before 2001, there was a decline in construction activity, which explains the decreasing tendency in paint application.
- 2D3d Paint application, wood: The paint consumption for applications on wood increased moderately between 1990 and 1998. But from 2001 onwards it shows a comparable development as the paint application in construction.
- 2D3d NFR Paint application, industrial & non industrial: Between 1990 and 2016, the activity of industrial and non-industrial paint application decreased significantly. There was a clear decrease between 2001 and 2004 due to structural changes in the industrial sectors and a widespread application of powder coatings from 2004 onwards. Since powder coatings are solvent-free their amounts are not included in the activity data.

Table 4-40 Activity data of coating applications, degreasing, dry cleaning and chemical products, manufacture and processing in Switzerland.

2D3a Solvent use	Unit	1990	1995	2000	2005
Coating applications (2D3d NFR)					
Paint application, construction	kt	122	66	33	42
Paint application, households	kt	12	13	13	12
Paint application, industrial	kt	20	21	21	5.7
Paint application, wood	kt	6.0	6.3	6.5	7.7
Paint application, car repair	kt	2.7	2.2	2.0	1.9
Degreasing (2D3e NFR)					
Cleaning of electronic components	kt	0.90	0.56	0.35	0.64
Degreasing of metal	kt	16	10	5.9	2.6
Other industrial cleaning	kt	0.6	0.6	0.6	1.4
Dry cleaning (2D3f NFR)	kt	1.30	0.77	0.23	0.10
Chemical products, manufacture and processing (2D3g NFR)					
Fine chemicals production	prod. index	70	100	163	224
Glue production	kt	19	32	44	60
Handling and storing of solvents	prod. index	70	100	163	224
Ink production	kt	20	18	18	18
Paint production	kt	138	122	117	122
Pharmaceutical production	kt	16	21	20	28
Polyester processing	kt	11	7	6	7
Polystyrene processing	kt	20	19	19	24
Polyurethane processing	kt	17	35	45	54
Production of adhesive tape	kt	2	NO	NO	NO
PVC processing	kt	94	94	78	64
Rubber processing	tyres	120'000	119'375	103'667	67'000
Tanning of leather	employees	110	108	102	88

2D3a Solvent use	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Coating applications (2D3d NFR)											
Paint application, construction	kt	48	51	54	56	59	61	42	42	40	41
Paint application, households	kt	11	11	11	11	11	11	10	10	10	10
Paint application, industrial	kt	5.7	5.5	5.3	5.2	5.1	5.0	5.0	5.0	5.0	5.0
Paint application, wood	kt	8.7	9.3	10.0	10.0	10.0	10.0	7.2	6.7	6.3	6.3
Paint application, car repair	kt	1.8	1.7	1.7	1.5	1.4	1.2	1.1	1.0	0.9	0.9
Degreasing (2D3e NFR)											
Cleaning of electronic components	kt	0.60	0.63	0.67	0.70	0.73	0.73	0.73	0.73	0.73	0.73
Degreasing of metal	kt	2.3	2.2	2.1	2.0	1.9	1.9	1.9	1.9	1.9	1.9
Other industrial cleaning	kt	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Dry cleaning (2D3f NFR)	kt	0.09	0.09	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07
Chemical products, manufacture and processing (2D3g NFR)											
Fine chemicals production	prod. index	280	295	314	299	302	305	307	310	313	316
Glue production	kt	64	64	63	63	63	62	62	62	61	61
Handling and storing of solvents	prod. index	280	295	314	299	302	305	307	310	313	316
Ink production	kt	19	19	19	21	24	26	26	26	25	25
Paint production	kt	125	126	126	126	126	126	125	124	123	123
Pharmaceutical production	kt	29	30	30	30	30	30	31	31	31	31
Polyester processing	kt	6.2	4.8	3.4	3.5	3.7	3.7	3.7	3.7	3.7	3.7
Polystyrene processing	kt	29	31	34	36	31	32	32	33	33	34
Polyurethane processing	kt	67	52	54	40	40	38	38	37	37	36
Production of adhesive tape	kt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
PVC processing	kt	73	62	52	55	40	38	37	36	35	34
Rubber processing	tyres	72'500	75'000	77'500	80'000	80'000	81'000	82'000	83'000	84'000	85'000
Tanning of leather	employees	87	76	65	54	44	33	22	11	NO	NO

Degreasing and dry cleaning (2D3e NFR, 2D3f NFR)

Methodology

Source category 2D3e NFR comprises emissions from degreasing of electronic components, metal and other industrial cleaning. For the determination of NMVOC emissions from degreasing and dry cleaning a Tier 2 method according to the EMEP Guidebook (EMEP/EEA 2016) is used based on the consumption of solvents. Switzerland's Informative Inventory Report 2019 contains a detailed description of the methods and country-specific data used for estimating the NMVOC emissions from 2D3e NFR Degreasing and 2D3f NFR dry cleaning (FOEN 2019d).

Emission factors

Emission factors for NMVOC emissions from degreasing are based on data from the association of Swiss mechanical and electric engineering industries (swissmem) including VOC balance evaluations in 2004, 2007 and 2012 and expert estimates as documented in the EMIS database (EMIS 2019/2D3e NFR). For emission factors see Table 4-39.

NMVOC emission factors for dry cleaning are estimated based on information from the emission control authority and analysis of about 170 VKTS (Swiss supervising association of textile cleaning) inspection protocols from the four biggest Swiss cantons (AG, BE, VD and ZH) of 2017 as documented in the EMIS database (EMIS 2019/2D3f NFR).

Activity data

Activity data of degreasing correspond to the annual consumption of solvents used for degreasing. Data are based on data from the association of Swiss mechanical and electric engineering industries (swissmem) in 2004, 2007 and 2012, VOC balances, import statistics and expert estimates, documented in the EMIS database (EMIS 2019/2D3e NFR)). A comparison between the surveys and the evaluations of VOC balances showed an underestimation of the survey data by about 6%. Thus, the emissions based on survey data from the industry association (swissmem) have been corrected by +10%. Activity data is provided in Table 4-40.

For dry cleaning, activity data is the amount of tetrachloroethylene (PER) and non-halogenated solvents used. The activity data from 2001 onwards has been calculated based on the (annual) number of dry-cleaning facilities in Switzerland according to VKTS and SFSO (business census) and the mean solvent consumption per facility based on an analysis of about 170 VKTS inspection protocols from the four biggest Swiss cantons (AG, BE, VD and ZH) of 2017. Activity data for 1990 are based on net imports of PER. For the years in between, data are interpolated linearly as documented in the EMIS database (EMIS 2019/2D3f NFR).

Chemical products, manufacture and processing (2D3g NFR)

Methodology

Based on the decision tree Fig. 3.1 in chapter 2D3g in EMEP/EEA (2016), for source category 2D3 Chemical products a Tier 2 method using country-specific emission factors is used for calculating the NMVOC emissions. Switzerland's Informative Inventory Report 2019 contains a detailed description of the methods and country-specific data used for estimating the NMVOC emissions from 2D3g NFR Chemical products, manufacture and processing (FOEN 2019d).

Emission factors

Emission factors for NMVOC are mainly provided by industry associations, i.e. for

- Fine chemicals production, pharmaceutical production and handling and storing of solvents: Swiss business association for the chemical, pharmaceutical and biotech industry (scienceindustries)
- Paint and ink production: Swiss association for coating and paint applications (VSLF) and the Swiss Organisation for the Solvent Recovery of Industrial Enterprises in the Packaging Sector (SOLV)
- Polyurethane processing: Swiss plastics association
- Polyester processing: Swiss polyester association
- Tanning of leather: Swiss leather tanning association.

For the other processes in source category 2D3 (2D3g NFR) data are based on information from the industry and expert estimates as documented in the EMIS database. (EMIS 2019/2D3g). For emission factors see Table 4-39.

Activity data

The activity data are mainly production or consumption data provided by industry associations and by the Swiss Federal Office of Statistics, i.e. for:

- Fine chemicals production and handling and storing of solvents: Swiss Federal Office of Statistics.
- Pharmaceutical production: Swiss business association for the chemical, pharmaceutical and biotech industry (scienceindustries).
- Paint and ink production: Swiss association for coating and paint applications (VSLF) and Swiss Organisation for the Solvent Recovery of Industrial Enterprises in the Packaging Sector (SOLV).
- Polyurethane processing: Swiss plastics association.
- Polyester processing: Swiss polyester association.
- Tanning of leather: Swiss leather tanning association. The last Swiss tannery ceased production at the beginning of 2015.
- For the other processes in source category 2D3a (2D3g NFR) data are based on information from the industry and expert estimates as documented in the EMIS database. Since 1994 no production of adhesive tape is occurring in Switzerland anymore.

For activity data see Table 4-40.

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 EMEP/EEA (2016), 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 2019/2D3b 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 4-41 Emission factors of 2D3b Road paving with asphalt and 2D3c Asphalt roofing for 2017.

	Unit	CO	NMVOC
2D3b Road paving	kg/t asphalt concrete	NA	0.54
2D3c Asphalt roofing	kg/t asphalt sealing sheeting	0.01	5.4

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 4-42 Activity data for road paving with asphalt, asphalt roofing and urea use in SCR catalysts.

	Unit	1990	1995	2000	2005
2D3b Road paving with asphalt					
Asphalt concrete	kt	5'500	4'800	5'170	4'780
2D3c Asphalt roofing					
Asphalt sealing sheeting	kt	54.0	55.9	57.7	50.7
2D3d Urea use in SCR catalysts					
AdBlue	kt	NO	NO	NO	0.3

	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
2D3b Road paving with asphalt											
Asphalt concrete	kt	5'160	5'200	5'250	5'300	4'770	4'770	5'260	4'850	4'710	5'260
2D3c Asphalt roofing											
Asphalt sealing sheeting	kt	54.5	61.0	67.5	74.0	73.6	73.3	72.9	72.6	72.2	71.9
2D3d Urea use in SCR catalysts											
AdBlue	kt	10.0	14.4	17.7	20.0	21.6	23.1	24.2	25.6	27.9	30.4

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 EMEP/EEA (2016), 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 2019/2D3c Dachpappen Produktion und Verlegung). Emissions of CO are determined based on a Tier 1 method using the default emission factor (EMEP/EEA 2016).

Indirect CO₂ emissions resulting from CO and NMVOC emissions in this source category are only included in CRF Table 6 and reported 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 factors of CO and PM₁₀ are taken from the EMEP/EEA Guidebook 2016 (EMEP/EEA 2016) (see Table 4-41).

Activity data

Activity data is based on data from industry and expert estimates as documented in the EMIS database (see Table 4-42).

Urea use in SCR catalysts of diesel engines (2D3d)

This source category encompasses CO₂ 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 in this submission following a methodology suggested in the EMEP/EEA guidebook 2016 (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 Ad Blue consumption estimates. Emissions are calculated according to following formula:

$$\text{CO}_2 \text{ Emissions} = \text{EF} \cdot \text{FC} \cdot \text{Share of SCR vehicles mileage} \cdot \text{Specific urea share}$$

“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 CO₂ emissions from urea use in SCR-catalysts in vehicles is a default value (EMEP/EEA 2016) considering the molecular mass conversion of urea into CO₂ during the reaction with water and the content of 32.5% of the aqueous AdBlue urea solution.

Activity data

Activity data on AdBlue consumption as well as annual mileage are provided by INFRAS (INFRAS 2017) on a yearly basis as documented in EMIS 2019/2D3d NFR Urea (AdBlue) Einsatz Strassenverkehr. For activity data see Table 4-42.

4.5.3 Uncertainties and time-series consistency

The uncertainty of total CO₂ emissions from the entire source category 2D – Non-energy products from fuels and solvent use is estimated to be 100% (expert estimate).

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 2019.

Major recalculations which contribute significantly to the total differences in direct and indirect CO₂ emissions of sector 2 IPPU between latest and previous submission are presented also in chp. 10.1.2.2.

- 2D1: In last year's submission of the inventory, there was a double-counting of CH₄ and N₂O emissions from lubricant use in two-stroke engines. CH₄ and N₂O emission factors of two-stroke engines reported in sector 1 Energy (1A2gvii, 1A3biv, 1A3dii, 1A4aii, 1A4bii, 1A4cii and 1A5b) include emissions from lubricants. Therefore, emissions of CH₄ and N₂O from source category 2D1 Lubricant use in two-stroke engines have been deleted in the current submission.
- 2D1: Activity data of lubricant use in two-stroke engines are related to the fuel use of the respective engines. The fuel use of two-stroke motorcycles has been revised for the entire time series based on the ex-post analysis 2016 for the road sector (see category-

specific recalculations for 1A3). This resulted in revised activity data of source category 2D1 Lubricant use unspecified as well since the total Swiss lubricant use is based on the net lubricant import which was not affected. In addition, Liechtenstein's lubricant use in 2016 has been corrected resulting in revised values of both source categories for 2016.

- 2D3a: The activity data and NMVOC emission factor of 2D3a (2D3d NFR) Paint application, car repair have been revised for 2016 and 2005–2016, respectively, based on new data and information from the industry association.
- 2D3a: The activity data and NMVOC emission factor of 2D3a (2D3d NFR) Paint application, construction have been revised for 2014–2016 based on new data and information from the industry association.
- 2D3a: The activity data and NMVOC emission factor of 2D3a (2D3d NFR) Paint application, wood have been revised for 2014–2016 and 2013–2016, respectively, based on new data and information from the industry association.
- 2D3a: The activity data and NMVOC emission factor of 2D3a (2D3d NFR) Paint application, households have been revised for 2016 based on a comprehensive study including all major Swiss DIY companies resulting in recalculated interpolated values for 1999–2015 as well.
- 2D3a: The source category 2D3a (2D3f NFR) Dry cleaning has been revised completely from 2001 onwards based on information and data from industry associations, emission control authorities and the Swiss Federal Statistical Office yielding recalculated activity data and NMVOC emission factors for the time series 1991–2016.
- 2D3a: The CO₂ emissions from post-combustion of NMVOC in source categories 2D3a (2D3d NFR) Industrial paint application, 2D3a (2D3f NFR) Degreasing and 2D3a (2D3g NFR) Chemical products have been revised for the entire time series 1990–2016. For all post-combustion plants, the NFR source category allocation has been verified. Furthermore, the so far applied default carbon content of 50% for installations with no available information on the solvent composition has been replaced by a mean source category-specific value. Additionally, no longer only the total CO₂ emissions per NFR source category are reported but also the total amount of solvents destroyed in the post-combustion plants.
- 2D3a: The activity data of source category 2D3a (2D3g NFR) Leather tanning has been revised from 2009 onwards since the last Swiss tannery ceased production in the beginning of 2015.
- 2D3d: Activity data from urea use in SCR catalysts of diesel engines depends on activity data in 1A3 and therefore there were minor adjustments. Largest change affects 2016.

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, NF₃ and SF₆ emissions from consumption of the applications listed below in Table 4-43.

Table 4-43 Specification of source category 2E Electronics industry in Switzerland.

2E	Source	Specification
2E1	Integrated circuit or semiconductor	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. 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 4-43 (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 (2019).

Methodology

A Tier 2a approach with process gas-specific parameters 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.

Imports of electronics industry were included in FOEN statistics under solvents until 2010. 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 4-43 (Carbotech, 2019). 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 2006 IPCC Guidelines are used for production and waste-air treatment. 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 is estimated at 50% (HFC), 98% (PFC), 61% (SF_6), 220% (NF_3) based on a Monte Carlo simulation. More information is available from Carbotech (2019).

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 current and the previous submissions. The general QA/QC measures are described in chp. 1.2.3.

4.6.5 Category-specific recalculations

No category-specific recalculations were carried out.

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 4-44 Key categories of 2F Product uses as substitutes for ozone depleting substances. Combined KCA results, level for 2017 and trend for 1990–2017, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
2F1	Refrigeration and air conditioning	HFC	L1, L2, T1, 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 4-45.

Table 4-45 Specification of source category 2F Product uses as substitutes for ozone depleting substances in Switzerland.

2F	Source	Specification
2F1	Refrigeration and air conditioning	Emissions from refrigeration and air conditioning (incl. heat pumps and tumble dryers)
2F2	Foam blowing agents	Emissions from foam blowing, incl. polyurethane 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 2017, stationary and mobile refrigeration and air conditioning equipment accounted by far for the highest emissions with a share of 96% of the total emissions in source category 2F. Further, emissions are dominated by HFCs and only a minor contribution comes from PFCs (generally less than 1%).

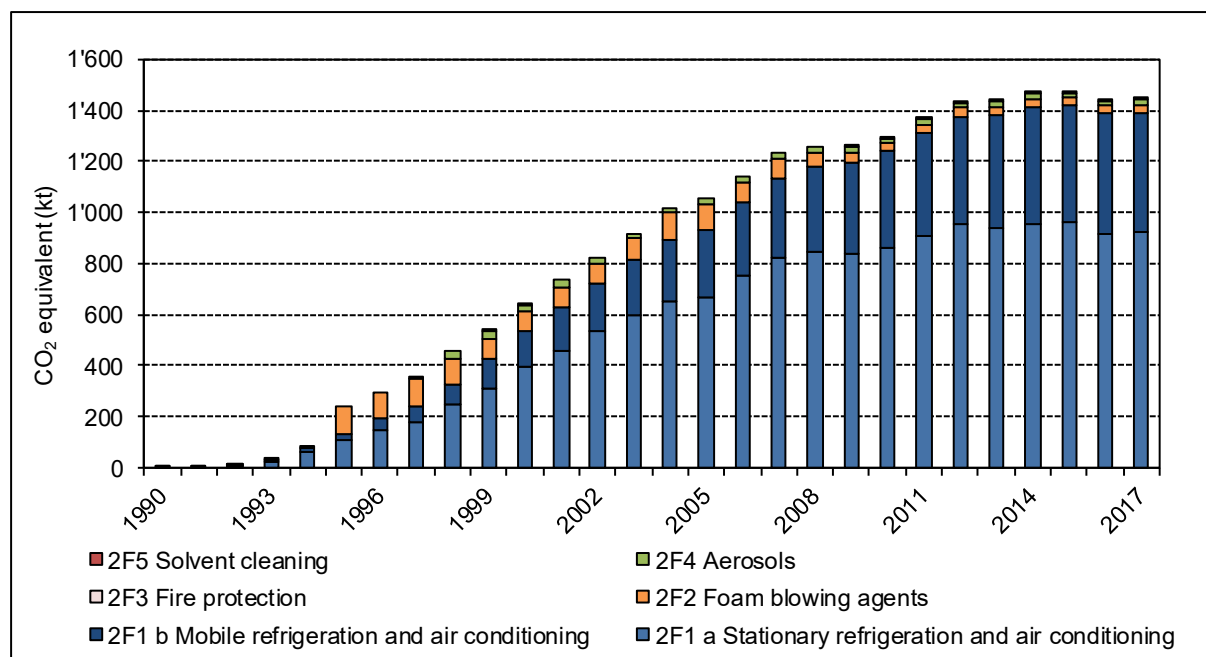


Figure 4-7 Development of emissions under source category 2F Product uses as substitutes for ozone depleting substances. HFC and small amounts of PFC are used as substitutes for ozone depleting substances. Most relevant today are emissions from the built up refrigerant stock in refrigeration and air conditioning equipment.

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. Where possible, the most important assumptions for the data model are documented in Table 4-46. More information of the individual data and models is available from Carbotech (2019) as well as related background documents. This information is FOEN internal due to confidentiality of data, but is open for consultation by reviewers.

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 informations 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).

Commercial and industrial refrigeration have been evaluated together in former years. Since the submission 2018 calculations are carried out separately. The total bulk refrigerant for commercial and industrial application is split considering typical use of refrigerant blends and information on commercial and industrial equipment provided to FOEN (Carbotech 2019). Parameters for commercial and industrial applications are given in Table 4-46. 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 one approach. Noteworthy, in the hypothetical but possible case of incomplete 'bottom up' evaluations, remaining imported refrigerant would be attributed to the production and maintenance of industrial and commercial refrigeration equipment. This might be a 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 4-8 shows the required data for the model calculation of refrigeration and air conditioning.

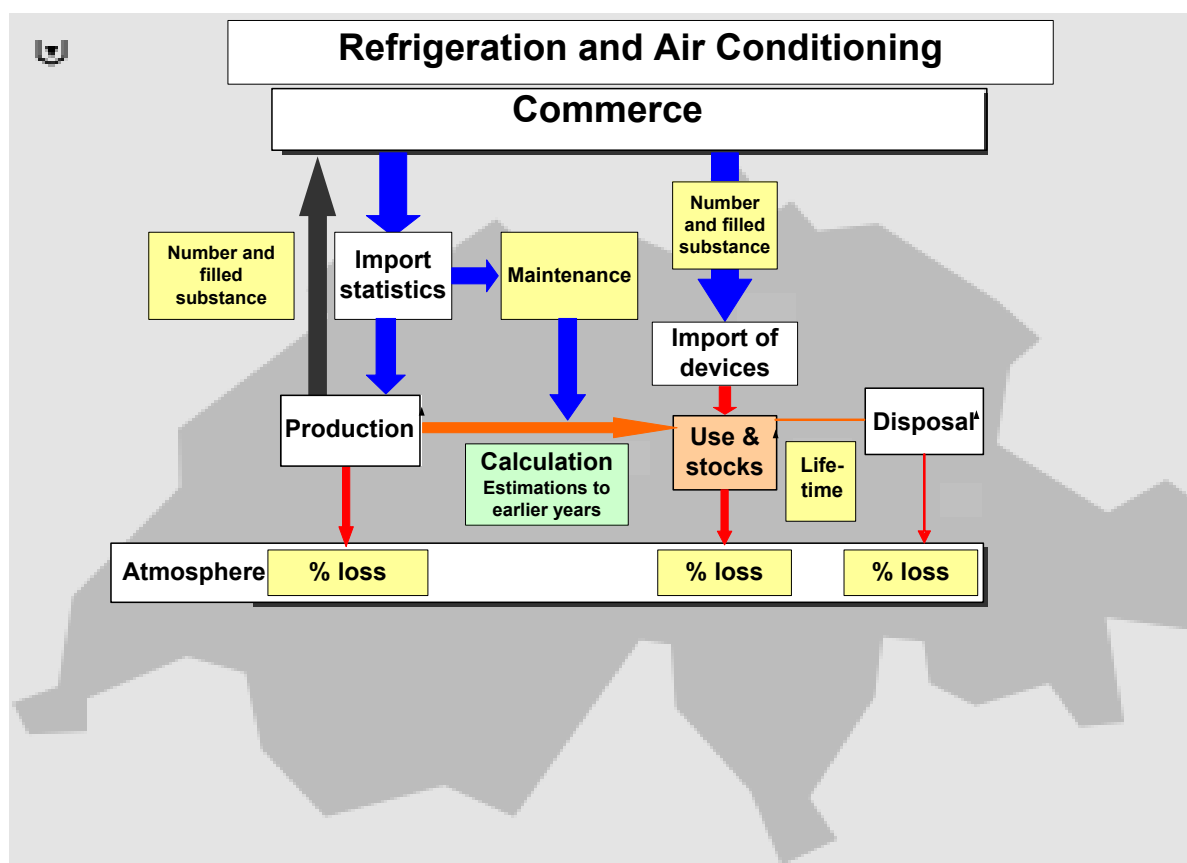


Figure 4-8 Required data for the model to calculate emissions from refrigeration and air conditioning in Switzerland.

In 2008, a revision of the Chemical Risk Reduction Ordinance (Swiss Confederation 2005) was introduced. As part of this revision, 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 was introduced. This data source provides valuable information and has been used to improve the estimates used for modelling emissions under source category 2F and for the split of commercial and industrial equipment. However, it did not allow to directly draw the stock data or emission factors for the national inventory.

Emission factors

Emission factors for 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 quality (confidential data from retailers and other type of industry). 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 4-46 displays the detailed model parameters used for the present submission. Changes of model parameters within the period 1990 to 2017 are indicated with values in

brackets. The parameters in brackets are applied for the inventory 2017. For product life emission factors of some equipment types, a dynamic model which implies that emission decrease linearly between 1995 and 2015 due to improved production technologies and the continuous sensibilisation of service technicians is applied. The start/end values are based on expert statements (UBA 2005, UBA 2007, Schwarz 2001, Schwarz and Wartmann 2005). The charge at end of life for different applications has been analysed considering the technical minimal charge of equipment and the expected frequency of 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 at site or waste treatment by specialized companies.

Table 4-46 Typical values of lifetime, charge and emission factors used in the model calculations for 1990 to 2017 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 periode.

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. 30% of the total emissions (CO₂ eq) of source category 2F1 Refrigeration and air conditioning in the inventory 2017.

For the inventory report 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 secondhand use. Export rates used in model calculations are given in Table 4-46.

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 have been calculated (Tier 1a) as residual balance between FOEN import statistics and consumption in PU spray, PU and XPS foams.

Emission factors

For emission factors and lifetime of XPS and PU foam, expert estimates and default values according to the 2006 IPCC Guidelines (IPCC 2006, Volume 3, p. 7.37) are used. For PU spray, 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 4-47 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 total production volume in the time period of HFC use. About one third of 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 CO₂). 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 available from Carbotech (2019) as well as related background documents at FOEN, but not reported due to confidentiality.

4.7.2.3 Fire protection (2F3)

No emissions occur in source category 2F3 within Switzerland. The application of HFCs, PFCs and SF₆ in fire extinguishers is prohibited by law.

4.7.2.4 Aerosols (2F4)

Methodology

The Tier 2a emission model for Aerosol / MDI 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.

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 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 current GHG inventory (submission 2018). 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 4-48 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 10'000 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, 2019).

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 4-48. 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 4-48 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 – 2016	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 4-49 illustrate the definition of ranges for the example of commercial refrigeration.

Table 4-49 Assumptions on probability ranges for the example of commercial refrigeration.

Parameter	applied "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 2016	7.8%	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, calculated value
Disposal loss emission factor (professional disposal)	10%	1%	40%	Normal distribution, StdDev10%
Professional disposal	85%	45%	95%	Normal distribution, StdDev5%

Table 4-50 summarises the results for the application-specific emission models. The “value 2016” represents the reported emissions in kt CO₂ eq for the specific application for the year 2016. The uncertainty values stem from the Monte Carlo analysis. Detailed data are available from background documents at FOEN (Carbotech 2019).

The uncertainty of the resulting total emissions from source category 2F Product uses as substitutes for ODS is about 18%. 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 4-50 Summary of results for model parameter “emissions” from Monte Carlo analysis for 2017 data on selected emission sources.

Application	Model parameter	Value 2017 kt CO ₂ eq.	Average kt CO ₂ eq.	Median kt CO ₂ eq.	min. kt CO ₂ eq.	max. kt CO ₂ eq.	Uncertainty %
2F1 Refrigeration and air conditioning	Emissions in kt CO ₂ eq.	1'408	1'409	1'437	1'150	1'927	15
2F2 Foam blowing agents		29.3	41.8	37.5	9.6	272.8	130
2F4 Aerosols		23.6	24.4	24.4	9.8	41.1	40
2F5 Solvents		1.3	1.3	1.3	0.5	2.7	62
Total 2F Product use as substitutes for ODS		1'462	1'477	1'500	1'170	2'244	18

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 current and the previous submission. 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 emission factor of category 2F used in the Swiss inventory was compared to the corresponding emission factors of other countries (UNFCCC: <http://unfccc.int/di/FlexibleQueries.do>) and to the IPCC default value if available (INFRAS 2012). Concerning ODS substitutes the following sources of emissions are deemed most relevant: HFC-125, HFC-134a, HFC-143a and HFC-32 from stationary and commercial refrigeration as well as mobile air conditioning. The product life factor is relevant, since there is no production of halocarbons in Switzerland. For all these sources Switzerland's emission factors lie in the midfield of the range of other countries except for the life factor in mobile air conditioning and commercial and industrial refrigeration. However, when compared to neighbouring countries such as Germany, very similar values are used. The Swiss product life factors are often lower than the average for the following reasons. First, since 2005 the Chemical Risk Reduction Ordinance (Swiss Confederation 2005) is in place that ensures the proper handling and disposal of halocarbons and SF₆. Second, the decommissioning sector is well-organized by the SENS foundation and recycling is taxed in advance. Third, servicing staff is well-trained to proper handling and disposal of respective appliances. And fourth, the good economic conditions allow a higher renewal frequency and higher equipment standard (export of old vehicles and equipment for secondhand use).

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 SF₆ 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 HFC-134a, HFC-125, HFC-143 and HFC-32 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 2019:

- 2F1a: HFC-245fa used for organic rankine cycles ORC mainly, lower emission factor applied 2013-2017 (ORC included under industrial refrigeration). Additional imports added corresponding to the consumption of specific plant 2016.
- 2F1a: HFC-134a model calculation have been optimized for the amount of air conditioning refrigerant in retiring vehicles 2015-2016.
- 2F1a: Calculations of blends R448 and R449 for commercial and industrial refrigeration has been included in the model 2015-2016.

4.7.6 Category-specific planned improvements

Gradual improvement of the data quality in co-operation with industry is ongoing. As in the past years, methodologies and emission models will be updated during the yearly process of F-gas inquiry. The focus will be on:

- Improvements of HFC emission calculations from refrigeration and air conditioning equipment.
- Changes are expected and will be analysed in this area due to the revision of the Chemical Risk Reduction Ordinance and CO₂ compensation programmes (share of products with HFC, recycling of HFC, early replacement of HFC).

4.8 Source category 2G – Other product manufacture and use

4.8.1 Source category description

Table 4-51 Key categories of 2G Other product manufacture and use. Combined KCA results, level for 2017 and trend for 1990–2017, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
2G	Other product manufacture and use	N ₂ O	T2
2G	Other product manufacture and use	SF ₆	L1

Table 4-52 Specification of source category 2G Other product manufacture and use in Switzerland.

2G	Source	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, research and laboratory use)
2G3	N ₂ O from product uses	Emissions of N ₂ O from the use of N ₂ O in hospitals; Emissions of N ₂ O 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; Emissions of CO ₂ , NO _x , CO and SO ₂ from use of fireworks; Emissions of CO ₂ , NO _x and CO from use of tobacco; 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 SF₆ on 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 SF₆ for other applications (i.e. research, magnesium foundry). SWISSMEM is collecting data from its members and is crosschecking the reported SF₆ consumption data with data from importers of SF₆. Installations in operation with electrical equipment containing SF₆ are periodically inspected for leakage, and losses are refilled (topping up). The refilled quantities and any SF₆ 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 SF₆ emissions.

Activity data

Activity data are based on industry information. The wide annual fluctuation of SF₆ 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 SF₆ 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 SF₆ and PFCs from other product use (2G2)

Methodology

The emissions reported under 2G2 are related to the use of SF₆ for industrial particle accelerators (2G2b), the use of SF₆ for soundproof windows (2G2c) and other PFC and SF₆ use (2G2e). 2G2e summarizes research/analytics and further applications (including the unallocated difference in SF₆ 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 SF₆ 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. Therefore, the unallocated amount of SF₆ under 2G2e has been assigned as application of cables and electrical control systems. 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 for reviewers on request.

Emission factors

For the unallocated amount of SF₆ assigned to cables and electrical control systems, the emission factor is assumed to be 4% for manufacturing and 1% per year during the product life. 100% of the remaining charge is 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 SF₆ in Switzerland.

Activity data

Activity data are based on import statistics and industry information. For the unallocated amount of SF₆ assigned to cables and electrical control systems 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 under source category 2G2e Other.

4.8.2.3 N₂O from product uses (2G3)

Methodology

Emissions of N₂O 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 N₂O 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 N₂O sold for anaesthesia purpose in Switzerland divided by the number of inhabitants. The amount of N₂O sold is derived from annual sales data from the main suppliers from 2005 onwards (EMIS 2019/2G3a Lachgasanwendung Spitler).

Source category 2G3b Other includes N₂O emissions from whipped-cream makers using gas capsules for private households and restaurants. The emission factor is calculated based on sales data and N₂O content of gas capsules sold in Switzerland divided by the number of inhabitants (EMIS 2019/2G3b Lachgasanwendung Haushalt).

Table 4-53 N₂O emission factors for the source categories 2G3a Medical applications and 2G3b Other.

2G3a Use of N ₂ O for anaesthesia	Unit	1990	1995	2000	2005
N ₂ O	g/inhabitant	43	29.8	16.6	12.0
2G3b N ₂ O from aerosol cans					
N ₂ O	g/inhabitant	9.6	10.1	10.7	11.3

2G3a Use of N ₂ O for anaesthesia	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
N ₂ O	g/inhabitant	8.0	7.0	7.0	6.0	5.7	3.5	3.8	3.3	2.5	2.4
2G3b N ₂ O from aerosol cans											
N ₂ O	g/inhabitant	11.6	11.8	11.9	12.0	11.7	11.3	11.0	10.7	10.3	10.0

Activity data

For the source categories 2G3a Medical applications and 2G3b Other the activity data correspond to the Swiss population (SFSO 2018c) (EMIS 2019/2G3a Lachgasanwendung Spitler and EMIS 2019/2G3b Lachgasanwendung Haushalt).

Table 4-54 Activity data for the source categories 2G3a Use of N₂O for anaesthesia and 2G3b N₂O from aerosol cans.

2G3 N ₂ O from product uses	Unit	1990	1995	2000	2005
2G3a, 2G3b	inhabitants	6'796'000	7'081'000	7'209'000	7'501'000

2G3 N ₂ O from product uses	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
2G3a, 2G3b	inhabitants	7'711'000	7'801'000	7'878'000	7'912'000	7'997'000	8'089'000	8'189'000	8'282'000	8'373'000	8'452'000

4.8.2.4 Other (2G4)

Since the 2006 IPCC Guidelines (vol. 3, chp. 5.5) refer to the EMEP/EEA Guidebook 2016 regarding methodologies for estimating NMVOC emissions from solvent use, the respective NFR codes are indicated as reference as well. In the following sections 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. From other product use (2G NFR) also CO₂, NO_x, CO and SO₂ as well as CO from the use of fireworks and tobacco, respectively, are emitted. Switzerland's Informative Inventory Report 2019 contains a detailed description of the methods and country-specific data used for estimating the NMVOC emissions from the most important sources within source category 2G4 Other (FOEN 2019d). Indirect CO₂ emissions resulting from NMVOC and CO emissions in this source category are only included in CRF Table 6 and reported in chp. 9.

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 CO₂ emissions from post-combustion of NMVOC are estimated based on industry data and expert estimates (Carbotech 2019a).

Emissions of HFC not accounted for in other source categories are reported under 2G4.

Post-combustion of NMVOC (2G4)

Methodology

The CO₂ 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 2019a). Post-combustion facilities are applied in source categories printing (NFR code 2D3h), other solvent use (NFR code 2D3i) and other product use (NFR codes 2G). For submission 2019, the source category allocation of all post-combustion plants has been verified. 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

Emission factors are derived from the composition of solvents. For installations with no information on the solvent composition, mean source category-specific values are applied.

Table 4-55 CO₂ emission factors for post-combustion of NMVOC in 2G4 Other.

2G4 Other	Unit	CO ₂			
Post-combustion of NMVOC		1990	1995	2000	2005
Printing (2D3h NFR)	t/t NMVOC	2.25	2.20	2.17	2.14
Other solvent use (2D3i NFR)	t/t NMVOC	2.06	2.04	2.02	2.01
Other product use (2G NFR)	t/t NMVOC	1.30	1.56	1.61	1.68

2G4 Other	Unit	CO ₂									
Post-combustion of NMVOC		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Printing (2D3h NFR)	t/t NMVOC	2.14	2.15	2.13	2.13	2.13	2.13	2.13	2.08	2.09	2.09
Other solvent use (2D3i NFR)	t/t NMVOC	2.00	2.01	2.02	2.02	2.02	2.02	2.01	2.28	2.28	2.28
Other product use (2G NFR)	t/t NMVOC	1.68	1.68	1.89	1.70	1.72	1.72	1.69	1.72	1.72	1.39

Activity data

Activity data are provided by the industry. For the ten most important installations, activity data are provided annually.

Table 4-56 Activity data of NMVOC post-combustion in 2G4 Other.

2G4 Other	Unit	1990	1995	2000	2005
Post-combustion of NMVOC					
Printing (2D3h NFR)	t NMVOC	2'188	9'357	11'276	12'933
Other solvent use (2D3i NFR)	t NMVOC	317	503	559	405
Other product use (2G NFR)	t NMVOC	412	935	1'118	953

2G4 Other	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Post-combustion of NMVOC											
Printing (2D3h NFR)	t NMVOC	12'769	12'865	13'331	15'083	14'249	14'488	14'286	14'294	14'911	15'630
Other solvent use (2D3i NFR)	t NMVOC	371	377	573	573	573	573	543	382	382	382
Other product use (2G NFR)	t NMVOC	953	953	622	866	833	833	850	872	871	2'532

Domestic solvent use (2D3a NFR)

Methodology

The source category 2G4 Domestic solvent use (2D3a NFR) Domestic solvent use including fungicides comprises mainly the use of cleaning agents and solvents in private households for building and furniture cleaning and cosmetics and toiletries but also the use of spray cans and pharmaceuticals. These products contain solvents, which evaporate during use or after the application. Among the numerous NMVOC emission sources, the use of household cleaning agents is the largest single source in source category 2D3.

Based on the decision tree Fig. 3.1 in chapter 2D3a in EMEP/EEA (2016), the emissions are calculated by a Tier 2 method (EMIS 2019/2D3a) using country-specific emission factors. All emissions related to domestic solvent use are calculated proportional to the Swiss population.

Emission factors

- Household cleaning agents:** The source category 2D3a Use of cleaning agents includes the use of cosmetics, toiletries, cleaning agents and care products. Its resulting emission factor bases thus on a multitude of products, their NMVOC contents, emission fractions and consumption numbers. About 80% of the NMVOC emissions stem from the use of cosmetics and toiletries whereas the rest arises from the use of cleaning agents and care products. Available data sources consist of surveys of the use of household cleaning agents, cosmetics and toiletries in Switzerland (1990) and information from the Swiss association of cosmetics and detergents (SKW 2010) as well as surveys from Germany (1998, 2005). From 2001 until 2010 a constant EF is assumed for domestic use of cleaning agents. The value is based both on information from the Swiss association of cosmetics and detergents (SKW 2010) and from a German study on NMVOC emissions from solvent use and abatement possibilities by Theloke (2005). There were no significant improvements in the solvent compositions of the employed detergents. In a study conducted in 2013/2014 in Switzerland better data of household cleaning agents, cosmetics and toiletries was collected based on comprehensive surveys at retailers, producers, industry associations and experts as well as analysis of import statistics (Hubschmid 2014). As a result of this study, the emission factor of household cleaning agents was adjusted in 2013. The study indicates again an increase in the NMVOC emission factor in 2013.

- *Domestic use of spray cans:* Emission factors of domestic use of spray cans are based on surveys in Switzerland (1990) and a Swiss study conducted in 2013/2014. This study provided better data of domestic spray cans based on comprehensive surveys at retailers, producers, industry associations and experts as well as analysis of import statistics (Hubschmid 2014). As a result of this study, the emission factor of spray cans was adjusted. It is assumed constant for the time period since 1998.
- *Domestic use of pharmaceutical products:* Emission factors of domestic use of pharmaceutical products are available from surveys in Switzerland (1990) and Germany (1998) and from the Swiss business association for the chemical, pharmaceutical and biotech industry (scienceindustries) for 2011, as documented in the EMIS database. For years with no survey data, emission factors are interpolated.

Table 4-57 Emission factors for NMVOC for source category 2G4 Other: domestic solvent use, printing, other solvent use, other product use in 2017.

2G4 Other	Unit	NMVOC
Domestic solvent use (2D3a NFR)		
Domestic use of spray cans	g/inhabitant	360
Domestic use of pharmaceuticals	g/inhabitant	30
Household cleaning agents	g/inhabitant	983
Printing (2D3h NFR)		
Printing	kg/t ink	280
Package printing	kg/t ink	177
Other solvent use (2D3i NFR)		
Production of cosmetics	kg/employee	63
Production of paper and paperboard	g/t	35
Production of perfume and flavour	kg/employee	38
Production of textiles	kg/employee	8
Production of tobacco	kg/employee	12
Removal of paint and lacquer	kg/t removal agent	400
Scientific laboratories	kg/employee	15
Other product use (2G NFR)		
Application of glues and adhesives	kg/t solvent	733
Commercial & industrial use of cleaning agents	g/employee	443
Cosmetic institutions	kg/employee	28
De-icing of airplanes	kg/t de-icing agent	54
Glass wool enduction	g/t glass wool	190
Hairdressers	kg/employee	14
Health care, other	kg/employee	8
Medical practices	kg/employee	8
Preservation of wood	kg/t preservative	110
Rock wool enduction	g/t rock wool	477
Underseal treatment & conservation of vehicles	kg/t underseal agent	440
Use of antifreeze agents in vehicles	kg/Mio vehicle km	8
Use of concrete additives	g/t additive	740
Use of cooling lubricants	kg/t lubricant	6
Use of lubricants	kg/t lubricant	340
Use of pesticides	kg/t pesticide	33
Use of tobacco	kg/Mio cigarette eq.	5

Activity data

As described in the methodology chapter, the activity data used for calculating the NMVOC emissions from domestic solvent use corresponds to the Swiss population (SFSO 2018c), see Table 4-58.

Table 4-58 Activity data for source category 2G4 domestic solvent use, printing, other solvent use, other product use.

2G4 Other	Unit	1990	1995	2000	2005
Domestic solvent use (2D3a NFR)	inhabitants	6'796'000	7'081'000	7'209'000	7'501'000
Printing (2D3h NFR)					
Printing	kt ink	13	13	14	5.5
Package printing	kt ink	5.9	5.9	5.5	9.1
Other solvent use (2D3i NFR)					
Fat, edible & non-edible oil extraction	kt	40	38	12	NO
Production of cosmetics	employees	2'200	2'200	2'267	2'100
Production of paper and paperboard	kt	1'510	1'560	1'780	1'750
Production of perfume and flavour	employees	2'200	2'325	2'567	3'200
Production of textiles	employees	25'200	26'763	24'300	17'067
Production of tobacco	employees	3'300	2'988	2'733	2'700
Removal of paint and lacquer	t	700	600	490	378
Scientific laboratories	employees	10'194	18'604	23'217	23'000
Vehicles dewaxing	vehicles	200'000	166'250	72'667	NO
Other product use (2G NFR)					
Application of glues and adhesives	kt	4.0	3.0	2.0	1.5
Commercial & industrial use of cleaning agents	employees	3'950'000	3'867'500	3'954'667	4'133'667
Cosmetic institutions	employees	2'600	3'100	3'533	3'800
De-icing of airplanes	kt	1.2	2.4	1.8	2.5
De-icing of airport surfaces	kt	0.3	0.4	0.3	0.4
Fireworks	kt	0.8	1.0	1.5	1.4
Glass wool enduction	kt	24	24	31	37
Hairdressers	employees	20'553	22'826	23'530	22'200
Health care, other	employees	113'000	129'250	145'667	161'667
Medical practices	employees	27'625	42'047	50'833	55'357
Preservation of wood	kt paint	6.0	7.9	8.7	7.2
Rock wool enduction	kt	38	40	51	46
Underseal treatment & conservation of vehicles	kt	0.06	0.06	0.08	0.12
Use of antifreeze agents in vehicles	Mio vehicle km	47'523	46'479	51'142	53'723
Use of concrete additives	kt	24	25	29	36
Use of cooling lubricants	kt	5.0	5.2	5.8	4.5
Use of lubricants	kt	1.3	1.3	1.3	3.7
Use of pesticides	kt	2.4	2.0	1.7	1.5
Use of tobacco	Mio cigarette eq.	16'192	15'774	15'381	13'369

2G4 Other	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Domestic solvent use (2D3a NFR)	inhabitants	7'711'000	7'801'000	7'878'000	7'912'000	7'997'000	8'089'000	8'189'000	8'282'000	8'373'000	8'452'000
Printing (2D3h NFR)											
Printing	kt ink	2.5	2.5	2.4	2.2	2.0	1.9	1.9	1.9	1.9	2.0
Package printing	kt ink	13	13	13	13	13	13	13	13	13	13
Other solvent use (2D3i NFR)											
Fat, edible & non-edible oil extraction	kt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Production of cosmetics	employees	2'100	2'100	2'100	2'100	2'100	2'100	2'100	2'100	2'100	2'100
Production of paper and paperboard	kt	1'700	1'540	1'540	1'380	1'372	1'363	1'355	1'346	1'338	1'329
Production of perfume and flavour	employees	3'425	3'450	3'475	3'500	3'521	3'542	3'563	3'583	3'604	3'625
Production of textiles	employees	16'200	14'200	13'800	14'800	14'768	14'737	14'705	14'674	14'642	14'611
Production of tobacco	employees	3'200	3'200	3'200	3'200	3'200	3'200	3'200	3'200	3'200	3'200
Removal of paint and lacquer	t	310	288	265	243	220	198	175	153	130	130
Scientific laboratories	employees	23'000	23'000	23'000	23'000	23'083	23'167	23'250	23'333	23'417	23'500
Vehicles dewaxing	vehicles	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Other product use (2G NFR)											
Application of glues and adhesives	kt	1.2	1.2	1.1	1.0	1.9	1.0	1.0	1.0	1.0	1.0
Commercial & industrial use of cleaning agents	employees	4'323'333	4'363'667	4'404'000	4'333'333	4'262'667	4'192'000	4'236'000	4'280'000	4'324'000	4'368'000
Cosmetic institutions	employees	4'400	4'600	4'800	5'000	5'111	5'222	5'333	5'444	5'556	5'667
De-icing of airplanes	kt	3.0	4.0	3.3	2.6	3.8	3.1	2.3	2.3	2.3	2.3
De-icing of airport surfaces	kt	NO	0.004	0.018	NO	NO	NO	NO	NO	NO	NO
Fireworks	kt	2.0	2.0	1.7	2.0	1.9	2.3	1.8	1.6	1.2	1.7
Glass wool enduction	kt	44	33	36	41	39	33	32	31	32	36
Hairdressers	employees	23'000	23'000	23'000	23'000	23'000	23'000	23'000	23'000	23'000	23'000
Health care, other	employees	163'000	163'000	163'000	163'000	163'000	163'000	163'000	163'000	163'000	163'000
Medical practices	employees	58'700	58'700	58'700	58'700	58'700	58'700	58'700	58'700	58'700	58'700
Preservation of wood	kt paint	6.1	5.3	4.5	3.6	2.8	2.0	2.0	2.0	2.0	2.0
Rock wool enduction	kt	58	53	56	57	57	54	53	47	52	52
Underseal treatment & conservation of vehicles	kt	0.14	0.15	0.16	0.17	0.18	0.17	0.17	0.17	0.17	0.17
Use of antifreeze agents in vehicles	Mio vehicle km	55'713	56'376	57'039	58'007	58'976	59'944	60'913	61'881	62'260	62'638
Use of concrete additives	kt	34	34	41	44	38	38	37	37	36	36
Use of cooling lubricants	kt	4.9	3.1	3.9	4.4	4.1	4.1	4.1	4.1	4.1	4.0
Use of lubricants	kt	0.4	0.3	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4
Use of pesticides	kt	1.7	1.9	2.0	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Use of tobacco	Mio cigarette eq.	13'310	13'667	12'443	11'856	12'705	12'162	10'628	10'284	10'731	10'731

Printing (2D3h NFR)

Methodology

The source category 2G4 Printing (2D3h NFR) has been split into 2G4 Other printing industry and 2G4 Package printing. A Tier 2 method according to the EMEP/EEA Guidebook 2016 is applied using country-specific emission factor for calculating the NMVOC emissions from ink applications.

Emission factors

Emission factors for NMVOC are based on data from industry associations (Swiss Organisation for the Solvent Recovery of Industrial Enterprises in the Packaging Sector (SOLV)), VOC balances in the printing industry, German studies on NMVOC emissions from solvent use (Theloke 2005) and expert estimates, as documented in the EMIS database (EMIS 2019/2G4). For emission factors see Table 4-57.

Activity data

The activity data used for calculating the NMVOC emissions correspond to the annual consumption of printing ink. This data stem from industry associations (SOLV), VOC balances in the printing industry and expert estimates, documented in the EMIS database (EMIS 2019/2G4). For activity data see Table 4-58.

Other solvent use (2D3i NFR)

Methodology

Source category 2G4 Other solvent use (NFR 2D3i) consists of a number of solvent uses in various production processes and services. Based on the decision tree Fig. 3.1 in chapter 2D3i in EMEP/EEA (2016), a Tier 2 method using country-specific emission factors is applied for calculating the NMVOC emissions from the different solvent applications in source category 2D3i Other solvent use (EMIS 2019/2G4). For the source category 2G4 Other solvent use (NFR 2D3i) Not-attributable solvent emissions so-called direct emission data is available only.

Emission factors

Emission factors for NMVOC are country-specific based on data from industry and services, industry associations, German studies on NMVOC emissions from solvent use (Theloke et al. 2000 and Theloke 2005) and expert estimates, as documented in the EMIS database (EMIS 2019/2G4). For emission factors see Table 4-57.

Activity data

For the majority of production processes and services – such as production of perfume and flavour and production of textiles – the activity data correspond to the respective number of employees (SFSO 2018d). The quantity of NMVOC emission per employee originates from the bottom-up approach in these industrial sectors and the decentralized political structure in Switzerland. The determined NMVOC emissions of representative production sites or service institutions are referred to the number of employees in order to calculate the Swiss total.

For production of paper and paperboard and fat, edible and non-edible oil extraction, the activity data are based on production volumes. Annual production volumes of paper and paperboard are provided by the Swiss association of pulp, paper and paperboard industry (ZPK). For the removal of paint and lacquer the activity data correspond to the amount of removal agent based on information from producers and retail trade.

For activity data see Table 4-58.

Other product use (2G NFR)

Methodology

Within source category 2G Other product use, the major NMVOC emission sources in 2017 are 2G Commercial and industrial use of cleaning agents and 2G Health care, other.

Based on the decision tree Fig. 3.1 in chapter 2G in EMEP/EEA (2016), for source category 2G Other product use Tier 2 methods using country-specific emission factors are applied for calculating the emissions from the different product applications and the use of fireworks and tobacco (EMIS 2019/2G).

For the source categories 2G Renovation of corrosion inhibiting coatings and 2G Use of aerosol cans in commerce and industry so-called direct emission data is available only.

Source category 2G De-icing of airplanes (and other de-icing operations) which was the second important emission source within 2G in the past has been revised completely for this submission. The revision was based on a comprehensive study including information and data from three Swiss airports (i.e. the two most important and a regional one) yielding recalculated activity data and NMVOC emission factors for the entire time series 1990-2016. The source category is now split into three source categories, i.e. 2G De-icing of airplanes and 2G De-icing of airport surfaces as well as 2G Use of antifreeze agents in vehicles. Since 2011 no NMVOC containing agents are used for de-icing of airport surfaces anymore.

Indirect CO₂ emissions from CO and NMVOC emissions from tobacco use are of biogenic origin and are therefore not reported in chp. 9 Indirect CO₂ and N₂O emissions.

Emission factors

Emission factors for NMVOC are based on data from industry and services, industry associations, German studies on NMVOC emissions from solvent use (Theloke et al. 2000 and Theloke 2005) and expert estimates, as documented in the EMIS database (EMIS 2019/2G4). For emission factors see Table 4-57.

Emission factors of CO₂, NO_x, CO and SO₂ from use of fireworks and tobacco (EMIS 2019/2G) are displayed in Table 4-59. Emission factors of fireworks are documented in FOEN (2014p). Emission factors for use of tobacco are according to the EMEP/EEA Guidebook 2016 (EMEP/EEA 2016). For tobacco consumption, a new emission factors for the so far missing pollutant NO_x has been introduced in submission 2019 and the emission factor for CO has been updated for 1990-2017.

Table 4-59 Emission factors for CO₂, NO_x, CO, SO₂ for source category 2G4 Fireworks and Use of tobacco in 2017.

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
Use of tobacco	kg/Mio cigarette eq.	1'000	1.8	55	NA

Activity data

For the production processes, such as enduction of glass and rock wool and part of the applications in services, such as preservation of wood and application of glues and adhesives the activity data are based on production volume or employed agents. For the other part of applications in services, such as house cleaning in services, commerce and industry and medical practices the activity data correspond to the respective number of employees. The quantity of NMVOC emission per employee originates from the bottom-up approach in these service sectors and the decentralized political structure in Switzerland. The determined NMVOC emissions of representative production sites or service institutions are referenced to the number of employees in order to calculate the Swiss total.

The activity data stem from industry, services, industry associations, Swiss federal statistical office and expert estimates and are documented in the EMIS database. Activity data for annual tobacco consumption and the annual firework sales are provided by the Swiss addiction prevention foundation ("Sucht Schweiz") and the statistics of the Swiss federal office for police (FEDPOL 2018), respectively.

For activity data see Table 4-58.

HFC not accounted in other source categories

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 and industry data.

Emission factors

Prompt emissions of HFC are calculated following the 2006 IPCC Guidelines assuming a total loss of product within two years (50% loss in the first and 50% in the second year).

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 CO₂ emissions from the entire source category 2G is estimated at 40% (expert estimate).

The uncertainty of N₂O emissions from source category 2G3, which is a key category for this gas regarding trend according to Approach 2, is estimated at 80% (expert estimate, see Table 1-10).

The uncertainty of SF₆, HFC and PFC emissions in source category 2G is estimated at 37%, 62% and 28% respectively based on a Monte Carlo analysis. Further details are available from background documents, confidential/internal excel calculations and the respective report (Carbotech, 2019).

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 SF₆, 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 well with the emissions from the inventory.

4.8.5 Category-specific recalculations

The following recalculations were implemented in submission 2019. Major recalculations which contribute significantly to the total differences emissions of sector 2 IPPU between latest and previous submission are presented also in chp. 10.1.2.2.

- 2G2e: Based on new information from a large consumer of CF₄ in source category 2G2e, the amount of CF₄ used on Swiss territory could be better constrained. Therefore, CF₄ use in 2G2e has been revised accordingly.

- 2G3b: The emission factor of N₂O from 2G3b Use of aerosol cans in households and restaurants has been updated and revised for 2017 and 2003, respectively, based on sales data yielding recalculated EF values for 1990–2010 and 2012–2016.
- 2G4: The source category 2G4 (2G NFR) De-icing of airplanes (and other de-icing operations) has been revised completely based on a comprehensive study including information and data from three Swiss airports (i.e. the two most important and a regional one) yielding recalculated activity data and NMVOC emission factors for the entire time series 1990–2016. The source category is now split into three sources, i.e. 2G4 De-icing of airplanes and 2G4 De-icing of airport surfaces as well as 2G4 Use of antifreeze agents in vehicles. Since 2011 no VOC-containing agents are used for de-icing of airport surfaces anymore.
- 2G4: The source category 2G4 (2D3i NFR) Removal of paint and lacquer has been revised completely for the entire time series 1990–2016. The so far used activity data of Swiss population has been replaced by the amount of removal agent. In addition, activity data and emission factor have been updated from 1997 onwards based on new values for 2016.
- 2G4: The CO₂ emissions from post-combustion of NMVOC in source category 2G4 Other have been revised for the entire time series 1990–2016. The post-combustion plants have been reallocated and disaggregated to the NFR source categories 2G4 (2D3h NFR) Printing, 2G4 (2D3i NFR) Other solvent use and 2G4 (2G NFR) Other product use. Furthermore, the so far applied default carbon content of 50% for installations with no available information on the solvent composition has been replaced by a mean source category-specific value. Additionally, no longer only the total CO₂ emissions per NFR source category are reported but also the total amount of solvents destroyed in the post-combustion plants.
- 2G4: Activity data for tobacco consumption for the year 2016 has been provisional in Submission 2018 and is now corrected according to the underlying updated statistics.
- 2G4: Emission factors for tobacco consumption for NO_x and CO have been introduced or updated, respectively.
- 2G4: Based on new information from a large consumer of HFC-134a in source category 2G4, the amount of HFC-134a used on Swiss territory could be better constrained. Therefore, HFC-134a use in 2G4 has been revised accordingly.

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	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 , NO _x , CO, NMVOC and SO ₂ from blasting and shooting;

4.9.2 Methodological Issues

4.9.2.1 Pulp and paper (2H1)

Methodology

In 2017, the production of chipboard and fibreboard are the relevant industrial processes in the source category 2H1 Pulp and paper. In Switzerland, chipboard and fibreboard are produced in one and two plants, respectively. 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 EMEP/EEA (2016) using country-specific emission factors.

Indirect CO₂ emissions resulting from NMVOC emissions in this source category are only included in CRF Table 6 and reported 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 2019/2H1. The implied emission factor given in Table 4-61 is production-weighted and related to chipboard and fibreboard production.

Table 4-61 Emission factors for CO and NMVOC in pulp and paper production and food and beverages industry, CO₂, NO_x, CO, NMVOC and SO₂ from blasting and shooting for 2017.

2H Other	Unit	CO ₂	NO _x	CO	NMVOC	SO ₂
2H1 Pulp and paper	g/t	NA	NA	NA	540	NA
2H2 Food and beverage industry (exc. beer, wine, spirits)	g/t	NA	NA	250	2'330	NA
2H2 Food and beverage industry (beer, wine, spirits)	g/m ³	NA	NA	NA	340	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 2019/2H1.

Table 4-62 Pulp and paper production, food and beverages production and amount of explosives used.

2H Other	Unit	1990	1995	2000	2005
2H1 Pulp and paper	kt	604	593	641	693
2H2 Food and beverage industry (exc. beer, wine, spirits)	kt	2'254	2'116	2'301	2'138
2H2 Food and beverage industry (beer, wine, spirits)	m3	560'972	516'519	492'208	452'877
2H3 Blasting and shooting; blasting agent and powder	kt	2.6	1.3	1.9	0.8

2H Other	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
2H1 Pulp and paper	kt	765	544	602	564	533	510	516	519	503	507
2H2 Food and beverage industry (exc. beer, wine, spirits)	kt	2'428	2'467	2'400	2'563	2'518	2'446	2'539	2'518	2'381	2'519
2H2 Food and beverage industry (beer, wine, spirits)	m3	479'293	465'753	467'699	461'453	454'903	449'070	446'567	447'709	439'556	435'426
2H3 Blasting and shooting; blasting agent and powder	kt	1.4	2.1	2.4	2.9	2.3	2.2	2.1	2.1	0.7	0.7

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 EMEP/EEA (2016) using country-specific emission factors. Since these CO and NMVOC emissions are of biogenic origin, they are not considered for calculation of indirect CO₂ 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 2019/2H2). 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 2019/2H2 (Table 4-62).

4.9.2.3 Other (2H3)

Methodology

For determination of emissions of CO₂, NO_x, CO, NMVOC and SO₂ from blasting and shooting, an analogous Tier 2 method with country-specific emission factors is used as documented in the EMIS database (EMIS 2019/2H3 Sprengen und Schiessen).

Indirect CO₂ emissions resulting from NMVOC and CO emissions in this source category are only included in CRF Table 6 and reported in chp. 9.

Emission factors

The emission factors for CO₂, NO_x, CO, NMVOC and SO₂ 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 2018) (Table 4-62).

4.9.3 Uncertainties and time-series consistency

The uncertainty for CO₂ 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

The following recalculations were implemented in submission 2019. These recalculations cause a change in emission levels 1990 and 2016 of less than 0.3 kt CO₂ eq.

- 2H2: Activity data for bread production has increased by 4% to 8% for the years 2011 and 2012 due to a correction in the underlying statistics.
- 2H2: Emission factors for bread production for CO₂ biog. and NMVOC were interchanged and had to be swapped.
- 2H2: The self-supply rate of grain has been changed in the underlying statistics. This correction leads to changes in the AD of mills for the years 2009, 2012 and 2014-2016.
- 2H2: Activity data for 2016 for meat production has been provisional in Submission 2018 and is now corrected according to the underlying updated statistics.

4.9.6 Category-specific planned improvements

No category-specific improvements are planned.

5 Agriculture

Responsibilities for sector Agriculture	
Overall responsibility for sector	Daniel Bretscher (Agroscope)
Author	Daniel Bretscher (Agroscope)
Sector experts	Chloé Wüst (Agroscope, QC), Christoph Ammann (Agroscope)
EMIS database operation	Sabine Schenker (FOEN)
Technical contributor	Dominik Eggli (Meteotest)
Annual updates (NIR text, tables, figures)	Daniel Bretscher (Agroscope)
Internal review	Regine Röthlisberger (FOEN)

5.1 Overview

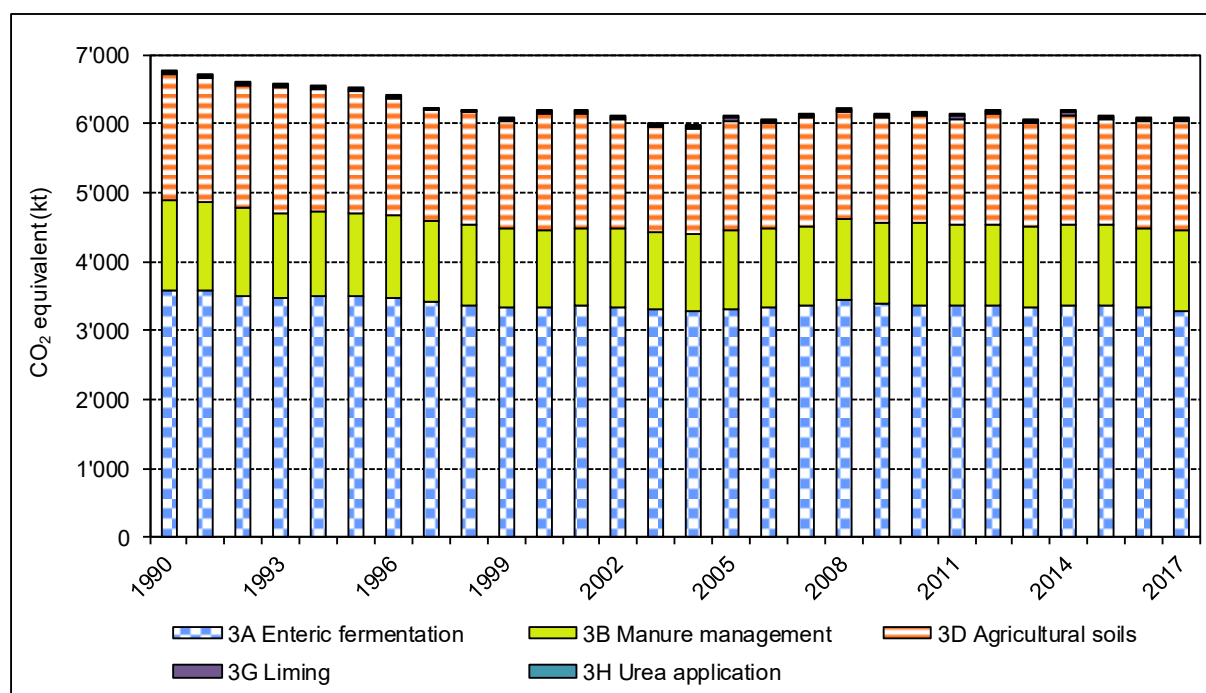
This chapter provides information on the estimation of the greenhouse gas emissions from the sector Agriculture. The following source categories are reported:

- 3A Enteric fermentation, CH₄ emissions from domestic livestock,
- 3B Manure management, emissions of CH₄, N₂O and NO_x,
- 3D Agricultural soils, emissions of N₂O, NO_x and NMVOC,
- 3G Liming, emissions of CO₂
- 3H Urea application; emissions of CO₂

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.

CO₂ emissions from soils are reported under Land use, land-use change and forestry. CO₂ emissions from energy use in agriculture are reported under 1A4c Agriculture/forestry/fishing.

Total greenhouse gas emissions from the agriculture sector in 2017 were 6'077 kt CO₂ equivalents which is a contribution of 12.9% to the total of Swiss greenhouse gas emissions (excluding indirect CO₂, excluding LULUCF, Table 2-5, Table 5-1). Main agricultural sources of greenhouse gases were 3A Enteric fermentation, emitting 54% of all agricultural greenhouse gases, followed by 3D Agricultural soils with 26% and 3B Manure management with 19% (Figure 5-1). 3G Liming and 3H Urea application contributed 0.5% and 0.2% respectively.

Figure 5-1 Greenhouse gas emissions of the agricultural sector in kt CO₂ equivalents.Table 5-1 Greenhouse gas emissions of the agricultural sector in kt CO₂ equivalents.

Gas	1990	1995	2000	2005
	CO ₂ equivalent (kt)			
CO ₂	49	42	39	42
CH ₄	4'453	4'313	4'072	4'051
N ₂ O	2'263	2'168	2'073	2'000
Sum	6'766	6'523	6'185	6'094

Gas	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	CO ₂ equivalent (kt)									
CO ₂	44	41	44	43	42	42	46	44	47	48
CH ₄	4'213	4'157	4'132	4'127	4'131	4'096	4'132	4'122	4'085	4'040
N ₂ O	1'956	1'932	1'983	1'949	2'010	1'919	2'000	1'931	1'960	1'989
Sum	6'213	6'131	6'159	6'120	6'182	6'057	6'178	6'097	6'093	6'077

CH₄ and N₂O emissions generally declined from 1990 until 2004 (Figure 5-2). Subsequently CH₄ emissions increased slightly until 2008 and decreased again afterwards. N₂O emissions remained more or less on a constant level since 2004. 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 2016b, 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. CO₂ 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.

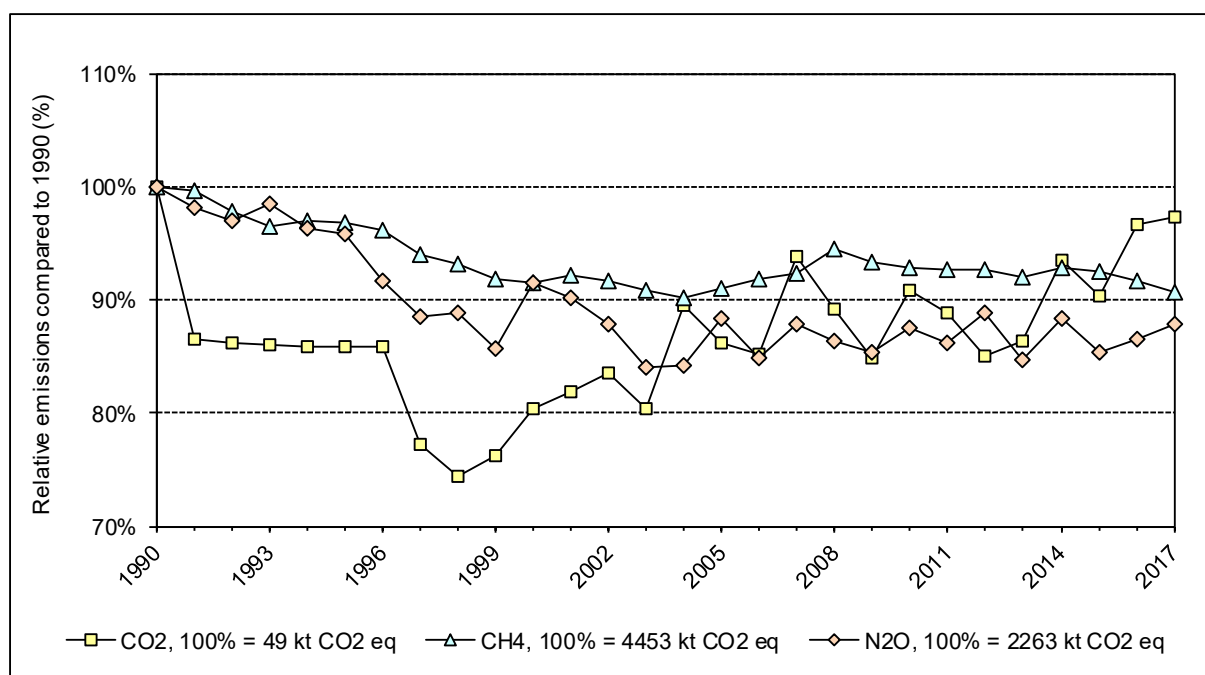


Figure 5-2 Relative trends of the greenhouse gas emissions of sector 5 Agriculture. The base year 1990 represents 100%.

Among the key categories of the Swiss inventory, five are from the agricultural sector (Figure 5-3).

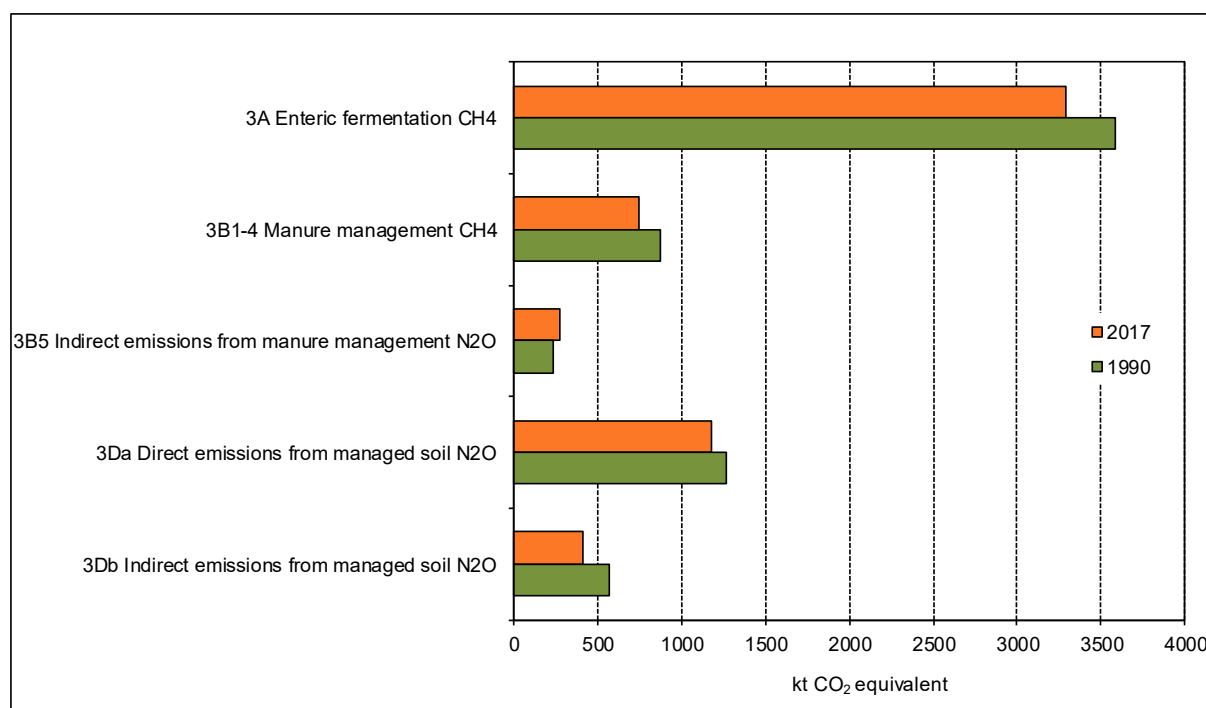


Figure 5-3 Key categories (Approach 1 and Approach 2) in the agricultural sector.

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 2017 and trend for 1990–2017, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

A	B	C	D
Code	IPCC Category	GHG	Identification Criteria
3A	Enteric Fermentation	CH ₄	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 CH₄ emissions increased, whereas since 2008 they were decreasing again.

Cattle contribute over 94% to the overall emissions from 3A Enteric fermentation and the contribution of mature dairy cattle is more than 62%.

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 protection law (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 (slaughtered 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.

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 CH₄ emissions is done by Agroscope, the Swiss centre of excellence for agricultural research (Agroscope 2019).

5.2.2.2 Emission factors

All emission factors for 3A Enteric fermentation are country-specific, based on IPCC equation 10.21 (IPCC 2006):

$$EF = \frac{GE * (Y_m \div 100) * 365 \text{ days} / y}{55.65 \text{ MJ} / \text{kg CH}_4}$$

EF = annual CH₄ 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.

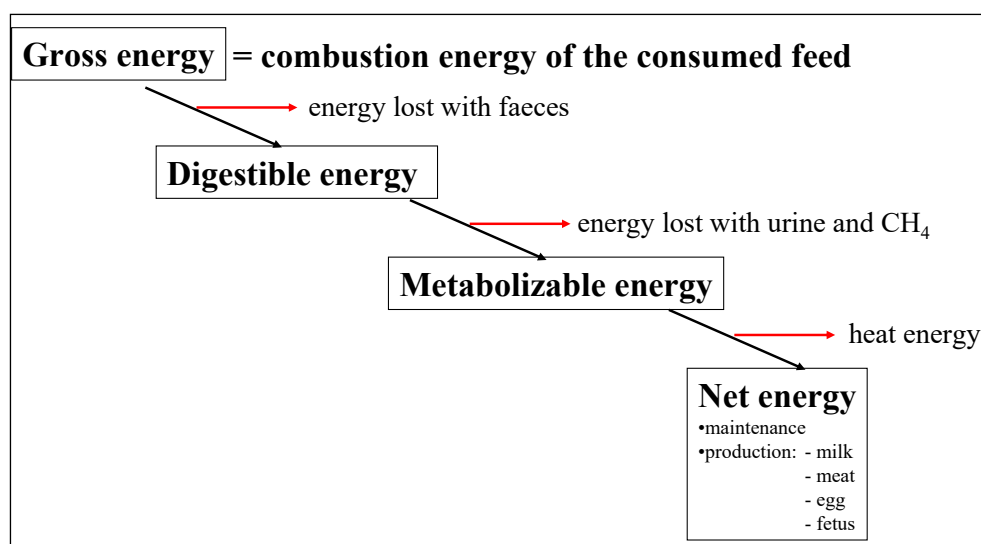


Figure 5-4 Levels of feed energy conversion (Soliva 2006).

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 2017.

Livestock Category		Conversion Factors	
Mature Dairy Cattle		NEL to GE	0.341
Other Mature Cattle		NEL to GE	0.265
Growing Cattle	<i>Fattening Calves</i>	ME to GE	0.939
	<i>Pre-Weaned Calves</i>	NEL to GE	0.299
	<i>Breeding Calves</i>	NEL to GE	0.358
	<i>Breeding Cattle (4-12 months)</i>	NEL to GE	0.319
	<i>Breeding Cattle (> 1 year)</i>	NEL to GE	0.313
	<i>Fattening Calves (0-4 months)</i>	NEV to GE	0.355
	<i>Fattening Cattle (4-12 months)</i>	NEV to GE	0.397
Sheep	<i>Fattening Sheep</i>	NEV to GE	0.350
	<i>Milksheep</i>	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). An average body weight of 650 kg was assumed for the typical Swiss mature dairy cattle. Statistics of annual milk production are provided by the Swiss Farmers Union (SBV 2018, Table 5-5). Milk production includes marketed milk, milk consumed by calves on farms and milk sold outside the commercial industry (MISTA 2017). 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 1990–2017.

In the year 2003 yearly milk yield surpassed 6000 kg. 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	1991	1992	1993	1994	1995	1996	1997	1998	1999
Population Size Mature Dairy Cattle	head	783'100	780'500	763'500	744'450	749'700	739'641	736'043	711'613	701'343	683'545
Lactation Period	day	305	305	305	305	305	305	305	305	305	305
Milk Yield Mature Dairy Cattle	kg/head/day	16.06	16.35	16.39	16.78	16.75	17.09	16.96	17.48	17.97	18.40
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		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Population Size Mature Dairy Cattle	head	669'410	669'410	657'924	638'288	621'008	620'708	618'065	614'795	628'516	599'361
Lactation Period	day	305	305	305	305	305	305	305	305	305	305
Milk Yield Mature Dairy Cattle	kg/head/day	18.75	18.97	19.34	19.77	20.43	20.45	20.57	21.21	21.66	22.27
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		2010	2011	2012	2013	2014	2015	2016	2017
Population Size Mature Dairy Cattle	head	589'024	589'239	591'212	586'609	587'385	583'277	575'766	569'185
Lactation Period	day	305	305	305	305	305	305	305	305
Milk Yield Mature Dairy Cattle	kg/head/day	22.46	22.63	22.57	22.27	22.87	23.10	22.98	22.74
Milk Yield Other Mature Cattle	kg/head/day	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. In general NE is subdivided into 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 3.3.

Gross Energy Intake		1990-2011									
		1990	1995	2000	2005	2006	2007	2008	2009	2010	2011
		MJ/head/day									
Cattle											
	Mature Dairy Cattle	259.3	267.4	280.1	291.6	292.2	295.2	297.2	299.8	300.7	301.4
	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
	<i>Fattening Calves</i>	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1
	<i>Pre-Weaned Calves</i>	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1
	<i>Breeding Calves</i>	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0
	<i>Breeding Cattle (4-12 months)</i>	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1
	<i>Breeding Cattle (> 1 year)</i>	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6
	<i>Fattening Calves (0-4 months)</i>	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9
	<i>Fattening Cattle (4-12 months)</i>	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	28.3	31.9	28.0	26.6	26.3	26.9	26.7	27.0	27.2	27.1
	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⁾	1.5	1.3	1.4	1.2	1.2	1.3	1.3	1.3	1.2	1.2
	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)	95.6	83.4	37.7	33.3	33.2	32.9	31.7	34.3	36.9	37.2

Gross Energy Intake		2012-2017					
		2012	2013	2014	2015	2016	2017
		MJ/head/day					
Cattle							
	Mature Dairy Cattle	301.2	299.8	302.5	303.6	303.1	301.9
	Other Mature Cattle	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
	<i>Fattening Calves</i>	47.1	47.1	47.1	47.1	47.1	47.1
	<i>Pre-Weaned Calves</i>	60.1	60.1	60.1	60.1	60.1	60.1
	<i>Breeding Calves</i>	44.0	44.0	44.0	44.0	44.0	44.0
	<i>Breeding Cattle (4-12 months)</i>	90.1	90.1	90.1	90.1	90.1	90.1
	<i>Breeding Cattle (> 1 year)</i>	143.6	143.6	143.6	143.6	143.6	143.6
	<i>Fattening Calves (0-4 months)</i>	56.9	56.9	56.9	56.9	56.9	56.9
	<i>Fattening Cattle (4-12 months)</i>	126.3	126.3	126.3	126.3	126.3	126.3
	Sheep	22.5	22.4	22.6	22.5	22.8	22.2
	Swine	26.9	28.0	28.3	28.2	28.6	28.8
	Buffalo (weighted average)	135.9	136.0	134.6	134.5	134.4	133.1
	Camels (weighted average)	31.6	31.9	31.8	31.6	31.2	31.2
	Deer (weighted average) ¹⁾	57.0	58.1	58.0	58.0	58.5	58.8
	Goats	25.6	25.6	25.0	25.5	24.8	23.9
	Horses (weighted average)	107.9	108.0	108.1	108.3	108.4	108.4
	Mules and Asses (weighted average)	39.9	39.6	39.6	39.6	39.6	39.5
	Poultry ²⁾	1.2	1.2	1.3	1.3	1.3	1.3
	Rabbits	1.2	1.2	1.2	1.2	1.2	1.2
	Livestock NCAC (weighted average)	37.9	38.2	38.5	37.2	38.2	38.1

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 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. Energy intake from milk or milk products is still 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 2018, Giuliani 2018). 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.

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 (2019). Resulting estimates are provided in Table 5-6 (main categories) and in Annex 3 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 Zürich (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: Table 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 2014). 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 2018) and the Swiss Federal Statistical Office (SFSO 2018a)(Table 5-8). All activity data 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 3 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.

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 Poncet et al. (2007, 2009) and Schmidlin et al. (2013). 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 2018b).

Table 5-8 Activity data for calculating methane emissions from 3A Enteric fermentation (ART/SHL 2012, SBV 2018, SFSO 2018a, SFSO 2018b). The complete time series on a livestock sub-category level are provided in Annex 3 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
	<i>Fattening Calves</i>	112	102	103	106	101	100	95	107	114	111
	<i>Pre-Weaned Calves</i>	10	18	36	62	67	72	76	84	86	86
	<i>Breeding Cattle 1st Year</i>										
	<i>Breeding Calves</i>	214	166	76	75	77	76	80	76	75	73
	<i>Breeding Cattle (4-12 months)</i>	132	129	161	147	147	147	152	148	146	142
	<i>Breeding Cattle (> 1 year)</i>										
	<i>Breeding Cattle 2nd Year</i>	253	239	222	205	210	210	213	216	215	213
	<i>Breeding Cattle 3rd Year</i>	151	139	130	113	110	109	110	112	111	109
	<i>Fattening Cattle</i>										
	<i>Fattening Calves (0-4 months)</i>	88	82	43	35	35	34	36	35	34	34
	<i>Fattening Cattle (4-12 months)</i>	100	110	105	112	114	114	116	112	110	109
Sheep		395	387	421	446	448	444	446	432	434	424
Swine		1'787	1'446	1'498	1'609	1'635	1'573	1'540	1'557	1'589	1'579
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		5'938	6'251	6'983	8'260	7'670	8'228	8'543	8'809	9'025	9'478
Rabbits		61	41	28	25	24	27	25	28	35	34
Livestock NCAC		28	30	94	86	82	80	86	90	91	99

Population Size		2012-2017					
		2012	2013	2014	2015	2016	2017
		1'000 head					
Cattle		1'565	1'557	1'563	1'554	1'555	1'545
Mature Dairy Cattle		591	587	587	583	576	569
Other Mature Cattle		114	117	118	118	121	123
Growing Cattle		859	854	857	853	859	852
	<i>Fattening Calves</i>	103	102	102	103	107	108
	<i>Pre-Weaned Calves</i>	88	90	91	91	93	96
	<i>Breeding Cattle 1st Year</i>						
	<i>Breeding Calves</i>	72	71	71	71	72	71
	<i>Breeding Cattle (4-12 months)</i>	139	137	138	139	139	138
	<i>Breeding Cattle (> 1 year)</i>						
	<i>Breeding Cattle 2nd Year</i>	211	210	210	209	209	208
	<i>Breeding Cattle 3rd Year</i>	106	103	101	99	97	98
	<i>Fattening Cattle</i>						
	<i>Fattening Calves (0-4 months)</i>	33	34	34	34	33	32
	<i>Fattening Cattle (4-12 months)</i>	107	108	109	108	107	102
Sheep		417	409	403	395	397	398
Swine		1'544	1'485	1'498	1'496	1'454	1'445
Buffalo		1	0	1	1	1	1
Camels		6	6	6	6	6	7
Deer ¹⁾		6	6	6	6	6	6
Goats		85	85	85	84	85	88
Horses		58	57	57	55	56	56
Mules and Asses		20	20	20	20	20	21
Poultry		9'955	10'079	10'723	10'825	10'994	11'502
Rabbits		28	28	27	25	25	22
Livestock NCAC		112	107	106	112	106	103

¹⁾ Deer: numbers correspond to animal places i.e. mother with offspring.

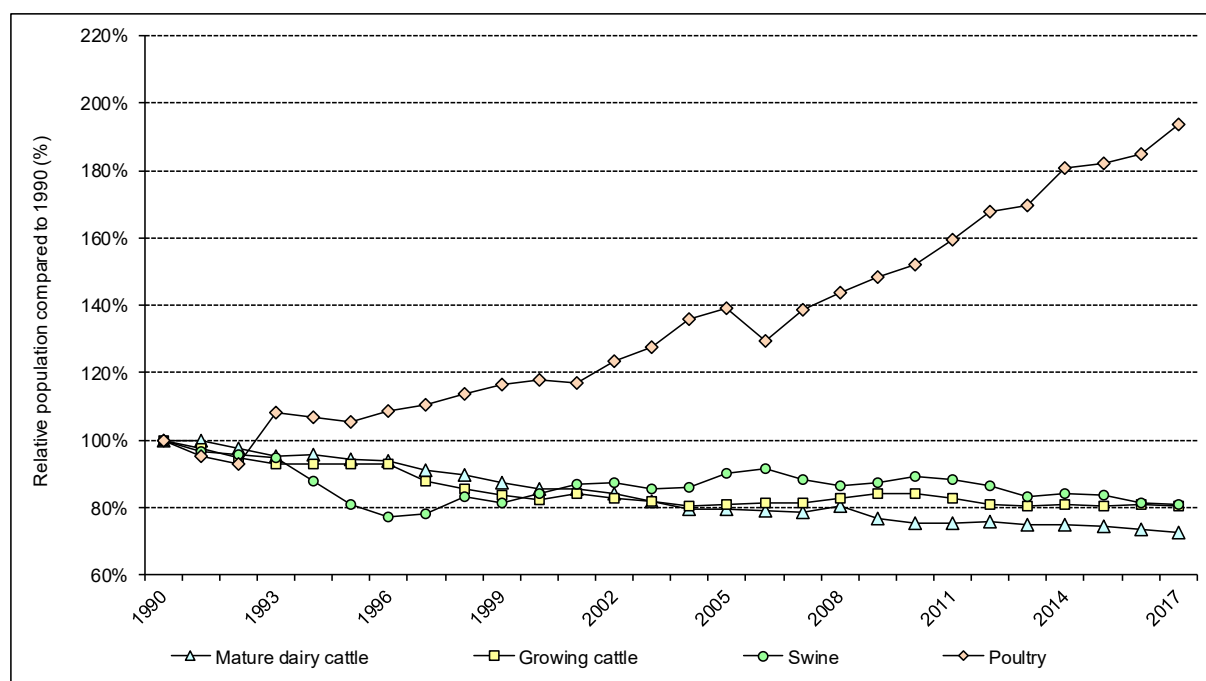


Figure 5-5 Relative development of the populations of main animal categories. The category with the strongest increase, i.e. other mature cattle, is not displayed, as it increases to over 1000% of the 1990 value by 2017.

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 2017 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 current activity and emission data as well as with new default uncertainties of the 2006 IPCC Guidelines. The arithmetic mean of the lower and upper bound uncertainty was used for activity data (6.4%) and for emission factors (16.9%), resulting in a combined uncertainty of 18.1% for Approach 1 analysis.

No approach 2 uncertainty analysis is conducted for submission 2019.

For further results and discussion of the uncertainties see chp. 1.6.1 and Annex A2.

The time series 1990–2017 are all considered consistent, although the following issues should be considered:

- Gross energy intake of some of the aggregated animal categories reveals 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 (Table 5-5).
- 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).
- For the last eight inventory years the population statistics of growing cattle were not available in the usual format. Data for 2009 to 2017 are based on the animal traffic database. 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. 2018). 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 by extrapolating the ratio between adults and juveniles.

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) 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.

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 $\pm 2\%$) 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. 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 $\pm 3\%$ with census data (April) always slightly above the annual mean. Data from the animal traffic database (i.e. cattle populations for the years 2009–2017) 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 default values (refer to Annex 3 A3.3).

Country-specific energy-intake rates for all cattle categories were compared to intake rates estimated with the IPCC 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 default method. Moreover, a discrepancy of approximately 6.4% was found when comparing the overall GE-intake of the cattle population with the respective estimate of the Swiss Farmers Union (Giuliani 2018). 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 CH₄ 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 CH₄ 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 CH₄ emissions and independent atmospheric measurements over Switzerland (see Annex 5).

5.2.5 Category-specific recalculations

General information on recalculations is provided in chp. 10.

Recalculations with an overall impact of >0.5 kt CO₂ equivalents are assessed quantitatively. All other recalculations are only described qualitatively.

- CH₄ and N₂O emissions from "Fattening Pigs over 25 kg" (subcategory of swine) and "Broilers" (subcategory of poultry) were revised for the years 2011-2016 due to a new assessment of animal turnover rates in stables. AD and EF were adjusted accordingly. The impact on overall emissions in kt CO₂ equivalents per year is approximately +0.7 (including emissions from 3A, 3B and 3D).
- CH₄ emissions from sheep, swine, goats and poultry and "other" (livestock NCAC) were recalculated for the years 2014-2016 due to revised EF. Provisional estimates for net energy intake from the Swiss Farmers Union were updated (Giuliani 2018). The impact on overall emissions in kt CO₂ equivalents is approximately +1.3, +2.1 and +6.6 for the years 2014, 2015 and 2016.

5.2.6 Category-specific planned improvements

No category-specific improvements are planned.

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 2017 and trend for 1990–2017, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

A	B	C	D
Code	IPCC Category	GHG	Identification Criteria
3B1-3B4	Manure Management	CH ₄	L1, L2
3B5	Indirect N ₂ O emissions from manure management	N ₂ O	L1; L2, T2

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 (CH₄) respectively five (N₂O) different manure management systems are considered as well as indirect N₂O emissions from 3B Manure management (Table 5-11). Additionally, NO_x emissions from manure management are estimated. In the reporting tables all NO_x emissions are reported under 3.D 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 remained more or less constant.

Significant contributors to CH₄ emissions from 3B Manure management are cattle with approximately 74% and swine with approximately 23% on average over the period 1990–

2017. Cattle and swine contribute significantly to N₂O emissions with 71% and 17% respectively on average over the period 1990–2017.

Leaching of NO₃⁻ 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 protection law (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 1 st year (Breeding Calves + Breeding Cattle 4-12 months), Breeding Cattle > 1 year (Breeding Cattle 2 nd year + Breeding Cattle 3 rd 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
3B4b	Camels	Bisons > 3 years ³ 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 (slaughtered 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 ₂ O	
3B6a	Direct Emissions	Liquid systems		Liquid systems	
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 Poultry system	Other	Deep litter 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 (CH₄: IPCC 2006 equation 10.23; N₂O: IPCC 2006 equation 10.25).

CH₄ 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).

N₂O 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., 2018). Detailed country-specific data on nitrogen excretion rates, manure management system distribution and nitrogen volatilisation were applied. Emission factors for direct N₂O emissions (EF₃) are based on IPCC (2006) whereas the emission factor for indirect emissions from atmospheric deposition is country-specific (Bühlmann et al. 2015 and Bühlmann 2014).

The N₂O 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 CH₄ and N₂O 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 CH₄ emissions had to be adapted to data availability for energy requirements, while the categorisation for the estimation of N₂O emissions is determined by the respective categorisation of the Swiss ammonia inventory (AGRAMMON, Kupper et al. 2018, Richner et al. 2017). Nevertheless, there is no inconsistency in the total number of animals as they are the same both for CH₄ and N₂O emissions. Note that although

not growing cattle in the proper sense, bulls are contained in the categories breeding cattle >1 year, breeding cattle 3rd year and/or fattening cattle according to their purposes.

The calculation of CH₄ and N₂O emissions is done by Agroscope, the Swiss centre of excellence for agricultural research (Agroscope 2019).

Table 5-12 Livestock categories for estimating CH₄ and N₂O emissions from 3B Manure management.

3B	CH ₄		N ₂ O	
Cattle	Mature Dairy Cattle		Mature Dairy Cattle	
	Other Mature Cattle		Other Mature Cattle	
	Growing Cattle	Fattening Calves ¹ Pre-Weaned Calves Breeding Cattle 1 st 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)	Growing Cattle	Fattening Calves ¹ Pre-Weaned Calves Breeding Cattle 1 st year Breeding Cattle 2 nd year Breeding Cattle 3 rd year Fattening Cattle
Sheep	Lambs < 1 year Mature Sheep		Fattening Sheep Milk Sheep	
Swine	Swine		Piglets Fattening Pig over 25 kg Dry Sows Nursing Sows Boars	
Buffalo	Bisons < 3 years ³ Bisons > 3 years ³		Bisons < 3 years ³ Bisons > 3 years ³	
Camels	Llamas < 2 years Llamas > 2 years Alpacas < 2 years Alpacas > 2 years		Llamas < 2 years Llamas > 2 years Alpacas < 2 years Alpacas > 2 years	
Deer	Fallow Deer Red Deer		Fallow Deer Red Deer	
Goats	Goats		Goat places	
Horses	Horses < 3 years Horses > 3 years		Horses < 3 years Horses > 3 years	
Mules and Asses	Mules Asses		Mules Asses	
Poultry	Poultry		Growers Layers Broilers Turkey Other Poultry	
Rabbits	Rabbits		Rabbits	
Livestock NCAC	Sheep Goats Horses < 3 years Horses > 3 years Mules Asses		Sheep Goats Horses < 3 years Horses > 3 years Mules Asses	

¹⁾ Fattening for veal with a milk based diet (slaughtered 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 CH₄

Calculation of CH₄ emissions from 3B Manure management is based on methods described in the 2006 IPCC Guidelines (IPCC 2006, equation 10.23):

$$EF_T = VS_T \cdot 365 \text{ days / year} \cdot B_{0T} \cdot 0.67 \text{ kg / m}^3 \cdot \sum_S MCF_S \cdot MS_{TS}$$

EF_T = annual CH₄ 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 CH₄ producing capacity for manure produced by livestock category *T* (m³/kg)

0.67 kg/m³ = conversion factor of m³ CH₄ to kilograms CH₄

MCF_S = CH₄ 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 according to equation 10.24 in the 2006 IPCC Guidelines (IPCC 2006):

$$VS = \left[GE \cdot \left(1 - \frac{DE\%}{100} \right) + (UE \cdot GE) \right] \cdot \left[\frac{1 - ASH}{EDF} \right]$$

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 (%)

(UE • GE) = urinary energy expressed as fraction of GE

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)

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 CH₄ 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 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 the high feeding level that is 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 per cent 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. Urinary energy expressed as fraction of gross energy was 0.04 (IPCC 2006).

For **calves and other growing cattle** IPCC default values of 65% respectively 60% were taken for the feed digestibility. For the urinary energy expressed as fraction of gross energy and for the energy density of the feed (EDF) the IPCC default values, i.e. 0.04 and 18.45 MJ/kg were 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 using 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 urinary energy as fraction of the gross energy was 0.04, 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 CH₄ producing capacity (B₀)*

For the methane producing capacity (B₀) 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 m³/kg).

5.3.2.2.3 *Methane conversion factor (MCF)*

For estimating CH₄ 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 (88% 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 2006 IPCC 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 undegraded 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 (4.4% of all volatile solids in 2017). 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 2018a) 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:

$$MCF_{PSAD} = MCF_{LS} * \left(\frac{14.49 * (e^{-k*AI_j} - 1)}{AI_j} + 1 \right)$$

MCF_{PSAD} = CH₄ conversion factor for pre-storage of liquid manure before delivery to biogas plants (%)

MCF_{LS} = CH₄ 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 (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 2017.

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.	13.5
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 (Kupper et al. 2018) based on expert judgement and values from the literature (1990, 1995) and on extensive farm surveys (2002, 2007, 2010 and 2015). 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 20th century. One of the most important voluntary programs 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 the length of stay on the pasture increased by 50%. In the year 2007 78% of the dairy cattle were held on farms participating in the RAUS program. The average number of pasture days (including all farms) in that year was 181, 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 usually 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.

The amount of manure digested anaerobically was estimated based on total energy production (SFOE 2018a) 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 CH₄

Activity data of all livestock categories covered by the official census were obtained from SBV (2018) and the SFSO (2018a). The respective data 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). Additionally to official statistical data, population data of livestock not covered by the agricultural census of the Swiss Federal Statistical Office were assessed (Poncet et al. 2007, Poncet et al. 2009, Schmidlin et al. 2013, SFSO 2017f). 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 3 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 3 A3.3.

MS Distribution		1990					1995					2002				
		%					%					%				
		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		63.6	27.6	8.3	0.5	0.0	65.6	24.5	9.5	0.4	0.0	65.2	16.3	18.0	0.5	0.0
Other Mature Cattle		41.1	32.2	26.3	0.5	0.0	39.2	34.2	26.2	0.4	0.0	39.7	20.7	39.1	0.5	0.0
Growing Cattle (weighted average)		47.4	31.8	15.7	0.5	4.5	48.4	30.9	15.8	0.4	4.5	42.1	25.5	27.3	0.5	4.6
	Fattening Calves	14.5	0.0	0.0	0.5	85.1	14.9	0.0	0.0	0.4	84.7	21.5	0.0	0.3	0.5	77.6
	Pre-Weaned Calves	41.1	32.2	26.3	0.5	0.0	39.2	34.2	26.2	0.4	0.0	41.2	21.0	37.3	0.5	0.0
	Breeding Cattle 1st Year	36.8	48.6	14.1	0.5	0.0	37.9	47.5	14.2	0.4	0.0	33.6	38.8	27.0	0.5	0.0
	Breeding Cattle 2nd Year	45.2	29.0	25.4	0.5	0.0	47.2	26.8	25.6	0.4	0.0	37.7	23.4	38.4	0.5	0.0
	Breeding Cattle 3rd Year	50.4	29.1	20.0	0.5	0.0	51.3	28.0	20.3	0.4	0.0	42.1	22.5	34.8	0.5	0.0
	Fattening Cattle	70.0	24.1	0.0	0.5	5.5	66.3	27.7	0.0	0.4	5.6	67.3	26.8	2.2	0.5	3.2
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	33.2	0.0	66.8
Swine (weighted average)		98.6	0.0	0.0	1.4	0.0	98.5	0.0	0.0	1.5	0.0	97.3	0.3	0.1	2.2	0.0
Buffalo (weighted average)		NA	NA	NA	NA	NA	47.5	26.8	25.6	0.0	0.0	38.2	23.5	38.4	0.0	0.0
Camels (weighted average)		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.0	0.0	33.5	0.0	66.5
Deer (weighted average)		0.0	0.0	30.7	0.0	69.3	0.0	0.0	30.7	0.0	69.3	0.0	0.0	33.5	0.0	66.5
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	12.2	0.0	87.8
Horses (weighted average)		0.0	93.2	6.8	0.0	0.0	0.0	93.2	6.8	0.0	0.0	0.0	76.1	23.9	0.0	0.0
Mules and Asses (weighted average)		0.0	93.2	6.8	0.0	0.0	0.0	93.2	6.8	0.0	0.0	0.0	76.9	23.1	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	2.6	0.0	97.4
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	93.2	6.8	0.0	0.0	0.0	89.5	7.1	0.0	3.4	0.0	37.3	27.7	0.0	35.0

MS Distribution		2007					2010					2015				
		%					%					%				
		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		67.2	13.7	17.7	1.4	0.0	66.7	14.5	16.9	2.0	0.0	69.1	11.2	15.9	3.8	0.0
Other Mature Cattle		49.3	20.3	29.0	1.4	0.0	47.6	18.0	32.4	2.0	0.0	50.2	14.6	31.5	3.8	0.0
Growing Cattle (weighted average)		45.3	24.0	24.7	1.4	4.7	44.5	25.0	22.7	2.0	5.8	46.4	22.2	22.4	3.8	5.3
	Fattening Calves	21.6	0.0	0.2	1.4	76.8	16.5	0.0	0.2	2.0	81.3	22.9	0.0	1.7	3.8	71.7
	Pre-Weaned Calves	49.8	18.7	30.1	1.4	0.0	44.3	32.9	20.9	2.0	0.0	34.6	29.7	32.0	3.8	0.0
	Breeding Cattle 1st Year	40.7	34.6	23.3	1.4	0.0	43.0	33.5	21.5	2.0	0.0	43.8	31.6	20.9	3.8	0.0
	Breeding Cattle 2nd Year	41.2	20.9	36.5	1.4	0.0	42.8	20.9	34.3	2.0	0.0	41.5	19.9	34.8	3.8	0.0
	Breeding Cattle 3rd Year	45.4	21.4	31.8	1.4	0.0	45.9	21.6	30.6	2.0	0.0	53.1	17.6	25.6	3.8	0.0
	Fattening Cattle	62.1	29.0	4.3	1.4	3.2	57.3	32.9	4.0	2.0	3.9	62.1	26.0	4.9	3.8	3.3
Sheep (weighted average)		0.0	0.0	39.3	0.0	60.7	0.0	0.0	33.7	0.0	66.3	0.0	0.0	37.0	0.0	63.0
Swine (weighted average)		92.0	0.1	1.2	6.6	0.0	90.6	0.3	0.1	9.0	0.0	81.5	0.0	0.0	18.5	0.0
Buffalo (weighted average)		42.4	21.1	36.5	0.0	0.0	44.5	21.2	34.3	0.0	0.0	44.8	20.4	34.8	0.0	0.0
Camels (weighted average)		0.0	0.0	40.2	0.0	59.8	0.0	0.0	34.5	0.0	65.5	0.0	0.0	36.7	0.0	63.3
Deer (weighted average)		0.0	0.0	40.2	0.0	59.8	0.0	0.0	34.5	0.0	65.5	0.0	0.0	36.7	0.0	63.3
Goats		0.0	0.0	7.1	0.0	92.9	0.0	0.0	10.0	0.0	90.0	0.0	0.0	11.6	0.0	88.4
Horses (weighted average)		0.0	78.7	21.3	0.0	0.0	0.0	74.4	25.6	0.0	0.0	0.0	78.7	21.3	0.0	0.0
Mules and Asses (weighted average)		0.0	75.2	24.8	0.0	0.0	0.0	79.3	20.7	0.0	0.0	0.0	77.6	22.4	0.0	0.0
Poultry (weighted average)		0.0	0.0	3.7	0.0	96.3	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
Livestock NCAC (weighted average)		0.0	33.8	30.1	0.0	36.2	0.0	39.5	28.1	0.0	32.4	0.0	42.1	27.0	0.0	30.9

5.3.2.4 Emission factors N₂O

Estimation of direct N₂O emissions from manure management relies basically on the same animal waste management systems as the estimation of CH₄ 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 as suggested for “Pit storage below animal confinements” was considered appropriate.

Table 5-15 Emission factors for calculating N₂O emissions from manure management. Blue: annually changing parameters, value for 2017.

Animal waste management system	Emission factor
	kg N ₂ O-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 N₂O emissions after volatilisation of NH₃ 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). 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%. Note that the emission factor in cell R37 of CRF Table3.B(b) refers to kg N₂O/kg N instead of kg N₂O-N/kg N.

5.3.2.5 Activity data N₂O

Activity data for N₂O emissions from 3B Manure management were estimated according to equation 10.25 of the 2006 IPCC Guidelines:

$$N_2O_{D(mm)} = \left[\sum_S \left[\sum_T (N_{(T)} \cdot Nex_{(T)} \cdot MS_{(T,S)}) \right] \cdot EF_{3(S)} \right] \cdot \frac{44}{28}$$

N₂O_{D(mm)} = direct N₂O emissions from manure management (kg N₂O/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 $(N_2O-N)_{(mm)}$ 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 (2018) and the SFSO (2018a). The respective data set 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 (Poncet et al. 2007, Poncet et al. 2009, Schmidlin et al. 2013, SFSO 2018b). 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 3 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. (2018) (Table 5-16). 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 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. (2018)). This more disaggregated approach leads to considerable lower calculated nitrogen excretion rates compared to IPCC 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 of mature dairy cattle is dependent on milk production and feed properties. After the year 2007 the yearly increase of milk production per cow slowed down. Consequently also the yearly increase of nitrogen excretion decreased.

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. 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 2006, which can be explained by the increasing use of protein-reduced fodder (Kupper et al. 2018). The same is true for **poultry**.

Table 5-16 Nitrogen excretion rates of Swiss livestock. The complete time series on a livestock sub-category level are provided in Annex 3 A3.3.

Nitrogen Excretion		1990-2011									
		1990	1995	2000	2005	2006	2007	2008	2009	2010	2011
		kg N/head/year									
Mature Dairy Cattle		100.4	101.5	103.9	108.0	109.1	110.1	110.3	110.4	110.5	110.7
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)		14.0	13.3	10.9	9.6	9.4	9.2	9.3	9.4	9.4	9.3
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)		0.6	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)		38.8	34.0	14.5	12.6	12.5	12.6	12.3	13.2	14.3	14.9

Nitrogen Excretion		2012-2017					
		2012	2013	2014	2015	2016	2017
		kg N/head/year					
Mature Dairy Cattle		111.0	111.2	111.4	111.6	111.6	111.6
Other Mature Cattle		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
	<i>Fattening Calves</i>	16.8	17.2	17.6	18.0	18.0	18.0
	<i>Pre-Weaned Calves</i>	22.0	22.0	22.0	22.0	22.0	22.0
	<i>Breeding Cattle 1st Year</i>	25.0	25.0	25.0	25.0	25.0	25.0
	<i>Breeding Cattle 2nd Year</i>	40.0	40.0	40.0	40.0	40.0	40.0
	<i>Breeding Cattle 3rd Year</i>	55.0	55.0	55.0	55.0	55.0	55.0
	<i>Fattening Cattle</i>	36.8	37.2	37.6	38.0	38.0	38.0
Sheep (weighted average)		8.5	8.6	8.5	8.4	8.4	8.5
Swine (weighted average)		9.2	9.2	9.1	9.2	9.2	9.2
Buffalo (weighted average)		36.9	36.9	36.4	36.4	36.4	35.9
Camels (weighted average)		12.8	12.9	12.8	12.7	12.6	12.6
Deer (weighted average) ¹⁾		22.5	23.0	23.0	23.0	23.1	23.3
Goats		11.5	11.6	11.6	11.4	11.4	11.4
Horses (weighted average)		43.7	43.8	43.8	43.8	43.8	43.9
Mules and Asses (weighted average)		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
Rabbits		1.0	1.0	1.0	1.0	1.0	1.0
Livestock NCAC (weighted average)		15.4	15.6	15.7	14.9	15.3	15.4

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. 2018) 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 CH₄ emissions from 3B Manure management (for further information refer to chp. 5.3.2.2.4) compared to estimating N₂O emissions from 3B Manure management. This is because cattle stables usually 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 3 A3.3.

5.3.2.5.4 *Volatilisation of NH₃, NO_x and N₂ from manure management systems*

For indirect N₂O emissions from manure management the deposition of volatilised NH₃ 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. 2018). 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 NH₃ emissions). Accordingly, the overall fraction of nitrogen 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 14.9 to 20.5%.

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. 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 (N₂) 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 (van Bruggen et al. 2014).

Note that volatilisation from pasture, range and paddock manure is included under 3Db (Indirect N₂O 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 5-20.

5.3.2.6 *NMVOC emissions from manure management*

The NMVOC emission factors for all livestock categories are based on default Tier 1 emission factors (EMEP/EEA 2016, chp. 3B Manure management, Table 3.4) taking into account the fractions of cattle getting silage feeding. 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 the EMEP/EEA Guidebook 2016 (EMEP/EEA 2016) 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 launched in 2018 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. In the meantime, NMVOC emissions are reported in the inventory based on a Tier 1 approach using default Tier 1 emission factors (EMEP/EEA 2016). Preliminary measurements indicate that emissions based on default Tier 1 emission factors rather tend to overestimate the actual NMVOC emissions.

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 new default uncertainties from the 2006 IPCC Guidelines. The arithmetic mean of the lower and upper bound was used for activity data and for emission factors in the Approach 1 analysis (Table 5-17).

No approach 2 uncertainty analysis is conducted for submission 2019. For further results also consult chp. 1.6.1.

Table 5-17 Uncertainties for 3B Manure management. (AD: Activity data; EF: Emission factor; CO: Combined).

Uncertainty 3B		Approach 1		
		AD	EF	CO
		%		
CH ₄		6.4	54.0	54.4
N ₂ O direct	Liquid/slurry / Anaerobic digester	31.7	75.0	81.4
N ₂ O direct	Solid storage / Deep bedding	31.7	75.0	81.4
N ₂ O indirect	Indirect emissions	46.6	240.0	244.5

The time series 1990–2017 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 and 2015 (extensive surveys on approximately 3000 farms). Values in-between the assessment years were interpolated linearly. For 2016 and 2017 the same values as in 2015 were applied.
- The emission factor for indirect N₂O emissions after volatilisation of NH₃ 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) 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.

For quality assurance of livestock population data and livestock energy intake consult chp. 5.2.4.

5.3.4.1 QA/QC and verification – CH₄

IPCC tables with data for estimating emission factors of all livestock categories (such as weight, feed digestibility, maximum CH₄ producing capacity (B₀) or daily excretion of volatile solids) were filled in, checked for consistency and confidence and compared with IPCC default values (refer to Annex 3 A3.3).

VS excretion of various animal categories is based on IPCC default values. 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 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 default value for liquid/slurry system, without natural crust cover or pit storage below animal confinements > 1 month, at a temperature ≤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. 2018). Furthermore, a series of laboratory measurements of MCF-values by the group of animal nutrition from the Swiss

Federal Institute of Technology in Zürich 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 5.2.

5.3.4.2 QA/QC and verification – N₂O

N₂O estimation is based on the Swiss ammonium emission model AGRAMMON that is documented in Kupper et al. (2018).

All relevant data needed for the calculation of N₂O emissions such as nitrogen excretion rates, manure management system distribution and N₂O emission factors were checked for consistency and were compared to the corresponding values of other countries and to the IPCC 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 (e.g. Spiess 2011). There was good agreement (average discrepancy of $\pm 2\%$) 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 behaviour 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 N₂O emissions using atmospheric measurements and an inverse modelling framework. The best estimate of annual N₂O emissions for the investigated period in 2017/2018 was 10.9 ± 1.7 Gg yr⁻¹, which compares to 8.2 ± 1.7 Gg yr⁻¹ given in this NIR for the year 2017 (2- σ confidence level). Due to the large uncertainties connected to both numbers, these estimates are not significantly different (see also Annex 5.2).

5.3.5 Category-specific recalculations

General information on recalculations is provided in chp. 10.

Recalculations with an overall impact of >0.5 kt CO₂ equivalents are assessed quantitatively. All other recalculations are only described qualitatively.

- N₂O emissions from "Fattening Pigs over 25 kg" (subcategory of swine) and "Broilers" (subcategory of poultry) were revised for the years 2011-2016 due to a new assessment of animal turnover rates in stables. AD and EF were adjusted accordingly. The impact on overall emissions in kt CO₂ equivalents per year is approximately +0.7 (including emissions from 3A, 3B and 3D).
- All estimates based on AGRAMMON data were recalculated for the whole time series due to the implementation of a new model version. The most important changes were the switch to a full nitrogen flow model (including N₂) and the revision of nitrogen excretion rates of some cattle and swine subcategories. More details on AGRAMMON recalculations can be found in chapter 3.6 of Kupper et al. (2018). The impact on overall emissions (including 3B and 3D) in kt CO₂ equivalents is approximately: 1990: -34.1; 2016: -36.0; mean 1990-2016: -32.2.
- CH₄ emissions from liquid manure systems were slightly revised for all years due to revised MCF values from new model runs. The new model runs were based on revised VS distributions to the different manure management systems from the new AGRAMMON model. Effects on overall emissions in kt CO₂ equivalents are approximately: 1990: 0.0; 2016: -0.3; mean 1990-2016: -0.1.
- Direct N₂O emissions from manure management in liquid systems were recalculated for all inventory years due to the revision of the respective emission factor in the course of the revision of the AGRAMMON model. The impact on overall emissions in kt CO₂ equivalents is approximately: 1990: +85.0; 2016: +62.6; mean 1990-2016: +66.9.
- Direct N₂O emissions from manure management were recalculated for all inventory years due to the revision of the amount of nitrogen managed in the manure management system (MS) "anaerobic digestion". The impact on overall emissions in kt CO₂ equivalents is approximately: 1990: +0.0; 2016: -0.8; mean 1990-2016: -0.2.
- Indirect N₂O emissions from manure management were recalculated for all inventory years due to the revision of activity data (amount of NO_x volatilised) in the course of the revision of the AGRAMMON model. The impact on overall emissions in kt CO₂ equivalents is approximately: 1990: +1.8; 2016: +1.6; mean 1990-2016: +1.6.

5.3.6 Category-specific planned improvements

An external peer review of the source category 3B Manure management is planned in 2020. Results will be integrated as soon as available.

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 yield of rice are not estimated by the Swiss Farmers Union (SBV 2018). Only one farm in the south of Switzerland is cultivating upland rice since 1997. CH₄ emissions are assumed to be zero. The area of upland rice was recalculated and is reported from 1997 onward in CRF Table 3.C (EMIS 2016/4C "Reisanbau").

5.5 Source category 3D – Agricultural soils

5.5.1 Source category description

Table 5-18 Key categories of 3D Agricultural soils. Combined KCA results, level for 2017 and trend for 1990–2017, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

A	B	C	D
Code	IPCC Category	GHG	Identification Criteria
3Da	Direct emissions from managed soils	N ₂ O	L1, L2, T2
3Db	Indirect emissions from managed soils	N ₂ O	L1; L2, T1, T2

The source category 3D includes direct and indirect N₂O emissions from managed soils (Table 5-19). 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 N₂O emissions are further subdivided in 1. Atmospheric deposition and 2. Nitrogen leaching and run-off. All indirect N₂O emissions after deposition of NO_x and NH₃ or after leaching of NO₃⁻ are reported under source category 3Db Indirect N₂O Emissions from managed soils. This includes indirect N₂O emissions after NO₃⁻ 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 N₂O emissions from managed soils or in CRF Table6 “Indirect emissions of N₂O and CO₂” (see also chp. 9).

Table 5-19 Specification of source category 3D Agricultural soils.

3D	Source	Specification
3Da	Direct N ₂ O emissions from managed soils	1. Inorganic N fertilisers 2. Organic N fertilisers (animal manure applied to soils, sewage sludge applied to soils, other organic fertilisers applied to soils) 3. Urine and dung deposited by grazing animals 4. Crop residues (incl. residues from meadows and pasture) 5. Mineralisation/immobilisation associated with loss/gain of soil organic matter 6. Cultivation of organic soils (i.e. histosols) 7. Other (domestic use of synthetic fertilisers)
3Db	Indirect N ₂ O emissions from managed soils	1. Atmospheric deposition 2. Nitrogen leaching and run-off

Furthermore, NO_x emissions from managed soils as well as NMVOC emissions are estimated.

Direct and indirect N₂O emissions from managed soils have decreased since 1990 in almost all major sub-categories. Only N₂O 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 21% 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 1990’s while most emissions were more or less stable after the year 2000.

The most significant N₂O emission sources are animal manure applied to soils (29%, mean 1990–2017), nitrogen input from atmospheric deposition (19%, mean 1990–2017), inorganic nitrogen fertilisers (16%, mean 1990–2017) and urine and dung deposited by grazing animals (12%, mean 1990–2017).

5.5.2 Methodological issues

5.5.2.1 Methodology

For the calculation of most N₂O 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 N₂O emissions from agriculture that basically uses the default emission factors, but adjusts the activity data to the particular situation of Switzerland. For the estimation of N₂O emissions from animal manure applied to soils as well as for the estimation of indirect N₂O 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. 2018). 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 FAL/RAC (2001), Walther et al. (1994) and Flisch et al. (2009). Most recently, the N-flow model was extended to include all gaseous N-species (including N₂) and new NO_x emission factors were implemented (Kupper 2017). Emission factors for N₂O are all IPCC default with the exception of the emission factor for indirect N₂O emissions from atmospheric deposition of N volatilised from managed soils (EF₄) which is country-specific.

The modelling of the N₂O emissions is done by Agroscope, the Swiss centre of excellence for agricultural research (Agroscope 2019) and is consistent with source category 3B N₂O emissions from manure management. The model structure is displayed in Figure 5-6 and the corresponding amounts of nitrogen are given in Table 5-20.

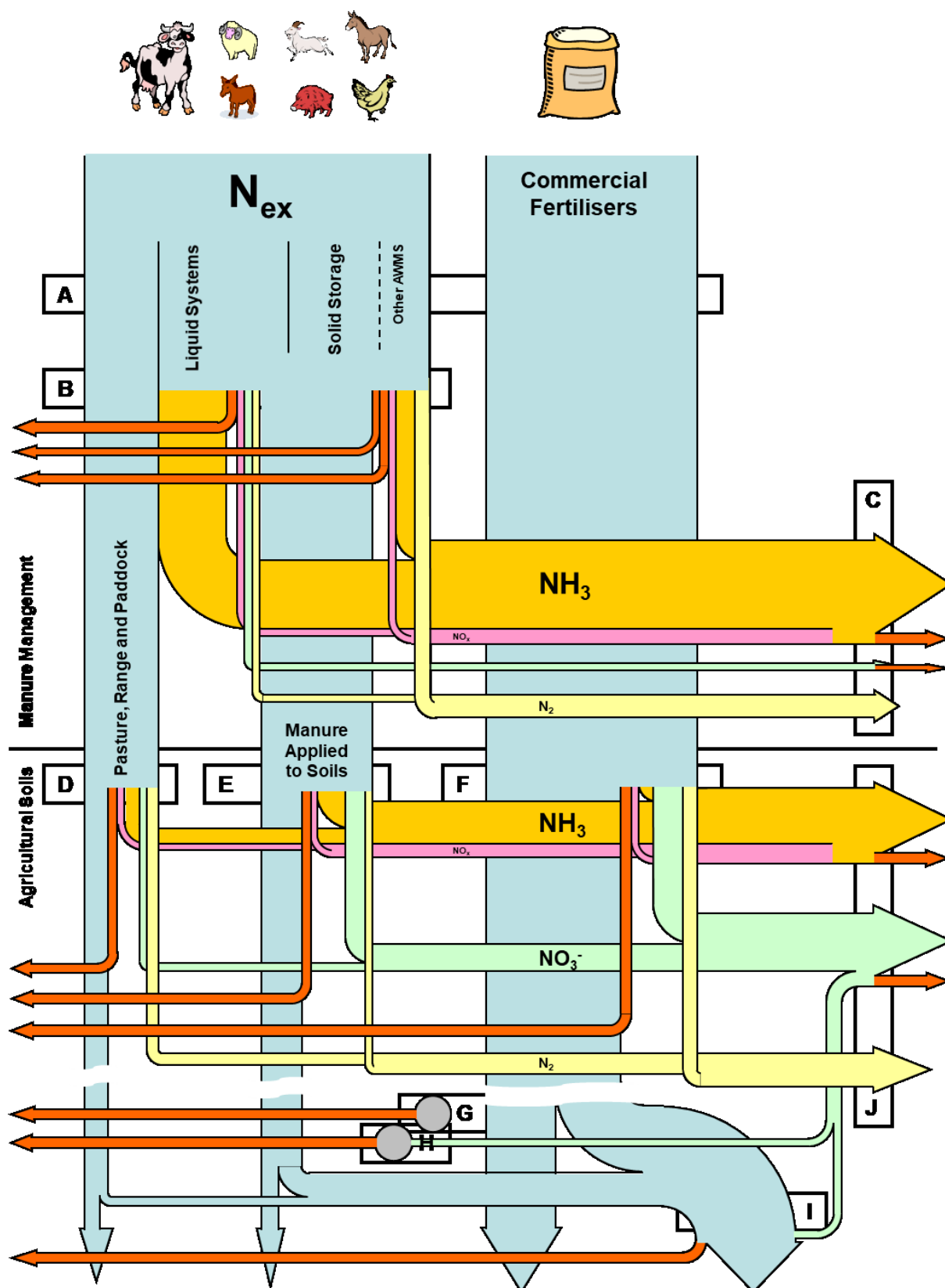


Figure 5-6 Diagram depicting the methodology of the approach to calculate the N_2O emissions in agriculture (red arrows). Black frames and the respective letters refer to the nitrogen flows in Table 5-20. Note that the figure shows explicitly the methodology of the approach and not necessarily the physical 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 5-20 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			CRF table
		1990	2016		
		tN			
A	1 Pasture, range and paddock	13'424	22'389	= B	3.Da3
	2 Liquid/slurry systems	91'671	71'522		3.B(b)
	3 Solid storage	35'486	17'617		3.B(b)
	4 Other AWMS	8'547	18'422		3.B(b)
	5 Commercial fertiliser	75'085	57'389	= F	3.Da1,2bc,7
B	1 Pasture, range and paddock	13'424	22'389	= A1 + A2 + A3 + A4	3.Da3
	2 NH ₃ volatilisation housing	11'066	14'685		3.B(b)5
	3 N ₂ O emission liquid/slurry	183	143		3.B(b)
	4 NO _x volatilisation liquid/slurry and digester	185	159		3.B(b)5
	5 Leaching manure management	0	0		3.B(b)5
	6 N ₂ volatilisation liquid/slurry and digester	1'851	1'588		
	7 Manure applied to soils	111'980	82'968		3.Da2a
	8 N ₂ O emission solid storage	177	88		3.B(b)
	9 N ₂ O emission other AWMS	46	57		3.B(b)
	10 NO _x volatilisation solid storage and deep litter	224	145		3.B(b)5
	11 NH ₃ volatilisation storage	8'805	6'894		3.B(b)5
	12 N ₂ volatilisation solid storage and deep litter	1'187	834		
C	1 NH ₃ deposition manure management	19'871	21'579	= B2+B11	3.B(b)5
	2 NO _x deposition manure management	409	304	= B4+B10	
	3 Leaching manure management	0	0	= B5	
D	1 Plant available N PR&P and N2 volatilisation	9'703	16'743	= B1	
	2 N ₂ O emission PR&P	257	423		3.Da3
	3 NO _x volatilisation PR&P	74	123		
	4 NH ₃ volatilisation PR&P	625	1'105		
	5 Leaching and run-off PR&P	2'767	3'994		
E	1 Plant available N animal manure and N ₂ vol.	59'979	50'117	= B7	
	2 N ₂ O emission application animal manure	1'120	830		3.Da2a
	3 NO _x volatilisation application animal manure	616	456		
	4 NH ₃ volatilisation application animal manure	27'188	16'764		
	5 Leaching and run-off application animal manure	23'077	14'801		
F	1 Plant available N com. fertiliser and N ₂ vol.	53'804	43'230	= A5	
	2 N ₂ O emission application com. fertiliser	751	566		3.Da1,2bc,7
	3 NO _x volatilisation application com. fertiliser	413	316		
	4 NH ₃ volatilisation application com. fertiliser	4'644	3'124		
	5 Leaching and run-off application com. fertiliser	15'474	10'153		
G	1 Cultivation of organic soils (ha)	18'039	17'339		3.Da6
H	1 Mineralisation/immobilisation soil organic matter	4'415	16'763		3.Da5
I	1 N in crop residues pasture, range and paddock	27'595	26'813		3.Da4
	2 N in crop residues arable crops	11'953	11'825		
J	1 NH ₃ deposition fertiliser appl. and PR&P	32'456	20'993	= D4+E4+F4	3.Db1
	2 NO _x deposition fertiliser appl. and PR&P	1'103	895	= D3+E3+F3	
	4 Leaching and run-off fertiliser appl. and PR&P	41'317	28'948	= D5+E5+F5	3.Db2
	5 Leaching and run-off mineralisation SOM	910	2'990		
	6 Leaching and run-off crop residues	8'150	6'893		

5.5.2.2 Direct N₂O emissions from managed soils (3Da)

Calculation of Direct N₂O emissions from managed soils is based on IPCC 2006 equation 11.1 including six terms for activity data and three different emission factors:

$$N_2O_{Direct} - N = (F_{SN} + F_{ON} + F_{CR} + F_{SOM}) \bullet EF_1 + F_{OS} \bullet EF_2 + F_{PRP} \bullet EF_3$$

$N_2O_{Direct}-N$ = 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/year)

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 5-21). 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 EF_1 reported is thus only slightly below 1.0%. The amount of fertilisers with nitrification inhibitors is classified as confidential (C). For reviewers there is an additional table available, including all confidential data and information. Due to the lack of data no other fertiliser 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 ($EF_{3PRP,CPP} = 0.02$) and the emission factor for sheep and "other animals" ($EF_{3PRP,SO} = 0.01$) according to the shares of nitrogen excreted by the respective animals.

Table 5-21 Emission factors for calculating direct N₂O emissions from managed soils (IPCC 2006). Blue: annually changing parameters, value for 2017.

Emission source	Emission factor
EF ₁ Inorganic N fertilisers (kg N ₂ O-N/kg)	0.0098
EF ₁ Organic N fertilisers (kg N ₂ O-N/kg)	0.0100
EF ₁ Crop residue (kg N ₂ O-N/kg)	0.0100
EF ₁ Mineralisation/immobilisation soil organic matter (kg N ₂ O-N/kg)	0.0100
EF ₁ Other (domestic synthetic fertilisers) (kg N ₂ O-N/kg)	0.0100
EF ₂ Cultivation of organic soils (kg N ₂ O-N/ha)	8.0000
EF ₃ Urine and dung deposited by grazing animals (kg N ₂ O-N/kg)	0.0189

5.5.2.2.2 Activity data

Activity data for calculation of 3Da Direct soil emissions includes 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 (2017). 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. 2018). 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 N₂O 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 5-20).

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 NH₃, NO_x, N₂O and N₂ 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. (2018). Since 2003 the use of sewage sludge as fertiliser is prohibited in Switzerland. However, a transition period applied for some areas. Cantons could therefore prolong this period until 2008 in individual cases (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. (2018). 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 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. 2018; 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 approximately 3000 farms (2000, 2007, 2010, 2015).

N₂O 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 yields were adopted from the statistical yearbooks of the Swiss Farmers Union (SBV 2018). Subsequently the relationship between nitrogen returned in crop residues and fresh matter crop yield was determined for each crop and hereafter the overall amount of nitrogen returned to soils was calculated as follows:

$$F_{CR,AC} = \sum_T \left(Y_T \cdot \frac{NR_T}{SY_T} \right)$$

$F_{CR,AC}$ = amount of nitrogen in crop residues from arable crops returned to soils (t N)

Y_T = amount of fresh matter crop yield 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)

Standard values for fresh matter crop yields and nitrogen contained in crop residues are given in the “Principles of Fertilisation in Arable and Forage Crop Production” (FAL/RAC 2001 and Richner et al. 2017). 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 N₂O 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 from feed not eaten by the animals and feed losses due to trampling effects.

$$F_{CR,MP} = \sum_P \left(A_P \cdot \frac{SY_{DM,P}}{10} \cdot N_{DM,P} \div 1000 \cdot R_P \right)$$

$F_{CR,MP}$ = amount of nitrogen in crop residues from meadows and pastures returned to soils (t N)

A_P = area of meadow and pasture of type P (ha)

$SY_{DM,P}$ = standard dry matter yield per area of meadow and pasture of type P (dt/ha)

$N_{DM,P}$ = dry matter nitrogen content of meadow and pasture of type P (kg/t)

R_P = ratio of residues to harvested yield for meadows and pasture of type P (kg/kg)

Areas of intensive meadows, natural meadows, pasture and alpine and Jurassic pasture were obtained from SBV (2018) and from the SFSO (2018a). Standard dry matter yields per area, nitrogen content of dry matter as well as % yield losses were based on the original IULIA model (Schmid et al. 2000) and on Richner et al. (2017).

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 3 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 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 N₂O emissions from nitrogen mineralisation are not identical with the net carbon stock changes reported in the reporting tables (CRF Table4.B and Table4.C). N₂O emissions from nitrogen mineralisation of land converted to cropland or land converted to grassland are reported under source category 4(III) "Direct nitrous oxide (N₂O) 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 N₂O emissions from **cultivated organic soils** are based on the area of cultivated organic soils and the IPCC default emission factor for N₂O 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 Table 4.B and 4.C (see also 6.2.2).

The relevant activity data for calculating N₂O emissions from soils are displayed in Table 5-22. Additional information is given in Annex 3 A3.3.

Table 5-22 Activity data for calculating 3Da Direct N₂O emissions from managed soils.

Activity Data		1990-1999									
		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		t N/yr									
1. Inorganic N fertilisers	Urea	16'284	11'966	11'650	11'335	11'021	10'707	10'391	7'555	6'405	6'690
	Other mineral fertilisers	50'391	54'913	55'035	50'646	47'326	47'652	45'899	41'086	42'511	44'461
2. Organic N fertilisers	a. Animal manure	111'980	110'280	107'753	105'620	104'588	102'268	100'121	95'616	93'207	88'918
	b. Sewage sludge	4'815	4'840	4'866	4'891	4'916	4'942	4'624	4'307	3'990	3'673
	c. Other organic fertilisers	817	884	988	1'033	1'151	1'286	1'369	1'427	1'489	1'686
3. Urine and dung deposited by grazing animals		13'424	13'663	13'743	13'648	13'905	14'035	15'977	17'207	18'449	19'214
4. Crop residues	Arable crops	11'953	11'620	11'805	11'741	11'134	11'350	12'670	12'053	12'454	10'933
	Residues M&P	27'595	27'382	27'201	26'985	26'729	26'515	26'697	26'901	27'160	27'280
5. Min./imm. associated with loss/gain of SOM		4'415	1'075	1'069	17'202	14'713	16'844	1'266	4'958	7'937	1'359
6. Cultivation of organic soils (ha)		18'039	18'014	17'989	17'964	17'941	17'912	17'883	17'852	17'821	17'790
7. Other (domestic inorganic fertilisers)		2'778	2'787	2'779	2'583	2'431	2'432	2'345	2'027	2'038	2'131

Activity Data		2000-2009									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		t N/yr									
1. Inorganic N fertilisers	Urea	7'631	7'815	8'020	6'754	7'875	6'605	5'977	8'305	6'600	5'302
	Other mineral fertilisers	43'042	46'788	45'281	44'098	43'392	43'478	43'227	43'282	41'985	40'456
2. Organic N fertilisers	a. Animal manure	86'098	84'710	82'070	81'272	80'708	82'187	82'915	83'354	85'140	84'160
	b. Sewage sludge	3'356	2'596	1'836	1'542	1'248	1'054	859	573	286	0
	c. Other organic fertilisers	1'829	1'948	1'994	1'998	2'089	2'201	2'406	2'638	2'762	3'012
3. Urine and dung deposited by grazing animals		21'312	23'010	24'476	24'178	23'747	23'885	24'061	24'077	24'271	23'753
4. Crop residues	Arable crops	12'345	10'752	11'722	10'011	12'152	11'750	10'876	11'786	11'690	12'103
	Residues M&P	27'456	27'396	27'305	27'305	27'193	26'928	26'812	26'729	26'494	26'517
5. Min./imm. associated with loss/gain of SOM		27'144	17'995	11'409	2'150	1'542	16'956	1'325	8'666	2'655	4'181
6. Cultivation of organic soils (ha)		17'758	17'727	17'696	17'665	17'634	17'602	17'576	17'550	17'528	17'505
7. Other (domestic inorganic fertilisers)		2'111	2'275	2'221	2'119	2'136	2'087	2'050	2'149	2'024	1'907

Activity Data		2010-2017							
		2010	2011	2012	2013	2014	2015	2016	2017
		t N/yr							
1. Inorganic N fertilisers	Urea	7'101	6'487	5'338	5'748	7'890	6'914	8'818	9'001
	Other mineral fertilisers	45'986	40'243	39'810	37'969	41'446	36'830	37'585	40'362
2. Organic N fertilisers	a. Animal manure	84'129	84'027	84'203	83'650	84'159	83'919	83'431	82'968
	b. Sewage sludge	0	0	0	0	0	0	0	0
	c. Other organic fertilisers	3'370	3'773	4'466	4'812	5'065	5'446	5'800	5'969
3. Urine and dung deposited by grazing animals		23'338	23'073	23'091	22'860	22'766	22'491	22'439	22'389
4. Crop residues	Arable crops	10'740	12'460	11'429	10'330	12'504	10'925	10'144	11'825
	Residues M&P	27'132	25'921	26'380	26'002	27'325	26'469	27'015	26'813
5. Min./imm. associated with loss/gain of SOM		6'248	7'924	21'426	9'417	13'862	10'801	14'587	16'763
6. Cultivation of organic soils (ha)		17'484	17'462	17'440	17'420	17'399	17'379	17'359	17'339
7. Other (domestic inorganic fertilisers)		2'212	1'947	1'881	1'822	2'056	1'823	1'933	2'057

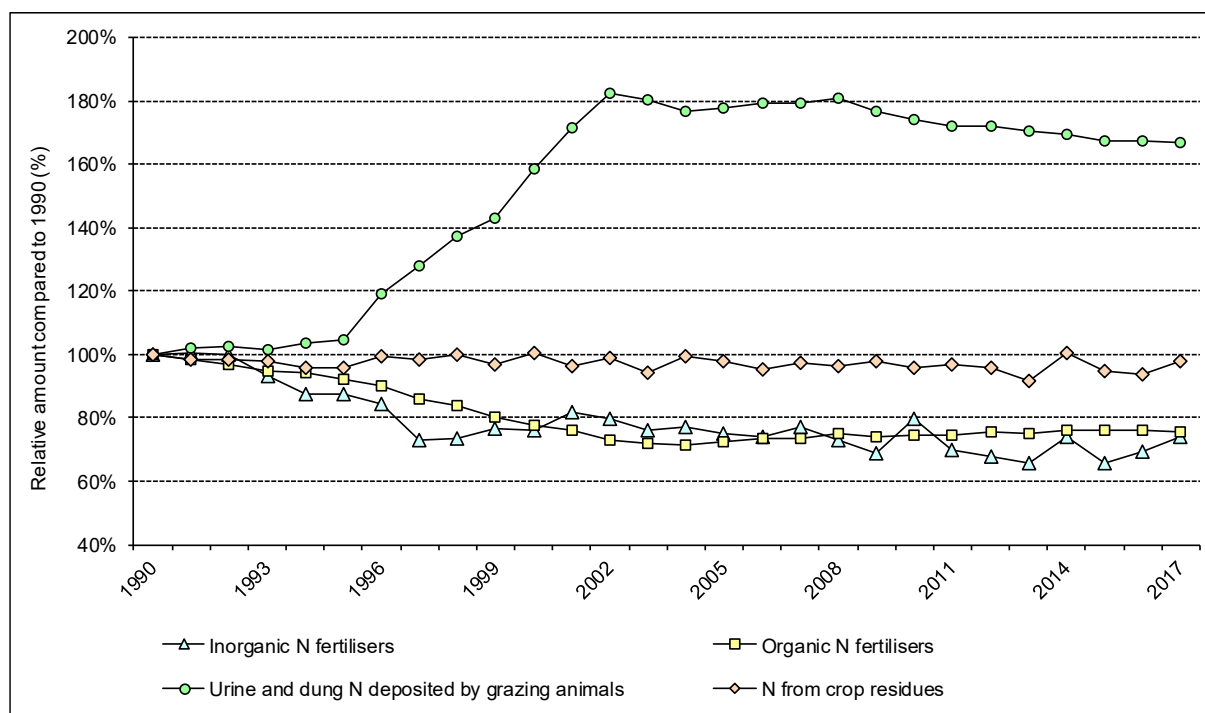


Figure 5-7 Relative development of the most important activity data for 3Da Direct N₂O emissions from managed soils.

Figure 5-7 represents the development of the most important activity data for 3Da Direct N₂O 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 21st 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 N₂O emissions from atmospheric deposition of N volatilised from managed soils (3Db1)

N₂O 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:

$$N_2O_{(ATD)} - N = \left\{ \left[\sum_i (F_{CN_i} * Frac_{GASF_i}) + \sum_T (F_{AM_T} * Frac_{GASM_T}) + \sum_T (F_{PRP_T} * Frac_{GASP_T}) \right] + [(F_{CN} + F_{AM}) * Frac_{NOXA} + F_{PRP} * Frac_{NOXP}] * EF_4 \right\}$$

$N_2O_{(ATD)}-N$ = 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 5-23). 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 (EMEP/EEA 2016). The weighted mean value for synthetic fertilisers excluding urea is 2.8% (mean 1990–2017). 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. 2018). 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 $\text{Frac}_{\text{GASF}}$ (including NO_x emissions) as reported in CRF Table 3.D declined considerably from 6.7% in 1990 to 5.0% in 2006 and then increased again to 6.0% in 2017 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. 2018). Overall weighted $\text{Frac}_{\text{GASMT}}$ for animal manure applied to soils slightly declined from 24.3% in the early 1990s to 20.2% in 2017 (Table 5-23).

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 ($\text{Frac}_{\text{GASPT}}$) range from 4.7% to 4.9%.

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 ($\text{Frac}_{\text{NOXA}}$ and $\text{Frac}_{\text{NOXP}}$) 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 5-24. Additional information is given in Annex 3 A3.3.

Table 5-23 Overview of NH₃ and NO_x emission factors used for the assessment of 3Db Indirect N₂O emissions from atmospheric deposition. Complete time series on a livestock sub-category level are provided in Annex 3 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})		6.18	6.05	5.42	4.67	4.46	4.84	4.69	4.58	4.71	4.80
	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	3.12	3.07	2.99
	Recycling Fertilisers (weighted average)	17.60	19.97	18.81	13.52	12.96	12.06	10.76	9.35	9.68	10.10
	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})		24.28	24.31	22.58	22.42	22.68	22.90	22.38	21.75	21.16	20.99
	Mature Dairy Cattle	26.69	26.78	25.40	25.30	25.47	25.63	25.00	24.38	23.76	23.44
	Other Mature Cattle	24.16	23.68	21.76	22.65	23.20	23.72	23.31	22.88	22.45	22.28
	Growing Cattle (weighted average)	24.47	24.54	22.60	22.80	23.19	23.57	23.02	22.47	21.92	21.73
	Sheep (weighted average)	3.73	4.39	4.11	5.19	5.61	6.04	5.86	5.69	5.54	5.40
	Swine (weighted average)	21.52	21.02	19.81	19.84	20.09	20.38	19.77	19.17	18.57	18.67
	Other Livestock (weighted average)	8.44	9.70	8.68	8.84	8.83	8.94	9.20	9.49	9.79	9.98
NH ₃ from urine and dung N deposited on PR&P (Frac _{GASPT})		4.65	4.69	4.78	4.90	4.92	4.95	4.91	4.87	4.84	4.85
	Mature Dairy Cattle	4.67	4.65	4.64	4.61	4.61	4.60	4.60	4.59	4.59	4.59
	Other Mature Cattle	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57
	Growing Cattle (weighted average)	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
	Swine (weighted average)	NA	NA	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.02
	Other Livestock (weighted average)	5.00	6.93	7.81	9.40	9.66	10.11	9.48	8.89	8.39	8.55
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		2012-2017					
		2012	2013	2014	2015	2016	2017
		%					
NH ₃ from commercial fertiliser N (Frac _{GASFI})		4.85	5.07	5.24	5.61	5.52	5.44
	Urea	13.11	13.11	13.11	13.11	13.10	13.10
	Other Mineral Fertilisers	3.11	3.12	3.04	3.37	2.82	2.82
	Recycling Fertilisers (weighted average)	10.70	11.04	11.29	11.54	11.80	11.92
	Sewage Sludge	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
	Digestate Liquid	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
NH ₃ from application of animal manure N (Frac _{GASMT})		20.78	20.60	20.42	20.25	20.23	20.21
	Mature Dairy Cattle	23.12	22.80	22.49	22.18	22.18	22.18
	Other Mature Cattle	22.11	21.94	21.77	21.60	21.60	21.60
	Growing Cattle (weighted average)	21.57	21.38	21.19	21.01	21.01	21.01
	Sheep (weighted average)	5.26	5.12	4.96	4.81	4.81	4.81
	Swine (weighted average)	18.77	18.85	18.95	19.06	19.06	19.07
	Other Livestock (weighted average)	10.03	10.18	10.40	10.57	10.64	10.73
NH ₃ from urine and dung N deposited on PR&P (Frac _{GASPT})		4.86	4.87	4.88	4.90	4.92	4.94
	Mature Dairy Cattle	4.59	4.59	4.59	4.59	4.59	4.59
	Other Mature Cattle	4.57	4.57	4.57	4.57	4.57	4.57
	Growing Cattle (weighted average)	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
	Swine (weighted average)	14.04	14.09	14.17	14.42	14.43	14.43
	Other Livestock (weighted average)	8.55	8.81	9.06	9.42	9.79	9.97
NO _x from applied fertilisers (Frac _{NOXA})		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

Table 5-24 Overview of N pools and flows for calculating 3Db Indirect N₂O emission from managed soils. Complete time series are provided in Annex 3 A3.3.

Nitrogen pools and flows		1990-2011									
		1990	1995	2000	2005	2006	2007	2008	2009	2010	2011
		t N/yr									
Deposition	Animals manure N applied to soils	111'980	102'268	86'098	82'187	82'915	83'354	85'140	84'160	84'129	84'027
	Commercial fertiliser	75'085	67'018	57'969	55'425	54'519	56'947	53'658	50'676	58'669	52'451
	Sum volatilised N (NH ₃ and NO _x)	33'559	30'588	24'510	23'074	23'307	23'937	23'656	22'654	22'614	22'148
	NH ₃ emissions from commercial fertilisers	4'644	4'058	3'142	2'590	2'432	2'755	2'516	2'319	2'766	2'519
	NH ₃ emissions from applied animal manure	27'188	24'864	19'440	18'426	18'805	19'085	19'052	18'305	17'804	17'633
	NH ₃ emissions from pasture, range and paddock	625	658	1'018	1'169	1'183	1'192	1'191	1'158	1'130	1'118
	NO _x emissions from commercial fertilisers	413	369	319	305	300	313	295	279	323	288
	NO _x emissions from applied animal manure	616	562	474	452	456	458	468	463	463	462
	NO _x emissions from PR&P	74	77	117	131	132	132	133	131	128	127
	Sum leaching and run-off	50'377	49'054	45'734	40'739	37'250	38'883	37'091	36'282	37'487	36'697
Leaching and run-off	Leaching and run-off from commercial fertilisers	15'474	13'811	11'411	10'399	10'128	10'446	9'733	9'118	10'445	9'330
	Leaching and run-off from applied animal manure	23'077	21'076	16'949	15'420	15'404	15'331	15'503	15'169	15'008	14'990
	Leaching and run-off from pasture, range and paddock	2'767	2'892	4'195	4'481	4'470	4'428	4'419	4'281	4'163	4'116
	Leaching and run-off from crop residues	8'150	7'803	7'835	7'257	7'002	7'084	6'953	6'961	6'756	6'847
	Leaching and run-off from mineralisation of SOM	910	3'471	5'343	3'181	246	1'594	483	754	1'115	1'414

Nitrogen pools and flows		2012-2017					
		2012	2013	2014	2015	2016	2017
		t N/yr					
Deposition	Animals manure N applied to soils	84'203	83'650	84'159	83'919	83'431	82'968
	Commercial fertiliser	51'495	50'350	56'456	51'013	54'136	57'389
	Sum volatilised N (NH ₃ and NO _x)	21'987	21'762	22'158	21'824	21'853	21'888
	NH ₃ emissions from commercial fertilisers	2'496	2'552	2'961	2'864	2'991	3'124
	NH ₃ emissions from applied animal manure	17'496	17'234	17'187	16'992	16'878	16'764
	NH ₃ emissions from pasture, range and paddock	1'122	1'113	1'111	1'102	1'105	1'105
	NO _x emissions from commercial fertilisers	283	277	311	281	298	316
	NO _x emissions from applied animal manure	463	460	463	462	459	456
	NO _x emissions from PR&P	127	126	125	124	123	123
	Sum leaching and run-off	38'867	36'116	38'699	36'653	37'741	38'831
Leaching and run-off	Leaching and run-off from commercial fertilisers	9'159	8'954	10'046	9'073	9'623	10'153
	Leaching and run-off from applied animal manure	15'021	14'923	15'013	14'970	14'883	14'801
	Leaching and run-off from pasture, range and paddock	4'119	4'078	4'061	4'012	4'003	3'994
	Leaching and run-off from crop residues	6'745	6'481	7'105	6'671	6'629	6'893
	Leaching and run-off from mineralisation of SOM	3'822	1'680	2'473	1'927	2'602	2'990

Figure 5-8 shows the development of the most important activity data for 3Db Indirect N₂O 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 NH₃ (Frac_{GASMT}) declined slightly and also contributed to the decreasing trend.

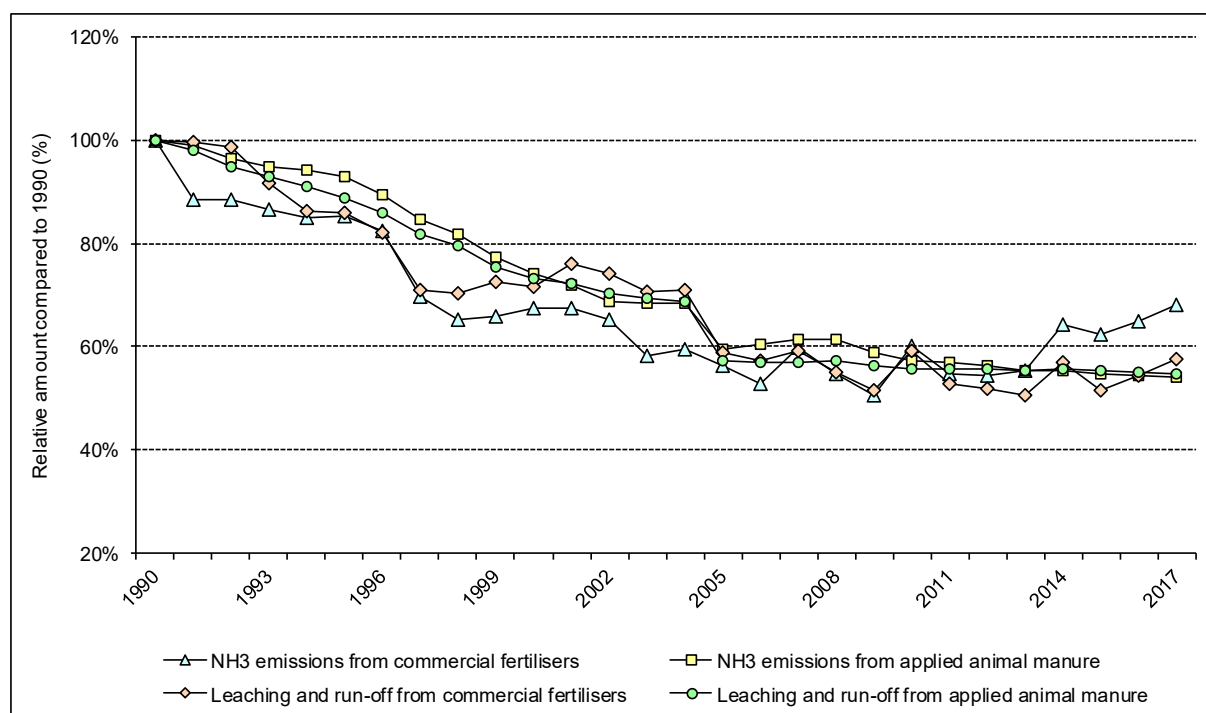


Figure 5-8 Relative development of the most important activity data for 3Db Indirect N₂O emissions from managed soils.

5.5.2.4 Indirect N₂O emissions from leaching and run-off from managed soils (3Db2)

N₂O emissions from leaching and run-off from managed soils are estimated based on equation 11.10 of the 2006 IPCC Guidelines:

$$N_2O_{(L)} - N = (F_{CN} + F_{AM} + F_{PRP} + F_{CR} + F_{SOM}) \cdot \text{Frac}_{\text{LEACH-(H)}} \cdot EF_5$$

$N_2O_{(L)} - N$ = annual amount of N₂O–N produced from leaching and run-off of N additions to managed soils (kg N₂O–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)

$\text{Frac}_{\text{LEACH-(H)}}$ = 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 N₂O emissions from N leaching and run-off (kg N₂O–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 numbers are contained in Table 5-22.

F_{ACLEACH} 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 5-24.

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 (F_{ACLEACH}).

5.5.2.5 NMVOC emissions from agricultural soils

The NMVOC emissions from crop production and agricultural soils were revised completely for the entire times series using a Tier 2 approach according to the EMEP/EEA Guidebook 2016 (EMEP/EEA 2016). 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 2016 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 arithmetic mean of the lower and upper bound uncertainty is used for activity data and for emission factors, resulting in combined Approach 1 uncertainties as shown in Table 5-25. For 3Da (Direct N₂O emissions – Fertilisers) the sub-positions 3Da 1, 2, 4, 5 and 7 were combined according to Approach 1 error propagation.

No approach 2 uncertainty analysis is conducted for submission 2019.

For further results also consult chp. 1.6.1.

Table 5-25 Uncertainties for 3D Agricultural soils. (AD: Activity data; EF: Emission factor; CO: Combined).

Uncertainty 3D		Approach 1		
		AD	EF	CO
		%		
Direct soil emissions	Fertilisers	12.8	135.0	135.6
	Organic soils	32.2	137.5	141.2
	Urine and dung deposited on PR&P	67.7	132.5	148.8
Indirect soil emissions	Atmospheric deposition	41.8	240.0	243.6
	Leaching and run-off	22.1	163.3	164.8

The time series 1990–2017 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 and 2015 (extensive surveys on approximately 3000 farms). Values in-between the assessment years were interpolated linearly.
- $Frac_{GASF}$, $Frac_{GASM}$ 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 N₂O emissions following volatilisation of NH₃ and NO_x from applied fertilisers and urine and dung excreted on PR&P 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) standard values are being analysed and discussed.

The Swiss ammonium emission model AGRAMMON is documented in Kupper et al. (2018) and Agrammon (2010). Generally the reporting of N₂O emissions in the Swiss national GHG inventory is consistent with the reporting of other nitrogen compounds (NH₃, 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}) were checked for consistency and confidence and were compared (where possible) to IPCC default values, 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.

N₂O 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). The N₂O emission factor for cultivated organic soils was validated by a study from Leifeld (2018) that used a large data set of C/N ratios in Swiss organic soils to predict N₂O emissions. The study concluded that the current national GHG inventory neither systematically over- nor underestimates total emissions. Furthermore, 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 N₂O emission factors under Swiss conditions based on a literature review (Krause et al. 2018). The authors found that the N₂O 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 values. Still, the numerical difference indicates that further efforts should be made to development country-specific emission factors (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} 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 N₂O emissions using atmospheric measurements and an inverse modelling framework. The best estimate of annual N₂O emissions for the investigated period in 2017/2018 was 10.9 ± 1.7 Gg yr⁻¹, which compares to 8.2 ± 1.7 Gg yr⁻¹ given in this NIR for the year 2017 (2-σ confidence level). Due to the large uncertainties connected to both numbers, these estimates are not significantly different (see Annex 5.2).

5.5.5 Category-specific recalculations

General information on recalculations is provided in chp. 10.

Recalculations with an overall impact of >0.5 kt CO₂ equivalents 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.
- All estimates based on AGRAMMON data were recalculated for the whole time series due to the implementation of a new model version. The most important changes were the switch to a full nitrogen flow model (including N₂) and the revision of nitrogen excretion rates of some cattle and swine subcategories. More details on AGRAMMON recalculations can be found in chapter 3.6 of Kupper et al. (2018). The impact on overall emissions (including 3B and 3D) in kt CO₂ equivalents is approximately: 1990: -34.1; 2016: -36.0; mean 1990-2016: -32.2.
- Direct and indirect N₂O emissions from agricultural soils were revised for the whole time series due to new AD for recycling fertilisers (compost, digestates). The impact on overall emissions in kt CO₂ equivalents is approximately: 1990: +0.4; 2016: +8.1; mean 1990-2016: +0.1.
- N₂O emissions from N in crop residues returned to soils were recalculated for the whole time series due to harmonisation of grassland yields (AD) with the updated methodology in the LULUCF sector. The recalculation affected both direct and indirect N₂O emissions from agricultural soils. The impact on overall emissions in kt CO₂ equivalents is approximately: 1990: +19.6; 2016: +18.0; mean 1990-2016: +15.8.
- N₂O emissions from N in crop residues returned to soils were recalculated for the year 2016 due to revised AD. Provisional data on crop harvests from the Swiss Farmers Union (SFU/SBV) was updated. The recalculation affected both direct and indirect N₂O emissions from agricultural soils. The impact on overall emissions in kt CO₂ equivalents is negligible.
- Direct and indirect N₂O emissions from N mineralised in association with loss of soil C were recalculated for the whole time series due to new data on N mineralisation in cropland and grassland (new Tier3 methodology in the LULUCF sector). The impact on overall emissions in kt CO₂ equivalents is approximately: 1990: +20.5; 2016: + 73.4; mean 1990-2016: +45.6.
- Direct N₂O emissions from cultivation of organic soils were recalculated for the whole time series due to slightly revised AD, i.e. revised estimates of the area of organic soils under cropland and grassland. The impact on overall emissions in kt CO₂ equivalents is negligible (<0.1).

5.5.6 Category-specific planned improvements

Starting in 2019, FOEN funds the development and evaluation of a process-oriented model for N₂O emissions in agricultural soils subject to common Swiss management practices.

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.

Emissions from open burning of branches in agriculture and forestry were reported here in the past. However, the respective emissions were moved to the LULUCF and the waste sector 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. 6.4.2.13) 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

CO₂ emission from 3G Liming is not a key category.

Emissions from the application of lime (Ca(CO₃)) and dolomite (CaMg(CO₃)₂) to agricultural soils are reported.

The emissions due to liming of agricultural soils range from 22.2 to 32.9 kt CO₂ per year.

5.8.2 Methodological issues

A simple Tier 1 approach was adopted using estimated amounts of lime and dolomite applied and IPCC 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(CO₃)) and for dolomite (0.13 t C per t CaMg(CO₃)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 (2008–2017). It was estimated by Agroscope in 2009 for the period 1990–2008. For 2009–2017 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 remained constant in this period (Agroscope 2014a). The split of lime into calcium carbonate and dolomite is based on the following assumptions and data:

- Ca(CO₃) contained in mixed compound fertilisers as reported by Agricura (2017)
- All material originating from nuclear power plants and from the sugar beet industry is Ca(CO₃)
- The remaining lime not covered under the points above was divided equally into Ca(CO₃) and CaMg(CO₃)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 $\pm 40\%$ was used as an approximation (Agroscope 2014a). For the emission factor of lime a lower uncertainty of $\pm 5\%$ was chosen, because it is a simple chemical process. The combined Approach 1 uncertainty is thus $\pm 40.3\%$.

No approach 2 uncertainty analysis is conducted for submission 2019.

For further results also consult chp. 1.6.1.

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.

No category-specific recalculations were carried out.

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

CO₂ emission from 3H Urea application is not a key category.

Adding urea to soils during fertilisation leads to a loss of CO₂ that was fixed during the industrial production process of the fertiliser. Emissions in Switzerland range from 8.7 to 26.7 kt CO₂ per year with a general decreasing trend from 1990 to 2017.

5.9.2 Methodological issues

A simple Tier 1 approach was adopted using estimated amounts of urea applied and IPCC default emission factors.

5.9.2.1 Emission factor

No country-specific emission factors are available. Consequently, the IPCC 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 (2017). 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 $\pm 5\%$ for the activity data was estimated according to ART (2008a). An uncertainty of $\pm 5\%$ was assumed for the emission factor since it is a simple chemical process. The combined Approach 1 uncertainty is hence $\pm 7.1\%$.

No approach 2 uncertainty analysis is conducted for submission 2019.

For further results also consult chp. 1.6.1.

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.

No category-specific recalculations were carried out.

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 and land use change (LULUCF)	
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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 1990–2017 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 AREA surveys 1, 2 and 3 were completed in 2013 and the interpretation of the entire Swiss territory is available for three time slices. In this submission, results of the ongoing AREA4 survey for the western and central part of Switzerland were included.

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 in 18 sub-divisions of land use. A further spatial stratification reflects "elevation" (3 zones), "geomorphologic and climatic conditions" (adopting the five production regions of the National Forest Inventory; NFI) and "soil type" (mineral, organic).

Country-specific emission factors and carbon stocks for Forest land were derived from three National Forest Inventories (NFI1, NFI2, NFI3, finalized in 1985, 1995, and 2006, respectively) and five annual tranches of the continuous NFI4 (2013–2017). The inventories comprised ca. 3'350 (5-years interval from NFI4), 6'500 (NFI2 and NFI3) 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 default values and expert estimates were used.

6.1.2 Emissions and removals

Table 6-1 and Figure 6-1 summarize the CO₂ emissions and removals as a result of carbon losses and gains for the years 1990–2017. The total net emissions and removals of CO₂ varied between -6'529 kt (1996) and 5'507 kt (2000).

Table 6-1 and Figure 6-1 show a breakdown of Switzerland's CO₂ balance in the LULUCF sector. Five components were differentiated:

- Gains in carbon stock of living biomass on all land uses and due to land-use changes; this component represents the largest sink of carbon.
- Losses in carbon stock of 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) due to land-use changes. Due to pronounced annual fluctuations of soil organic carbon in mineral soils on cropland and grassland there is a clear net removal in some years. In most years however, the soils are net emitters.
- Net carbon stock changes in Harvested wood products (HWP). In the period under investigation this component persistently represents a sink of carbon, i.e. the carbon stock stored in wood products was increasing.

The largest part of gains and losses in carbon stocks of biomass occurred in forests, where growth of biomass (gains) exceeded cut and mortality (losses), except for the years 2000, 2006, and 2007 (see also chp. 2.3.3). Overall, the LULUCF sector was a sink of on average -2'648 kt CO₂ yr⁻¹ between 1990 and 2017 (see Table 6-1 and Figure 6-3).

Table 6-1 CO₂ emissions and removals in the LULUCF sector broken down for: (i) CO₂ removals due to the gain (growth) of living biomass, (ii) CO₂ emissions due to the loss (cut and mortality) of living biomass, (iii) net CO₂ emissions and removals from dead organic matter, (iv) net CO₂ emissions from soils, and (v) net CO₂ removals from Harvested wood products. Positive values refer to emissions; negative values refer to removals. In this data set, emissions of CH₄ and N₂O are not included; GHG (i.e. CO₂, CH₄, N₂O) emissions and removals in the LULUCF sector (in CO₂ eq) are shown in Figure 6-3.

LULUCF	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
	kt CO ₂									
Gains of living biomass	-12'793	-12'814	-12'744	-12'752	-12'783	-12'764	-12'673	-12'686	-12'753	-12'658
Losses of living biomass	11'966	9'182	8'877	8'695	9'187	9'277	9'106	9'894	10'967	10'602
Net change in dead organic matter	-455	-1'139	-422	-605	119	-674	-2'305	-1'340	-1'311	-928
Net change in organic and mineral soils	17	-759	-266	707	582	760	-370	65	235	-188
LULUCF (excluding HWP)	-1266	-5531	-4555	-3956	-2895	-3402	-6243	-4067	-2862	-3172
Net change in Harvested wood products (HWP)	-1'305	-823	-530	-475	-363	-503	-286	-255	-251	-404
Total LULUCF	-2571	-6354	-5085	-4431	-3258	-3905	-6529	-4322	-3113	-3575

LULUCF	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	kt CO ₂									
Gains of living biomass	-12'675	-12'668	-12'790	-12'685	-12'713	-12'782	-13'234	-13'242	-13'301	-13'426
Losses of living biomass	18'354	12'148	10'107	11'134	11'094	11'428	13'320	13'296	12'380	11'631
Net change in dead organic matter	-649	-852	-317	-1'296	-840	-1'240	-1'154	-559	-934	-1'063
Net change in organic and mineral soils	1'186	811	554	-510	-329	783	-55	471	-145	85
LULUCF (excluding HWP)	6216	-561	-2446	-3357	-2789	-1812	-1123	-34	-1999	-2772
Net change in Harvested wood products (HWP)	-709	-542	-408	-440	-606	-739	-542	-515	-382	-410
Total LULUCF	5507	-1103	-2853	-3797	-3395	-2551	-1665	-548	-2381	-3182

LULUCF	2010	2011	2012	2013	2014	2015	2016	2017	Mean
	kt CO ₂								
Gains of living biomass	-13'317	-13'307	-13'385	-13'331	-13'355	-13'360	-13'398	-13'388	-12'992
Losses of living biomass	12'288	12'242	11'258	11'652	11'978	11'114	10'885	11'559	11'272
Net change in dead organic matter	-1'578	-165	-624	-911	255	-499	-291	-598	-799
Net change in organic and mineral soils	345	206	1'120	549	701	728	749	935	320
LULUCF (excluding HWP)	-2263	-1024	-1632	-2040	-421	-2018	-2055	-1492	-2'199
Net change in Harvested wood products (HWP)	-415	-459	-294	-89	-300	-228	-125	-166	-449
Total LULUCF	-2678	-1482	-1925	-2130	-720	-2246	-2180	-1658	-2'648

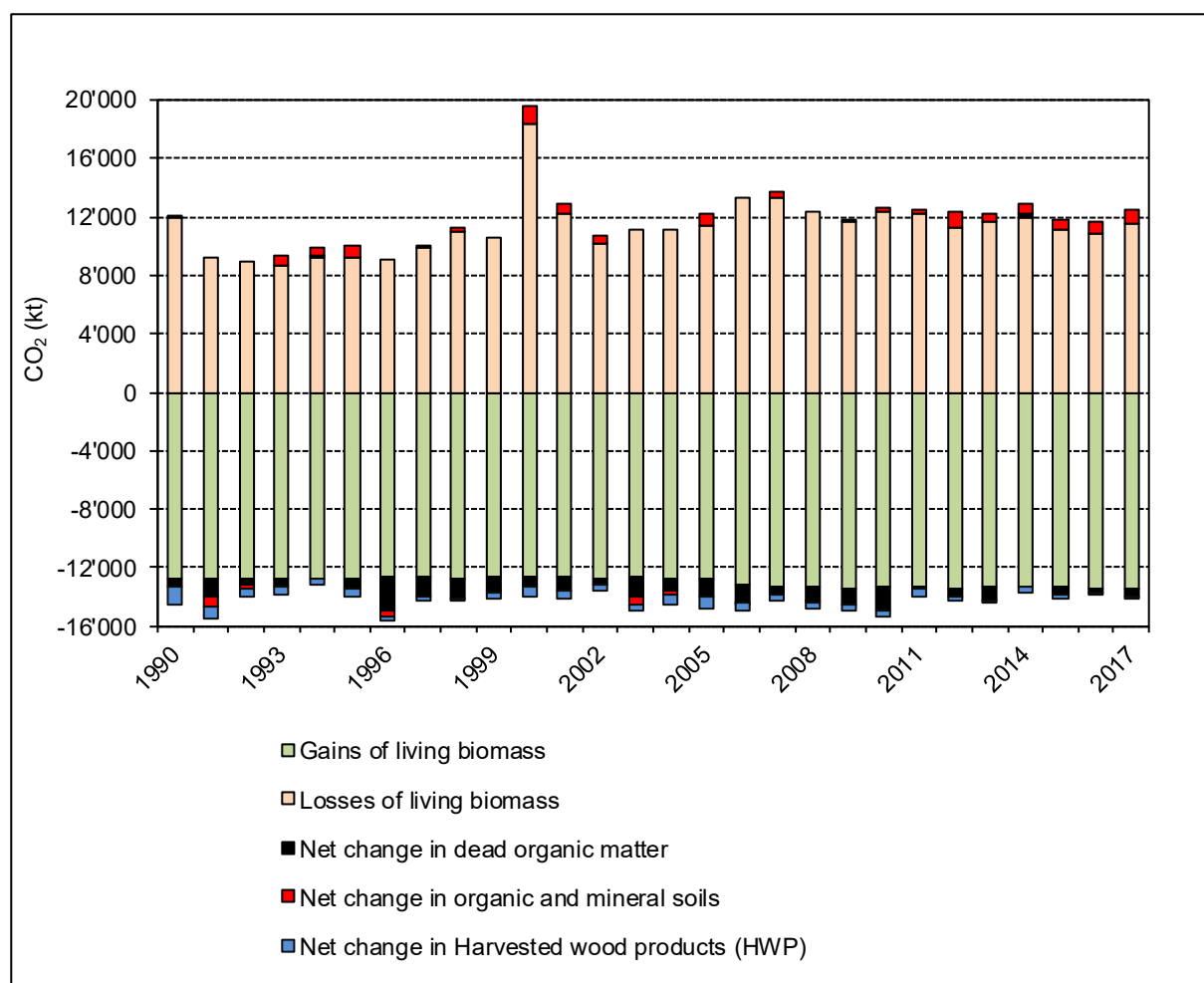


Figure 6-1 CO₂ emissions and removals in the LULUCF sector (in kt CO₂), broken down for: (i) CO₂ removals due to the gain (growth) of living biomass, (ii) CO₂ emissions due to the loss (cut and mortality) of living biomass, (iii) net CO₂ emissions and removals from dead organic matter, (iv) net CO₂ emissions from soils, and (v) net CO₂ removals from Harvested wood products. Positive values indicate emissions, negative values indicate removals.

The non-CO₂ emissions associated with land use, land-use change and forestry were relatively small. Between 1990 and 2017 maximum annual CH₄ emissions were 1.30 kt yr⁻¹, and maximum annual N₂O emissions were 0.20 kt yr⁻¹ (32 kt CO₂ eq and 59 kt CO₂ eq, respectively; see year 1997 in Figure 6-2). The emissions arose from (1) drained organic soils (N₂O; CRF Table4(II)), (2) flooded lands/reservoirs (CH₄; 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 N₂O emissions; CRF Table4(III)), (4) nitrogen leaching and run-off on non-agricultural soils and land-use change (indirect N₂O emissions; CRF Table4(IV)), (5) wildfires on Forest land and Grassland (CH₄ and N₂O; CRF Table4(V)), and (6) controlled burning of residues from forestry (CH₄ and N₂O; CRF Table4(V)). The calculation methods are based on default procedures of IPCC (2006, Volume 4).

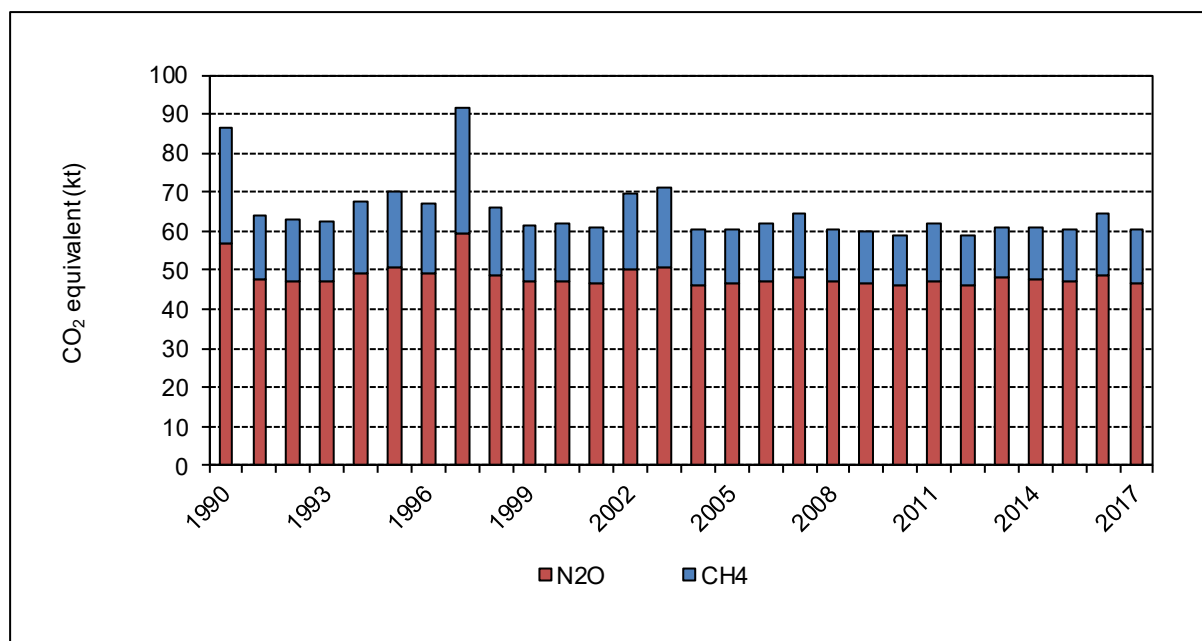


Figure 6-2 N₂O and CH₄ emissions in the LULUCF sector (in kt CO₂ eq).

Figure 6-3 shows the resulting net GHG emissions and removals in the LULUCF sector 1990–2017, including both CO₂ and non-CO₂ (i.e. CH₄, N₂O) fluxes. Further explanatory notes on LULUCF data can be found in chp. 2.3.3 “Emission trends in sector 4 LULUCF”.

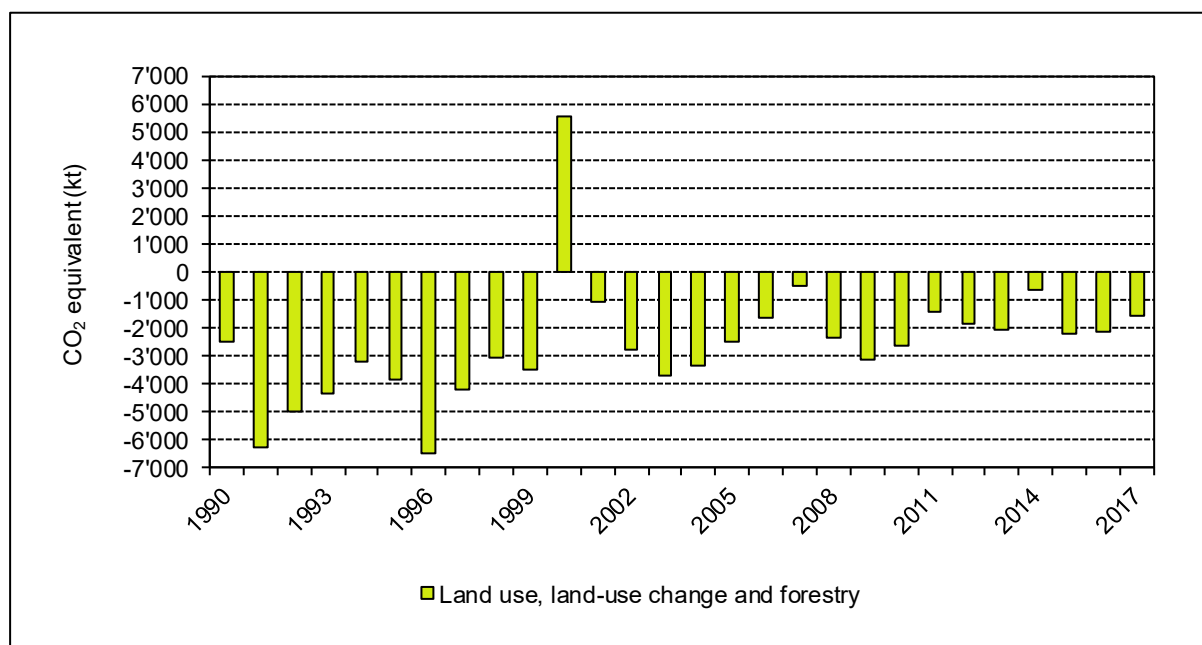


Figure 6-3 Net GHG emissions and removals in the LULUCF sector (in kt CO₂ eq). Positive values refer to net emissions, negative values refer to net removals.

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 ($gainC_l$), the loss of carbon in living biomass ($lossC_l$), the net carbon stock change in dead wood ($changeC_d$), in litter ($changeC_h$), and in soil ($changeC_s$) for each spatial stratum of the combination categories (CC).
For non-Forest land: Measure, model or estimate the gain of carbon in living biomass ($gainC_l$), the loss of carbon in living biomass ($lossC_l$), the net carbon stock change in dead organic matter ($changeC_{dom}$), and in soil ($changeC_s$) 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 (ΔC_l), in dead wood (ΔC_d), in litter (ΔC_h), and in soil (ΔC_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 (ΔC_l), in dead organic matter (ΔC_{dom}), and in soil (ΔC_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 subdivision 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: prod 4A2: productive	12
	unproductive forest	brush forest and forest on unproductive areas meeting the criteria of forest land	4A1: unprod 4A2: unproductive	13
B. Cropland		arable and tillage land (annual crops and leys in arable rotations)	cropland	21
C. Grassland	permanent grassland	meadows, pastures (low-land and alpine)	permanent	31
	shrub vegetation	agricultural and unproductive areas predominantly covered by shrubs	4C1: shrub 4C2: woody	32
	vineyard, low-stem orchard, tree nursery	perennial agricultural plants with woody biomass	4C1: vine 4C2: woody	33
	copse	agricultural and unproductive areas covered by perennial woody biomass including trees	4C1: copse 4C2: woody	34
	orchard	permanent grassland with fruit trees	4C1: orchard 4C2: woody	35
	stony grassland	grass, herbs and shrubs on stony surfaces	4C1: stony 4C2: unproductive	36
	unproductive grassland	unproductive grass vegetation	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):

$\text{stockC}_{l,i,CC}$	carbon stock in living biomass (t C ha^{-1})
$\text{stockC}_{d,i,CC}$	carbon stock in dead wood (t C ha^{-1})
$\text{stockC}_{h,i,CC}$	carbon stock litter (organic soil horizons) (t C ha^{-1})
$\text{stockC}_{s,i,CC}$	carbon stock in soil (t C ha^{-1})
$\text{gainC}_{l,i,CC}$	annual gain (gross growth) of carbon in living biomass ($\text{t C ha}^{-1} \text{ yr}^{-1}$)
$\text{lossC}_{l,i,CC}$	annual loss (cut and mortality) of carbon in living biomass ($\text{t C ha}^{-1} \text{ yr}^{-1}$)
$\text{changeC}_{d,i,CC}$	annual net carbon stock change in dead wood ($\text{t C ha}^{-1} \text{ yr}^{-1}$)
$\text{changeC}_{h,i,CC}$	annual net carbon stock change in litter ($\text{t C ha}^{-1} \text{ yr}^{-1}$)
$\text{changeC}_{s,i,CC}$	annual net carbon stock change in soil ($\text{t C ha}^{-1} \text{ yr}^{-1}$)

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):

$$\text{stockC}_{\text{dom},i,CC} = \text{stockC}_{d,i,CC} + \text{stockC}_{h,i,CC}$$

$$\text{changeC}_{\text{dom},i,CC} = \text{changeC}_{d,i,CC} + \text{changeC}_{h,i,CC}$$

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:

$$\text{deltaC}_{l,i,ba} = (\text{gainC}_{l,i,a} - \text{lossC}_{l,i,a}) * A_{i,ba} \quad (6.1)$$

$$\text{deltaC}_{d,i,ba} = \text{changeC}_{d,i,a} * A_{i,ba} \quad (6.2)$$

$$\text{deltaC}_{h,i,ba} = \text{changeC}_{h,i,a} * A_{i,ba} \quad (6.3)$$

$$\text{deltaC}_{s,i,ba} = \text{changeC}_{s,i,a} * A_{i,ba} \quad (6.4)$$

The stock-difference approach for calculating carbon stock changes is defined as:

$$\text{deltaC}_{l,i,ba} = [(\text{stockC}_{l,i,a} - \text{stockC}_{l,i,b}) / \text{CT}] * A_{i,ba} \quad (6.5)$$

$$\text{deltaC}_{d,i,ba} = [(\text{stockC}_{d,i,a} - \text{stockC}_{d,i,b}) / \text{CT}] * A_{i,ba} \quad (6.6)$$

$$\text{deltaC}_{h,i,ba} = [(\text{stockC}_{h,i,a} - \text{stockC}_{h,i,b}) / \text{CT}] * A_{i,ba} \quad (6.7)$$

$$\text{deltaC}_{s,i,ba} = [(\text{stockC}_{s,i,a} - \text{stockC}_{s,i,b}) / \text{CT}] * A_{i,ba} \quad (6.8)$$

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. 6.8.2.3). 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 to 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 KP and UNFCCC	gain-loss	gain-loss	gain-loss	gain-loss	
CC13 to CC12 UNFCCC: 4A1 KP: Forest management	gain-loss	stock-diff., 20	stock-diff., 20	gain-loss	
CC12 to CC13 UNFCCC: 4A1 KP: Forest management	stock-diff., 20	stock-diff., 20	stock-diff., 20	gain-loss	
CC11 to CC12 UNFCCC: 4A1 KP: Afforestation >20 yr	gain-loss	gain-loss	gain-loss	gain-loss	
change to CC11 UNFCCC: 4A2 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 UNFCCC: 4A2 KP: Forest management	gain-loss	stock-diff., 20	stock-diff., 20	gain-loss	
change to CC51 UNFCCC: 4E2 KP: Deforestation	stock-diff., 1	stock-diff., 1	stock-diff., 20 (20%)	stock-diff., 20 (20%)	Soil carbon stock reduced by 20% (buildings and constructions; sealed areas)
change to CC52-54 UNFCCC: 4E2 KP: Deforestation	stock-diff., 1	stock-diff., 1	stock-diff., 20	gain-loss	Unsealed settlement areas
change to CC21 UNFCCC: 4B2 KP: Deforestation	stock-diff., 1	stock-diff., 1	stock-diff., 20	gain-loss	Cropland
change to CC31-37 UNFCCC: 4C2 KP: Deforestation	stock-diff., 1	stock-diff., 1	stock-diff., 20	gain-loss	Grassland
change to CC41 UNFCCC: 4D2 KP: Deforestation	stock-diff., 1	stock-diff., 1	stock-diff., 1	gain-loss	Surface water
change to CC42 UNFCCC: 4D2 KP: Deforestation	stock-diff., 1	stock-diff., 1	stock-diff., 20	gain-loss	Unproductive wetland
change to CC61 UNFCCC: 4F2 KP: Deforestation	stock-diff., 1	stock-diff., 1	stock-diff., 20	stock-diff., 20	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 ($\text{stockC}_{s,i,a} - \text{stockC}_{s,i,b}$) 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). 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). Note: 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 (chapter 1 in FOEN 2019f) 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 ΔC are accordingly summarised. Positive values of $\Delta C_{l,i,ba}$ were inserted in the column "Gains" and negative values in the column "Losses", respectively. The values of $\Delta C_{d,i,ba}$, $\Delta C_{h,i,ba}$ 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 $\Delta C_{dom,i,ba}$ were inserted into columns "Net carbon stock change in dead organic matter" in the reporting tables Table4.B to Table4.F. The values of $\Delta C_{s,i,ba}$ 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 Carbon stocks and stock changes at a glance

Table 6-4 lists carbon stocks, gains, losses and net changes of carbon for the pools living biomass, dead wood, litter and soil stratified by combination category (CC) and spatial strata for the year 1990. The values remain constant during the inventory period 1990–2017 with the following exceptions (highlighted cells):

- Carbon stock, gain and loss of living biomass, carbon stock and net change in dead wood, net change in litter, and net change in mineral soils of productive forest (CC12): Derivation of the data and the annual values are described in chp. 6.4.2.5, chp. 6.4.2.6 and chp. 6.4.2.7.
- Carbon stock, gain and loss of living biomass of cropland (CC21): Annual data of CC21 are listed in chp. 6.5.2.
- Carbon stocks and net changes of carbon stocks in mineral soils under Cropland and permanent grassland: Derivation of the data and the annual values are described in chp. 6.5.2.3 / 6.5.2.4.3 and chp. 6.6.2.3 / 6.6.2.4.

The derivation of the individual carbon stocks and emission factors is explained in detail in chapters 6.4 to 6.9. Positive values refer to gains in carbon stock, negative values refer to losses in carbon stock.

Table 6-4 Carbon stocks and changes in living biomass, in dead wood, in litter and in soils for the combination categories (CC), stratified by elevation zone, NFI production region, and soil type. The values are valid for the whole inventory period since 1990 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 z	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)	Gain of living biomass (gainCl,i)	Loss of 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	82.65	145.6	2.39	-0.21	0	0	0	-2.6
	1	2	10.00	0	0	102.03	145.6	2.39	-0.21	0	0	0	-2.6
	1	3	7.50	0	0	121.34	145.6	1.35	-0.1	0	0	0	-2.6
	2	1	10.00	0	0	55.40	145.6	2.39	-0.21	0	0	0	-2.6
	2	2	10.00	0	0	62.12	145.6	2.39	-0.21	0	0	0	-2.6
	2	3	7.50	0	0	122.00	145.6	1.35	-0.1	0	0	0	-2.6
	3	1	10.00	0	0	66.10	145.6	2.39	-0.21	0	0	0	-2.6
	3	2	10.00	0	0	75.91	145.6	2.39	-0.21	0	0	0	-2.6
	3	3	7.50	0	0	95.78	145.6	1.35	-0.1	0	0	0	-2.6
	4	1	10.00	0	0	66.47	145.6	2.39	-0.21	0	0	0	-2.6
	4	2	10.00	0	0	74.39	145.6	2.39	-0.21	0	0	0	-2.6
	4	3	7.50	0	0	69.48	145.6	1.35	-0.1	0	0	0	-2.6
	5	1	10.00	0	0	102.37	145.6	2.39	-0.21	0	0	0	-2.6
	5	2	10.00	0	0	108.99	145.6	2.39	-0.21	0	0	0	-2.6
	5	3	7.50	0	0	107.08	145.6	1.35	-0.1	0	0	0	-2.6
12 Productive forest	1	1	128.65	4.86	9.51	82.65	145.6	3.60	-2.38	0.02	-0.11	0.00	-2.6
	1	2	125.27	5.24	7.53	102.03	145.6	3.21	-2.28	0.03	-0.06	0.00	-2.6
	1	3	84.74	4.54	7.76	121.34	145.6	1.95	-1.36	-0.03	-0.16	0.00	-2.6
	2	1	134.51	8.10	8.70	55.40	145.6	4.63	-4.77	0.03	-0.13	0.00	-2.6
	2	2	147.20	7.79	11.42	62.12	145.6	4.63	-4.61	0.03	-0.09	0.00	-2.6
	2	3	102.11	7.79	11.42	122.00	145.6	1.60	-1.05	0.03	-0.09	0.00	-2.6
	3	1	135.07	7.61	7.51	66.10	145.6	4.56	-3.35	0.09	-0.01	0.00	-2.6
	3	2	147.49	7.61	16.29	75.91	145.6	4.15	-3.78	0.09	-0.01	0.00	-2.6
	3	3	118.79	6.00	26.21	95.78	145.6	2.48	-2.75	0.02	-0.03	0.00	-2.6
	4	1	92.97	5.67	3.15	66.47	145.6	3.24	-3.19	0.09	0.01	0.00	-2.6
	4	2	103.37	5.67	19.99	74.39	145.6	2.49	-2.59	0.09	0.01	0.00	-2.6
	4	3	94.98	5.14	33.37	69.48	145.6	1.81	-2.47	0.11	0.11	0.00	-2.6
	5	1	72.68	2.22	8.22	102.37	145.6	2.74	-0.92	0.07	0.02	0.00	-2.6
	5	2	76.85	2.08	11.03	108.99	145.6	2.20	-0.61	0.07	0.14	0.00	-2.6
	5	3	76.43	1.76	30.77	107.08	145.6	1.61	-0.30	0.02	0.15	0.00	-2.6
13 Unproductive forest	1	1	38.53	0	9.51	82.65	145.6	0	0	0	0	0	-2.6
	1	2	51.10	0	7.53	102.03	145.6	0	0	0	0	0	-2.6
	1	3	51.34	0	7.76	121.34	145.6	0	0	0	0	0	-2.6
	2	1	20.45	0	8.70	55.40	145.6	0	0	0	0	0	-2.6
	2	2	35.83	0	11.42	62.12	145.6	0	0	0	0	0	-2.6
	2	3	51.33	0	11.42	122.00	145.6	0	0	0	0	0	-2.6
	3	1	20.45	0	7.51	66.10	145.6	0	0	0	0	0	-2.6
	3	2	47.53	0	16.29	75.91	145.6	0	0	0	0	0	-2.6
	3	3	42.36	0	26.21	95.78	145.6	0	0	0	0	0	-2.6
	4	1	21.60	0	3.15	66.47	145.6	0	0	0	0	0	-2.6
	4	2	31.48	0	19.99	74.39	145.6	0	0	0	0	0	-2.6
	4	3	29.88	0	33.37	69.48	145.6	0	0	0	0	0	-2.6
	5	1	20.83	0	8.22	102.37	145.6	0	0	0	0	0	-2.6
	5	2	23.82	0	11.03	108.99	145.6	0	0	0	0	0	-2.6
	5	3	24.35	0	30.77	107.08	145.6	0	0	0	0	0	-2.6

(Table 6-4 continued)

Combination category (CC)	NFI region	Elevation zone z	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)	Gain of living biomass (gainCl,i)	Loss of 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]					
21 Cropland	n.s.	1	3.51	0	0	49.91	240	0.06	0.00	0	0	0.08	-9.52
	n.s.	2	3.57	0	0	49.45	240	0.06	0.00	0	0	0.00	-9.52
	n.s.	3	3.70	0	0	40.38	240	0.08	0.00	0	0	0.18	-9.52
31 Permanent Grassland	n.s.	1	4.98	0	0	59.40	240	0	0	0	0	-0.01	-9.52
	n.s.	2	4.82	0	0	60.95	240	0	0	0	0	-0.09	-9.52
	n.s.	3	6.50	0	0	49.05	240	0	0	0	0	0.26	-9.52
32 Shrub Vegetation	n.s.	1	20.45	0	0	62.02	240	0	0	0	0	0	-5.3
	n.s.	2	20.45	0	0	67.50	240	0	0	0	0	0	-5.3
	n.s.	3	20.45	0	0	75.18	240	0	0	0	0	0	-5.3
33 Vineyards et al.	n.s.	n.s.	5.36	0	0	53.40	240	0	0	0	0	0	-9.52
34 Copse	n.s.	1	20.45	0	0	62.02	240	0	0	0	0	0	-5.3
	n.s.	2	20.45	0	0	67.50	240	0	0	0	0	0	-5.3
	n.s.	3	20.45	0	0	75.18	240	0	0	0	0	0	-5.3
35 Orchards	n.s.	n.s.	22.73	0	0	64.76	240	0	0	0	0	0	-9.52
36 Stony Grassland	n.s.	n.s.	7.16	0	0	26.31	240	0	0	0	0	0	-5.3
37 Unproductive Grassland	n.s.	n.s.	6.40	0	0	68.23	240	0	0	0	0	0	-5.3
41 Surface Waters	n.s.	n.s.	0	0	0	0	240	0	0	0	0	0	0
42 Unproductive Wetland	n.s.	n.s.	6.50	0	0	68.23	240	0	0	0	0	0	-5.3
51 Buildings, Constructions	n.s.	n.s.	0	0	0	0	0	0	0	0	0	0	0
52 Herbaceous Biomass in S.	n.s.	n.s.	9.54	0	0	53.40	240	0	0	0	0	0	-9.52
53 Shrubs in Settlements	n.s.	n.s.	15.43	0	0	53.40	240	0	0	0	0	0	-5.3
54 Trees in Settlements	n.s.	n.s.	20.72	0	0	53.40	240	0	0	0	0	0	-5.3
61 Other Land	n.s.	n.s.	0	0	0	0	0	0	0	0	0	0	0

Legend	
Elevation zones:	NFI regions:
1 < 601 m	1 Jura
2 601 - 1200 m	2 Central Plateau
3 > 1200 m	3 Pre-Alps
	4 Alps
	5 Southern Alps

n.s. = no stratification
Annual data

6.1.5 Uncertainty estimates

Table 6-5 gives an overview of uncertainty estimates of activity data (AD) and of emission factors (EF). The term emission factor is not quite appropriate for categories 4A–4G as the basic processes are carbon stock changes (CSC) causing either emissions or removals of CO₂.

For categories 4A–4F, the uncertainties of AD mainly depend on the uncertainty of the AREA survey data (highlighted in yellow; see chp. 6.3.3, Table 6-10). For categories 4D1, 4(II)–4(V) and 4G other data sources are relevant, e.g. for 4D1 it is the uncertainty of the area of organic soils. They are presented in detail in the respective chapters (6.X.3) of the LULUCF categories, along with the uncertainty estimates for EF.

In general, AD uncertainty is lower than EF uncertainty, because AD are mostly based on a systematic survey with high spatial resolution (such as AREA), while EFs include parameters that are difficult to measure or to model such as carbon stocks in biomass, growth rates and biogeochemical processes.

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.

IPCC category		Gas	AD uncertainty	EF/CSC uncertainty 1990	EF/CSC uncertainty 2017
			%	%	
4A1	Forest land remaining forest land	CO ₂	1.1	88.6	88.6
4A2	Land converted to forest land	CO ₂	1.5	88.6	88.6
4B1	Cropland remaining cropland	CO ₂	4.9	228.9	62.8
4B2	Land converted to cropland	CO ₂	5.1	68.9	97.1
4C1	Grassland remaining grassland	CO ₂	5.2	458.7	374.7
4C2	Land converted to grassland	CO ₂	5.3	49.4	38.4
4D1	Wetlands remaining wetlands	CO ₂	61.9	72.2	72.2
4D2	Land converted to wetlands	CO ₂	3.9	22.1	19.1
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 ₂ O	34.1	66.9	66.9
4(II)D2	Flooded land	CH ₄	10.0	70.0	70.0
4(III)	N mineralization	N ₂ O	83.5	135.0	135.0
4(IV)2	N leaching and runoff	N ₂ O	85.8	161.5	161.5
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 ₂ O	30.0	70.0	70.0
4G	Harvested wood products	CO ₂	4.5	57.0	57.0

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 the AREA surveys (see chp. 6.3.1), every sample point on a hectare-mesh in Switzerland was 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 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 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 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 Table 4.1. 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.

Land Use (NOLU04) acc. to AREA		Combination Categories (CC)																	
Land Cover (NOLC04) acc. to AREA	Settlement and urban areas	Combination Categories (CC)																	
		10 Artificial areas	11 Sealed surfaces	12 Buildings	13 Greenhouses	14 Gardens with border and patch structures	15 Lawns	16 Trees in artificial areas	17 Mix of small structures	20 Grass and herb vegetation	21 Grass and herb vegetation	30 Brush vegetation	31 Shrub	32 Brush meadows	33 Short-stem fruit trees	34 Vines	35 Permanent garden plants and brush crops	40 Tree vegetation	41 Closed forest
18 Combination Categories (CC)	Settlement and urban areas	101 Industrial and commercial areas > 1 ha	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		102 Industrial and commercial areas < 1 ha	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		103 Residential areas (one and two-family houses)	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		104 Residential areas (terraced houses)	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		105 Residential areas (blocks of flats)	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		106 Public buildings and surroundings	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		107 Agricultural buildings and surroundings	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		108 Unspecified buildings and surroundings	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		109 Unspecified buildings and surroundings	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		110 Unspecified buildings and surroundings	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		111 Unspecified buildings and surroundings	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		112 Unspecified buildings and surroundings	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		113 Unspecified buildings and surroundings	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		114 Unspecified buildings and surroundings	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		115 Unspecified buildings and surroundings	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		116 Unspecified buildings and surroundings	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		117 Unspecified buildings and surroundings	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		118 Unspecified buildings and surroundings	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		119 Unspecified buildings and surroundings	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		120 Unspecified buildings and surroundings	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		121 Motorways	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		122 Roads	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		123 Parking areas	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		124 Railway surface	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		125 Airports and airfields	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		126 Energy supply plants	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		127 Waste treatment plants	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		128 Other supply or waste treatment plants	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		129 Quarries, mines	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		130 Construction sites	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		131 Unexploited urban areas	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		132 Public parks	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		133 Sport facilities	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		134 Camping areas	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		135 Garden allotments	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		136 Cemeteries	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		137 Agricultural areas	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		138 Orchards	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		139 Vineyards	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		140 Horticuture	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		141 Arable land, in general	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		142 Semi-natural grassland, in general	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		143 Farm pastures, in general	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		144 Alpine meadows, in general	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		145 Alpine pastures, in general	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		146 Alpine sheep grazing pastures, in general	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		147 Forest	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		148 Afforestation	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		149 Damaged forest	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		150 Lumbering areas	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		151 Unproductive areas	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		152 Lakes	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		153 Streams, rivers	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		154 Flood protection structures	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		155 Unused	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		156 Avalanche and rockfall protection structures	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		157 Alpine sport facilities	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
		158 Landscape intervention	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51

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.

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 a ranges of SOC and peat depth that are wider than those given in the IPCC 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 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.

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.

Forest production region

Forest land was furthermore differentiated into the five production regions of the National Forest Inventory (EAFV/BFL 1988; Brassel and Brändli 1999; Brändli 2010). The NFI production regions were adopted from EAFV/BFL (1988) as shown in Figure 6-4:

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 carbon emissions and removals.

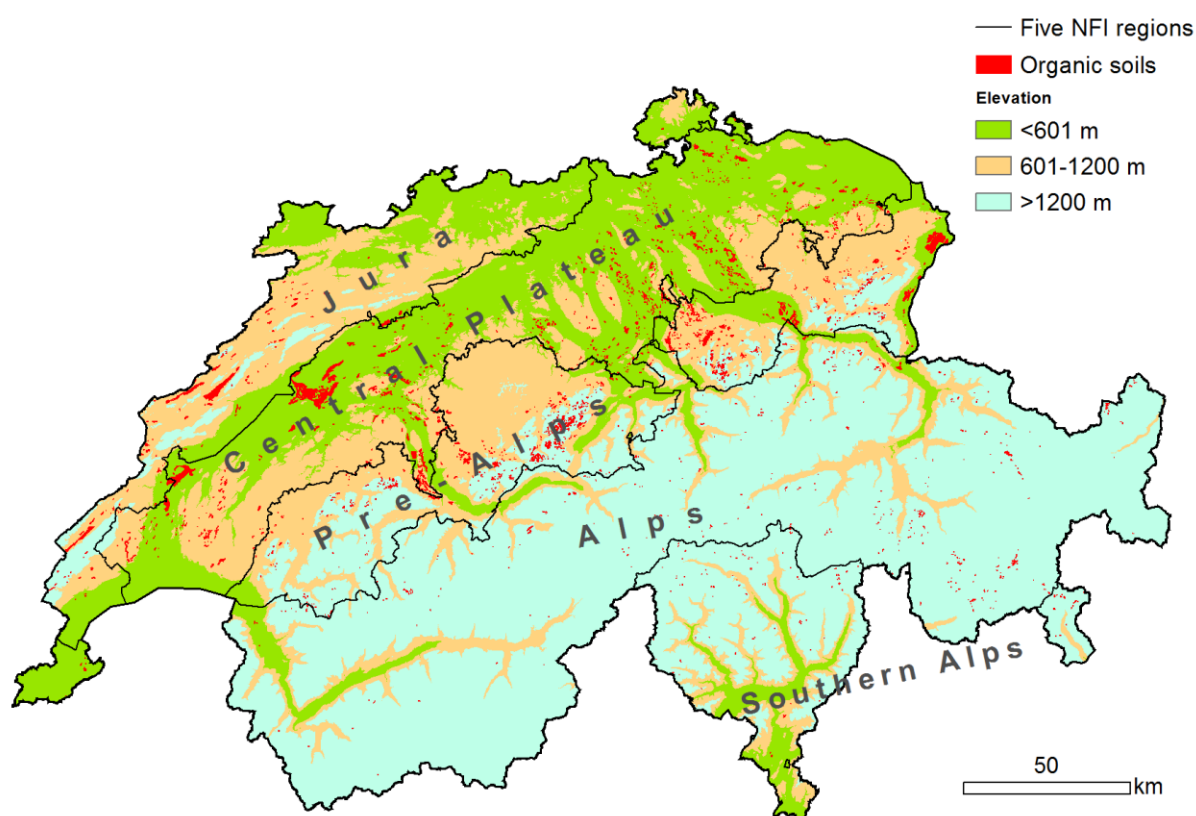


Figure 6-4 Map showing the spatial stratification according to NFI production region, elevation zone, and soil type.

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. The country's total area is 4'129'052 ha (SFSO 2018).

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	161.2	21.4	173.3	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 2017. For example, the area of afforestations (CC11) decreased by 82% during this period, while the area of productive forests (CC12) increased by 4%. The area of CC11 is decreasing because on the one hand afforestations activities slowed down over the inventory period (see Table 6-9) and because on the other hand most of the afforestations turn to 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 2017, in kha. The country's total area is 4'129'052 ha (SFSO 2018).

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	104.5	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	1115.4	105.1	428.0	931.6	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	1117.2	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	105.5	424.2	931.8	152.7	26.4	83.4	1.3	150.5	65.4	161.6	25.2	184.2	71.9	4.2	26.2	593.0	4129.1
1997	2.8	1120.2	105.6	422.1	932.1	152.3	26.3	82.5	1.2	150.4	65.2	161.7	25.2	185.8	72.7	4.2	26.1	592.6	4129.1
1998	2.6	1121.5	105.7	420.1	932.5	152.1	26.2	81.5	1.2	150.4	65.1	161.7	25.2	187.3	73.5	4.2	26.0	592.2	4129.1
1999	2.4	1122.8	105.8	418.1	932.8	151.9	26.1	80.6	1.2	150.5	64.9	161.8	25.2	188.8	74.4	4.2	25.9	591.9	4129.1
2000	2.2	1124.1	105.9	416.1	933.1	151.7	26.1	79.7	1.1	150.5	64.7	161.8	25.2	190.3	75.2	4.2	25.8	591.5	4129.1
2001	2.0	1125.4	106.0	414.0	933.4	151.5	26.0	78.7	1.1	150.5	64.5	161.8	25.3	191.8	76.0	4.2	25.7	591.1	4129.1
2002	1.7	1126.7	106.1	412.0	933.7	151.3	25.9	77.8	1.1	150.6	64.4	161.9	25.3	193.4	76.8	4.2	25.6	590.7	4129.1
2003	1.5	1128.0	106.1	410.0	934.1	151.1	25.8	76.9	1.1	150.6	64.2	161.9	25.3	194.9	77.7	4.2	25.4	590.3	4129.1
2004	1.3	1129.3	106.2	408.0	934.4	150.9	25.7	75.9	1.0	150.6	64.0	162.0	25.3	196.4	78.5	4.2	25.3	590.0	4129.1
2005	1.2	1130.7	106.2	406.4	934.1	150.7	25.6	75.0	1.0	150.7	63.9	162.0	25.3	198.0	79.3	4.2	25.2	589.7	4129.1
2006	1.0	1132.1	106.3	404.6	933.9	150.6	25.6	74.0	1.0	150.8	63.7	162.1	25.3	199.6	79.9	4.2	25.2	589.4	4129.1
2007	0.9	1133.6	106.3	402.9	933.6	150.5	25.5	73.1	1.0	150.8	63.6	162.1	25.3	201.2	80.4	4.2	25.2	589.0	4129.1
2008	0.8	1135.7	106.6	401.3	933.2	150.2	25.4	72.2	0.9	151.0	63.3	162.2	25.3	202.7	80.6	4.1	25.3	588.2	4129.1
2009	0.8	1137.5	106.8	399.6	932.5	150.0	25.4	71.6	0.9	151.1	63.1	162.3	25.3	204.2	80.8	4.1	25.6	587.5	4129.1
2010	0.8	1138.9	106.9	397.9	931.7	149.9	25.3	71.2	0.9	151.2	62.9	162.3	25.4	205.8	81.1	4.1	25.9	587.0	4129.1
2011	0.7	1140.3	107.0	396.2	930.9	149.8	25.2	70.8	0.9	151.3	62.7	162.3	25.4	207.4	81.3	4.1	26.1	586.5	4129.1
2012	0.7	1141.7	107.1	394.4	930.1	149.7	25.2	70.4	0.9	151.4	62.6	162.4	25.4	208.9	81.6	4.1	26.4	586.0	4129.1
2013	0.7	1143.3	107.4	393.3	929.0	149.6	25.0	69.8	0.9	151.5	62.4	162.4	25.4	210.6	81.7	4.1	26.4	585.5	4129.1
2014	0.7	1145.2	107.8	392.5	927.7	149.3	24.9	69.3	0.9	151.7	62.2	162.4	25.3	212.2	81.7	4.1	26.4	584.6	4129.1
2015	0.7	1147.1	108.2	392.6	925.5	149.1	24.8	68.6	0.9	151.8	62.0	162.5	25.3	213.8	82.0	4.0	26.3	583.8	4129.1
2016	0.7	1148.7	108.6	392.5	923.4	148.9	24.7	68.1	0.9	152.0	61.8	162.5	25.3	215.3	82.4	4.0	26.2	583.1	4129.1
2017	0.7	1150.1	108.7	390.9	922.5	148.8	24.6	67.7	0.9	152.1	61.6	162.6	25.3	216.8	82.7	4.0	26.5	582.7	4129.1
Change:	-82	4	4	-10	-2	-4	-7	-24	-45	0	-7	1	1	24	21	1	6	-2	0

The annual land-use changes across the entire territory of Switzerland (change-matrices, see examples for 1990 and 2017 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 2019). 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 2017 (change matrices). Units: ha/year, rounded values. Empty cells indicate that no change occurred.

1990		change to CC																		
		11	12	13	21	31	32	33	34	35	36	37	41	42	51	52	53	54	61	decrease
change from CC	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

2017		change to CC																		
		11	12	13	21	31	32	33	34	35	36	37	41	42	51	52	53	54	61	decrease
change from CC	11		56	0			0								0		0			57
	12			338	1	240	113	3	78	0	31	19	20	18	94	27	9	13	65	1069
	13		798		2	404	82	2	88	0	8	3	1	3	28	16	2	11	12	1460
	21	1	1	2		2301	5	159	41	5	5	7	5	9	468	224	9	6	14	3262
	31	12	143	511	1448		977	82	360	4	86	44	9	15	802	450	18	17	75	5052
	32	2	724	583	2	148		3	348		25	13	7	1	12	4	2	1	35	1910
	33	0	4	2	122	95	4		32	2	0	1		0	34	26	2	2	4	330
	34	1	552	71	36	556	52	9		7	10	21	7	1	82	53	2	27	16	1502
	35				1	7		1	17						1	0				26
	36	0	23	27	1	125	240	0	51			64	4	1	5	1			54	595
	37	2	17	3	0	7	224		67		20		3	1	4	1			13	362
	41	0	4	1	0	1	6		3		4	4		14	5	1	0	0	113	157
	42		37	7	0	1	0		2		0	0	7		1	1	0	1	1	59
	51	15	17	2	55	147	9	2	5		7	9	6	3		358	54	41	8	737
	52	8	6	1	16	52	3	1	3		1	3	2	2	520		73	533	1	1224
	53	2	19	0	4	8	4	0	1		0	1	0	0	53	44		55		192
	54	1	9	1	0	2	0		4			0	0	1	135	307	26			488
	61	0	32	14	9	67	87	5	37		488	18	110	2	6	0				875
	increase	46	2443	1564	1697	4162	1805	267	1136	18	686	206	181	69	2249	1513	198	707	410	19355

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 2018) form the basis of activity data. In the course of the AREA surveys, every hectare of Switzerland's territory (4'129'052 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 four datasets were used:

- 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: 51% of territory processed.

The aerial photos for AREA1, AREA2 and AREA3 were taken 1977–1986, 1990–1998 and 2004–2009, 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 AREA4 survey was started in 2014. In this submission data based on aerial photos taken 2012–2017 were included.

The website <https://map.geo.admin.ch> allows a visualization of the completed AREA surveys. See the example <https://s.geo.admin.ch/8054e4be63> for the change in direct neighbourhood of a FOEN building in Bern-Ittigen (Legend: yellow cross represents sample point; circles represent land cover, squares represent land use, from left to right for AREA1, AREA2 and AREA3, respectively). Click circles and squares 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).

The inter-survey period is not identical throughout the Swiss territory, but varies regionally. It averages approximately 12 years for AREA1, AREA2 and AREA3; for AREA4 the period will be shorter, 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.

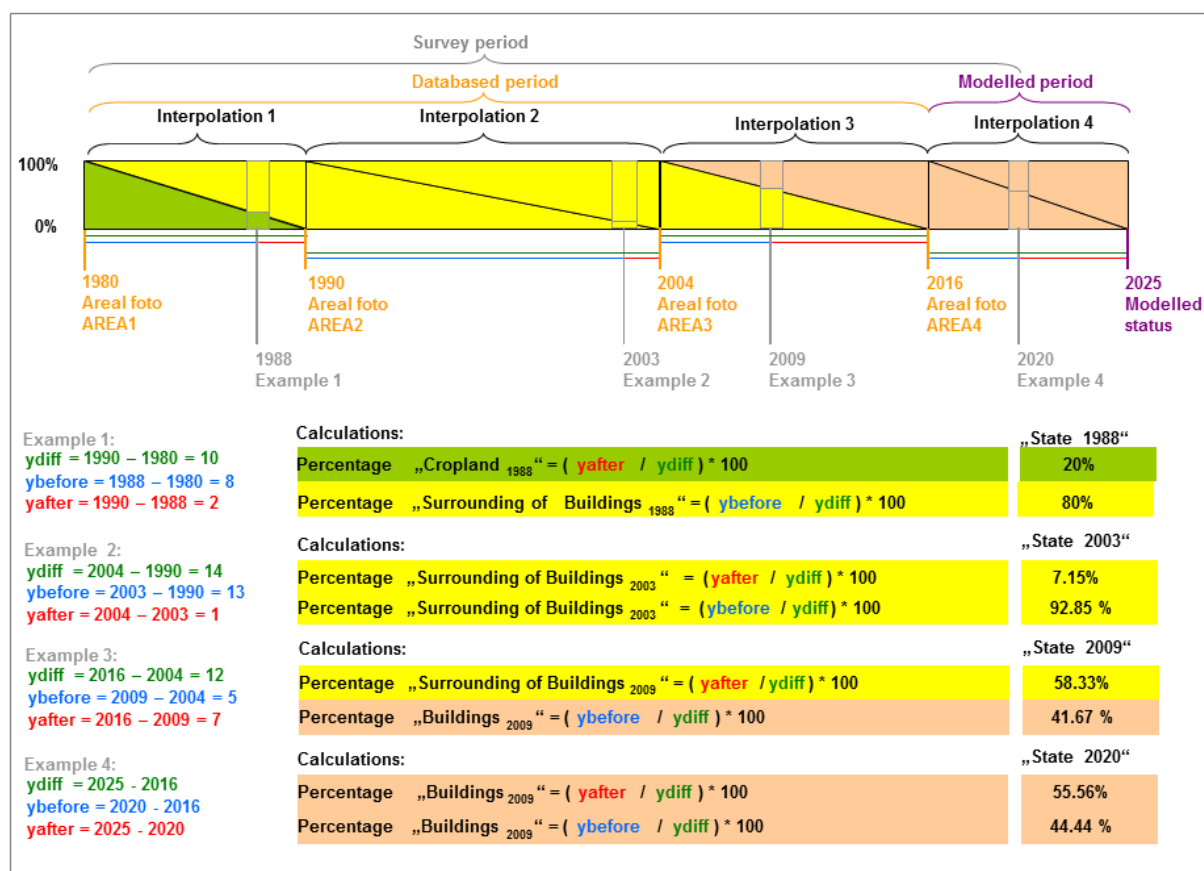


Figure 6-5 Hypothetical development of land use for a supposed survey period 1980–2020. The linear land-use changes between AREA1, AREA2, AREA3 and AREA4 considering as example a hectare changing from “Cropland” to “Surrounding of Buildings” and later from “Surrounding of Buildings” to “Buildings”. For 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”).

After completion, AREA4 will comprehend aerial photos from 2012–2018.

To obtain consistent and complete nationwide data for each year during the ongoing AREA4 survey two analyses are required:

1) For those hectares that currently have no data in AREA4, the land-use states after AREA3 were interpolated between AREA3 and a "virtual" 4th survey (AREA4v). AREA4v was modelled for each sample point using a Markov-chain approach, where transition probabilities between AREA3 and AREA4v were assessed based on the transition distribution between AREA2 and AREA3 within each spatial stratum (Sigmaplan 2019).

2) For those hectares that were already covered by AREA4, the land-use states after the flight year of AREA4 were interpolated between AREA4 and a "virtual" 5th survey (AREA5v). AREA5v was modeled 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 2019). Therefore, the land-use changes occurring after the flight year of AREA4 (i.e. when it was covered) were calculated from the linear development detected between AREA4 and the virtual 5th 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 for activity data (AD) and emission factors (or biomass parameters) is shown in Table 6-5. Details related to uncertainties of AREA data are presented in this chapter, while uncertainties of other AD (such as consumption of Harvested wood products) and uncertainties of 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 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 2018) 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

$$U_{\text{sampling}} = 100 * 1.96 * (\text{number of points})^{-0.5}$$

The number of sampling points lies between 2'606 (for 4D2) and 1'350'768 (for 4C1) leading to values of U_{sampling} between 3.8% and 0.2%.

The overall uncertainty was calculated as:

$$U_{\text{overall}} = (U_{\text{interpret}}^2 + U_{\text{sampling}}^2)^{0.5}$$

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 (2018); uncertainties of 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	1.6	5.1
4C1	Grassland remaining grassland	5.2	0.2	5.2
4C2	Land converted to grassland	5.2	0.9	5.3
4D1	Wetlands remaining wetlands	0.9	0.5	1.0
4D2	Land converted to wetlands	0.9	3.8	3.9
4E1	Settlements remaining settlements	4.4	0.4	4.4
4E2	Land converted to settlements	4.4	1.2	4.6
4F1	Other land remaining other land	1.4	0.3	1.4
4F2	Land converted to other land	1.4	2.9	3.2

An analysis of the uncertainty of the spatial allocation of organic soils published by Wüst-Galley et al. (2015) resulted in: 27.4% for forest land, 37.8% for Cropland, 55.9% for Grassland and 61.9% for Wetlands. For Forest land (chp. 6.4.3) and Settlements (chp. 6.8.3) CO₂ emissions from organic soils were not considered in the calculation of the overall uncertainty (Meteotest 2019).

Activity data for wildfires were taken from the Swissfire database (see chapters 6.4.2.12 and 6.6.2.6). 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.

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 (2018) were checked for consistency (Sigmaplan 2019).

The temporal interpolation and extrapolation of the AREA sample is quite a complex procedure, whose internal consistency was checked systematically as described in Sigmaplan (2019). Further checks (interannual comparisons, plausibility) were carried out after producing the land-use change tables presented in chp. 6.2.3.

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 in FOEN (2018; see chp. 11.3.2.2).

The total country area remains constant over the inventory period.

6.3.5 Recalculations of activity data

The AD time series 1990–2016 was updated as a result of the following activities:

- 4A-4F: The most recent land-use data from the fourth area survey (AREA4) were included (SFSO 2018). They are based on aerial photographs from 2012 and 2017. The interpolation and projection procedures were adapted accordingly (see chp. 6.3.2 and Sigmaplan 2019).
- 4A-4F: Along with the AREA4 survey the SFSO continuously performs consistency checks and, where appropriate, corrections in the data of AREA3 (2004–2009).
- 4A-4F: The total area of the country recorded by the AREA survey increased by 10 ha to 4'129'052 ha (SFSO 2018). 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

The uncertainty of Switzerland's activity data for land areas will decrease gradually with the increase in the sample size of the current survey AREA4. Interpretation and further processing of AREA4 is expected to be completed in 2020.

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 phase the design of the land-use categories used in the GHG inventory (i.e. the combination categories CC) will be scrutinised.

6.4 Category 4A – Forest land

6.4.1 Description

Table 6-11 Key categories in category 4A. Combined KCA results, level for 2017 and trend for 1990–2017, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
4A1	Forest land remaining forest land	CO ₂	L1, L2, T1, T2
4A2	Land converted to forest land	CO ₂	L1, L2, T1, T2

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 burned, 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. 6.4.2.8.

6.4.2 Methodological issues

6.4.2.1 Choice of method and National Forest Inventories

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 (2019b) and Didion et al. 2019 (Fig. 15.1) contain a schematic overview and a detailed description of all tree biomass elements reported. Currently not considered in the estimates for living biomass, dead wood, and litter are (1) trees with DBH <12 cm with branches, foliage, and roots, and (2) non-tree understory vegetation including shrubs, ferns, grasses, sedges, and herbs.

The four available Swiss National Forest Inventories (NFIs) are NFI1, NFI2, NFI3, and NFI4 (see Table 6-12). A description of NFI1 and NFI2 methodologies can be found in EAFV/BFL (1988) and in Brassel and Brändli (1999). Data and methodology of NFI3 are described in Brändli (2010). The inventories NFI1, NFI2 and NFI3 were based on full surveys that were repeated in intervals of approximately 10 years. The fourth inventory (NFI4, 2009–2017) is carried out as a continuous survey where annually a nationally representative subsample of approximately 12% of the Swiss forests is surveyed and evaluated. Otherwise, the methodology remained identical to Brändli (2010). 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 and NFI4 (2013–2017), accessible forest plots without brush forest.

	NFI1	NFI2	NFI3	NFI4 (2013-2017)
Inventory cycle	1983-1985	1993-1995	2004-2006	2013-2017
Grid size	1 x 1 km	1.4 x 1.4 km	1.4 x 1.4 km	1.4 x 1.4 km
Terrestrial sample plots	10'981	6'412	6'608	3'347
Measured single trees	128'441	76'394	77'959	39'496

Data for growing stock (in carbon mass of total living biomass) were estimated for a particular inventory. Gross growth (gain in carbon stock of total living biomass), cut and mortality (loss in carbon stock of total living biomass), and dead wood and litter production were based on the observed changes between two consecutive inventories (chp. 6.4.2.3, 6.4.2.5, and 6.4.2.6; see Table 4 and 5 in Thürig et al. 2018; chp. 2.3.3 in Didion and Thürig 2018). Carbon stock changes between two inventories are 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.

For assembling the results for the GHG inventory 1990–2017, NFI4 data for the years 2013–2017 were available in addition to the data from NFI1, NFI2, and NFI3, and the respective inventory periods NFI1-2, NFI2-3, and NFI3-4 (2013-2017). Results on growing stock based on the 5-year subset of the NFI4 and for growth and cut and mortality based on the inventory period NFI34 (2013-2017) were summarised in the data release NFI4 (2013–2017) (Thürig et al. 2018).

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 and Thürig, 2018). Data from the total number of plots is used to calculate carbon stock changes between two inventories. Footnote 1: not applicable in this first NFI period; footnote 2: for the period NFI3-4 only sample plots common to NFI3 and the sample plots in NFI4 visited in the years 2013 to 2017 were considered.

NFI period	Forest in previous period	Converted to forest since previous period	Total for period
	Number of sample plots		
NFI1-2	NA ¹	NA ¹	5456
NFI2-3	5370	211	5581
NFI3-4 (2013-2017) ²	3'046	165	3'211

Consequences following the use of NFI4 data (2013–2017; this submission) instead of NFI4 data (2011–2015; FOEN 2018)

Most recent NFI4 data from the years 2013 to 2017 were available for this submission resulting in an update of the estimate of biomass in growing stock and requiring a recalculation of the time series of carbon stock changes for living biomass since 2006. The differences between data reported in FOEN (2018) and in this submission were described in detail in Thürig et al. (2018). The estimate of biomass in growing stock was $0.57 \text{ t} \pm 4.94 \text{ t ha}^{-1}$ higher in the NFI4 (data years 2013-2017; this submission) than in the NFI4 (data years 2011-2015; previous submission). This corresponds to an increase of $+0.22\% \pm 2\%$.

Carbon stock changes (gains and losses) were calculated based on observed changes between two inventories, in this case NFI3 and NFI4, thereby affecting the values since 2006. Gross growth decreased by $-0.11 \pm 0.12 \text{ t ha}^{-1} \text{ yr}^{-1}$ mainly caused by a decrease of gross growth of deciduous trees on the Central Plateau and in the Jura region. This is a decrease of $-1.8 \pm 1\%$. Cut and mortality decreased by $-0.25 \pm 0.32 \text{ t ha}^{-1} \text{ yr}^{-1}$ mainly due to a decrease of losses on the Central Plateau. This is a decrease of $-4.7 \pm 3\%$. The consequences of the use of NFI4 data (2013–2017) instead of NFI4 data (2011–2015) on total carbon stock changes were a shift from 2006 onwards, which is emphasized by the pronounced changes in the activity data from 2006 onwards. However, most changes are within two standard errors or slightly above.

In addition, minor effects on the data for living biomass resulted from revisions following plausibility and consistency checks in the course of regular QA/QC procedures of the NFI database. Adjustments of single tree measurements, data derivations, and data deliveries caused a very small decrease of biomass in growing stock for national estimates (-0.3%) and also in small changes of gross growth ($+0.7\%$) and cut and mortality ($+0.6\%$).

6.4.2.2 Stratification

Spatial strata

Forests in Switzerland reveal a high heterogeneity in terms of elevation, growth conditions, tree species composition, and interannual growth variability. To account for the heterogeneity, the Swiss NFI uses a spatial stratification based on five production regions and three elevation belts (Brändli 2010). To find explanatory variables that significantly reduce the variance of gross growth, an analysis of variance was done (Table 6-14).

Table 6-14 Analysis of variance of gross growth of data from NFI2 and NFI3. Explanatory variables: Tree species, NFI production region, and elevation.

	Gross growth	
	F-value	p-value
Coniferous / broadleaved	421	<0.0001
Production region	45	<0.0001
Elevation	34	<0.0001

The analysis of variance indicated that production region, elevation, and tree species all significantly explain differences in gross growth. Therefore, the explanatory variables considered here were:

- tree species: coniferous and broadleaved species
- the five NFI production regions:
1. Jura, 2. Central Plateau, 3. Pre-Alps, 4. Alps, 5. Southern Alps
- elevation: <601 m, 601–1200 m, >1200 m.

Values for growing stock, gross growth, harvesting and mortality were calculated for each of the resulting 30 strata.

Additional stratification: eastern and western Alps

In the Swiss Alps (NFI production region 4) below an elevation of 1200 m, climate between the eastern and the western part differs substantially. An additional stratification for the eastern and the western part of the Alps below 1200 m (Alps <601 m east, Alps <601 m west, Alps 601–1200 m east, Alps 601–1200 m west) was included; see Thürig et al. 2005a for details). This additional stratification resulted in very small datasets for these four strata in the NFI3-4.

Gains and losses in carbon stock of living biomass were estimated for the eastern and western Alps separately. The emission factors for the Alps below 1200 m were then calculated as a weighted mean of the percentage of forest biomass situated in the western and in the eastern Alps. The ratios for the pooled emission factors correspond to the biomass ratios for the two regions, which were calculated for the three periods between NFI1 and NFI2, NFI2 and NFI3, and NFI3 and NFI4 (2013–2017) (Table 6-15).

Table 6-15 Ratio of biomass in the eastern and western Alps (NFI production region 4) for 1985–1994 (derived from NFI1 and NFI2; source: Brassel and Brändli 1999), for 1995–2005 (derived from NFI2 and NFI3 data; source: Brändli 2010) and for 2006–2017 (derived from NFI3 and NFI4 (2013–2017) data; source: Thürig et al. 2018). For NFI4 (2013–2017), NFI production region 4 <601 m and 601–1200 m were aggregated.

Elevation [m]	1985 - 1994		1995 – 2005		2006-2017	
	NFI1-2 Eastern	NFI1-2 Western	NFI2-3 Eastern	NFI2-3 Western	NFI3-4 Eastern	NFI3-4 Western
<601	0.56	0.44	0.53	0.47	0.58	0.42
601-1200	0.62	0.38	0.61	0.39	0.58	0.42

Aggregation of strata

Since only the data for the years 2013 to 2017 of the continuously sampled NFI4 (see chp. 6.4.2.1) were used in this submission, several spatial strata were represented by a low number of plots (Thürig et al. 2018). Due to the large variability between sample plots a minimum number of sample plots is needed to obtain reliable estimates of means and sampling errors. Smaller strata were thus merged with neighbouring strata for this submission. For NFI4 (2013–2017), the following strata were aggregated 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 (263 plots)
- NFI production region 3 Pre-Alps ≤600 m and 601-1200 m:
new stratum NFI production region 3 Pre-Alps ≤1200 m (368 plots)
- NFI production region 4 Alps West ≤600 m and 601-1200 m:
new stratum NFI production region 4 Alps West ≤1200 m (150 plots)
- NFI production region 4 Alps East ≤600 m and 601-1200 m:
new stratum NFI production region 4 Alps East ≤1200 m (152 plots)

6.4.2.3 Estimation of growing stock in biomass

Growing stock of trees with DBH ≥ 12 cm in the Swiss GHG inventory is defined as the biomass of all tree elements (stem-wood over bark including stump, large (coarse) and small branches, needles/leaves, and roots). It was estimated based on established allometries to tree-dimensions and wood densities (Table 6-16). Biomass estimates for stem-wood over bark including stump and for all branches are derived based on volume models (chp. 13.2 and 13.3 in Herold et al. 2019) and conversion to biomass (chp. 15.2 in Didion et al. 2019). Foliage and coarse root biomass are derived directly from tree diameter at breast height (DBH; chp. 15.3 in Didion et al. 2019). Fine roots are reported under litter (see chp. 6.4.2.6). Except for coarse roots, the biomass functions were empirically derived from a large number of single-tree data from Swiss forest sites (see references in Table 6-16). Stumps of standing and lying trees are included in total living biomass according to Table 6-16.

Table 6-16 Applied allometric biomass functions, dependencies and references. DBH: tree diameter at breast height; D7: diameter at tree height 7 m.

Tree elements	Input parameter	Nr. of trees	References
Stem-wood over bark incl. stump	DBH, D7, height, wood density	38'000	chp. 13.2 in Herold et al. 2019 chp. 15.2 in Didion et al. 2019
Branches: small (< 7 cm) and large (≥ 7 cm diameter)	DBH wood density	38'000	chp. 13.2 in Herold et al. 2019 chp. 15.2 in Didion et al. 2019
Foliage: needles, leaves	DBH	631	Perrucoud et al. 1999, chp. 15.3 in Didion et al. 2019
Coarse roots (≥ 5mm) - broadleaved trees - coniferous trees	DBH	443 114	Wutzler et al. 2008 Zell and Thürig 2013 chp. 15.2 in Didion et al. 2019

The total biomass of all individual trees was calculated and, in a second step, single-tree estimates of gains and losses were obtained as the difference in tree biomass of alive trees between subsequent NFIs (chp. 6.4.2.5; Thürig and Herold 2013).

6.4.2.4 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 Tab. 4.3 in Volume 4 of IPCC (2006), and on the fact that in Switzerland coniferous trees are more abundant than broadleaved trees (see Table 051 in Brändli 2010).

6.4.2.5 Productive forests (CC12): growing stock, gains and losses of living biomass

Values for growing stock in 2005 (based on NFI3), gains (gross growth) and losses (cut and mortality) of living biomass for productive forests (CC12, without afforestations) were derived from 5'456 common plots measured during NFI1 and NFI2, 5'581 samples measured during NFI2 and NFI3 and 3'211 samples measured during NFI3 and NFI4 (2013–2017) (see Table 6-13). All values derived from the national forest inventories refer to above- and below-ground biomass in mass units (t C ha^{-1}) per spatial stratum.

Annual gain of living biomass – gross growth

Annual values of gross growth were derived from the NFI1 and NFI2 datasets for the period 1985–1994, from the NFI2 and NFI3 datasets for the period 1995–2005 and from the NFI3 and NFI4 (2013–2017) datasets for the period 2006–2017. Annual values of gross growth were assumed to remain constant in the intersurvey periods of NFI1 to NFI2, NFI2 to NFI3 and of NFI3 to NFI4 (2013–2017), respectively (Table 6-18).

Annual loss of living biomass – cut and mortality

An average value for cut and mortality (CM) was derived from the NFI1 and NFI2 dataset for the period 1985–1994, from the NFI2 and NFI3 datasets for the period 1995–2005 and from the NFI3 and NFI4 (2013–2017) datasets for the period 2006–2017. To obtain annual values of cut and mortality (CM_y) for each individual NFI-intersurvey-period, i.e. the years 1985 to 1994, 1995 to 2005 and 2006 to 2017, 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 6-17; FOEN 2019f and former editions; Swiss Federal Statistical Office: Wood production in Switzerland 1975–2017, <https://www.pxweb.bfs.admin.ch/>). These relative harvesting amounts, used as weighting factors, were calculated for each year per NFI intersurvey period.

Data from the forest statistics (Table 6-17) show that harvesting rates were exceptionally high in 1990 after storm Vivian (February 1990) and in 2000 after the storm Lothar (December 1999). Harvesting rates in Swiss forests tended to increase since 1991. In 2008

harvesting rates started to decline due to the international and domestic economic framework conditions.

Table 6-17 Annual harvesting amount in m³ merchantable wood specified for five NFI production region as well as for coniferous and broadleaved tree species (FOEN 2019f and former editions; <https://www.pxweb.bfs.admin.ch>).

Year	1. Jura		2. Central plateau		3. Pre-Alps		4. Alps		5. Southern Alps		Total
	Conif. [m ³]	Broadl. [m ³]	Conif. [m ³]	Broadl. [m ³]	Conif. [m ³]	Broadl. [m ³]	Conif. [m ³]	Broadl. [m ³]	Conif. [m ³]	Broadl. [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	653'049	359'808	1'810'839	614'845	1'010'979	180'546	514'905	70'603	35'462	33'614	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

Growing stock: calculation of time series

In order to develop a consistent time series, annual growing stocks of living biomass (stockC_i) 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):

$$\text{stockC}_{i,i,\text{CC12},iy} = \text{stockC}_{i,i,\text{CC12},2005} - \sum_{n=2005}^{iy} [\text{gainC}_{i,i,\text{CC12},n}] + \sum_{n=2005}^{iy} [\text{lossC}_{i,i,\text{CC12},n}] \text{ for } iy < 2005$$

$$\text{stockC}_{i,i,\text{CC12},iy} = \text{stockC}_{i,i,\text{CC12},2005} \text{ for } iy = 2005$$

$$\text{stockC}_{i,i,\text{CC12},iy} = \text{stockC}_{i,i,\text{CC12},2005} + \sum_{n=2006}^{iy} [\text{gainC}_{i,i,\text{CC12},n}] - \sum_{n=2006}^{iy} [\text{lossC}_{i,i,\text{CC12},n}] \text{ for } iy > 2005$$

where "iy" indicates the inventory year (here: 1985-2016), "n" the years between 2005 and the inventory year iy.

The backward calculation was used for the time period 1985–2004 ($i_y < 2005$), where the annual growing stock equals the growing stock 2005 minus the net change based on the gains due to the annual gross growth ($\text{gainC}_{l,i,\text{CC12},i_y}$) and the losses due to the annual amounts of cut and mortality ($\text{lossC}_{l,i,\text{CC12},i_y}$).

The forward calculation was used for the time period after 2005 ($i_y > 2005$), where the annual growing stock equals the growing stock 2005 plus the net change based on the gains due to the annual gross growth ($\text{gainC}_{l,i,\text{CC12},i_y}$) and the losses due the annual amounts of cut and mortality ($\text{lossC}_{l,i,\text{CC12},i_y}$).

Annual values of gross growth (gains in carbon stock of living biomass), cut and mortality (losses in carbon stock of living biomass) and calculated growing stocks (carbon stocks in living biomass) for the period 1990 to 2017 specified for all spatial strata are displayed in Table 6-18.

All working steps and data required to reproduce the calculation of emission factors for productive forests (CC12) in the period 1990–2017 are summarized in FOEN (2019b).

Table 6-18 Annual carbon data of living biomass for productive forest (CC12) stratified for NFI production region (NFI) and elevation zone (Elev.) for stocks (stockCl), gains (gross growth, gainCl) and losses (cut and mortality, lossCl). 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	129.11	129.01	128.93	129.08
1	2	132.57	133.59	134.64	135.47	136.09	136.57	136.80	136.81	137.01	137.52
1	3	91.47	92.38	93.30	94.06	94.70	95.30	95.38	95.30	95.40	95.76
2	1	135.39	134.39	134.81	134.68	134.37	133.68	132.11	130.96	130.46	130.34
2	2	150.00	149.04	149.58	149.52	149.25	148.67	146.87	145.55	144.96	144.81
2	3	106.15	105.96	106.20	106.26	106.25	106.19	108.15	110.31	112.78	115.44
3	1	151.23	152.21	153.91	155.40	156.81	158.25	158.70	159.10	159.75	160.61
3	2	156.83	156.00	156.38	156.43	156.59	156.97	156.19	155.32	154.91	154.99
3	3	123.92	123.30	123.49	123.46	123.58	123.92	124.41	124.85	125.50	126.39
4	1	104.45	106.39	108.26	110.07	111.88	113.65	110.77	110.01	109.13	108.08
4	2	111.91	112.98	113.98	114.88	115.91	116.88	116.64	117.09	117.44	117.69
4	3	99.99	100.73	101.42	101.99	102.77	103.49	104.55	105.52	106.42	107.28
5	1	82.98	83.71	84.43	85.17	85.90	86.70	87.45	88.34	89.23	90.19
5	2	90.98	92.58	94.16	95.74	97.33	98.93	100.27	101.62	102.99	104.37
5	3	88.06	89.54	90.93	92.26	93.67	95.02	96.45	97.74	99.10	100.45

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017		
CC12: carbon stock in living biomass (stockCl,i) [t C ha ⁻¹]											
1	1	128.97	128.83	128.92	128.83	128.57	128.66	128.69	128.70		
1	2	137.82	138.16	138.71	139.16	139.44	140.06	140.61	141.17		
1	3	95.97	96.24	96.65	97.01	97.26	97.74	98.18	98.62		
2	1	130.30	130.27	130.52	130.77	130.92	131.16	131.63	131.70		
2	2	144.75	144.71	144.99	145.26	145.44	145.73	146.25	146.34		
2	3	118.14	120.85	123.69	126.53	129.32	132.16	135.11	137.86		
3	1	161.08	161.52	162.44	163.09	163.65	164.51	165.43	166.23		
3	2	154.57	154.16	154.43	154.54	154.52	154.96	155.39	155.65		
3	3	127.08	127.79	128.76	129.71	130.62	131.71	132.78	133.78		
4	1	106.73	105.46	104.37	102.87	101.53	100.53	99.57	98.64		
4	2	117.77	117.90	118.15	118.18	118.31	118.63	119.01	119.39		
4	3	108.07	108.91	109.80	110.67	111.56	112.52	113.57	114.58		
5	1	90.77	91.29	91.94	92.55	93.21	93.72	93.95	94.39		
5	2	105.62	106.85	108.14	109.39	110.61	111.84	112.96	114.15		
5	3	101.73	103.00	104.36	105.61	106.63	107.90	109.11	110.29		

(Table 6-18 continued)

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CC12: gain of 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 of living biomass (gainCl,i) [t C ha ⁻¹ yr ⁻¹]											
1	1	3.37	3.37	3.37	3.37	3.37	3.37	3.57	3.57	3.57	3.57
1	2	3.04	3.04	3.04	3.04	3.04	3.04	3.25	3.25	3.25	3.25
1	3	1.80	1.80	1.80	1.80	1.80	1.80	2.13	2.13	2.13	2.13
2	1	4.54	4.54	4.54	4.54	4.54	4.54	4.51	4.51	4.51	4.51
2	2	4.56	4.56	4.56	4.56	4.56	4.56	4.82	4.82	4.82	4.82
2	3	1.28	1.28	1.28	1.28	1.28	1.28	4.82	4.82	4.82	4.82
3	1	4.23	4.23	4.23	4.23	4.23	4.23	4.20	4.20	4.20	4.20
3	2	4.15	4.15	4.15	4.15	4.15	4.15	4.20	4.20	4.20	4.20
3	3	2.50	2.50	2.50	2.50	2.50	2.50	2.37	2.37	2.37	2.37
4	1	3.44	3.44	3.44	3.44	3.44	3.44	2.48	2.48	2.48	2.48
4	2	2.50	2.50	2.50	2.50	2.50	2.50	2.34	2.56	2.56	2.56
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	2.70	2.70	2.70	2.70
5	2	2.18	2.18	2.18	2.18	2.18	2.18	2.07	2.07	2.07	2.07
5	3	1.79	1.79	1.79	1.79	1.79	1.79	1.93	1.93	1.93	1.93

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017		
CC12: gain of living biomass (gainCl,i) [t C ha ⁻¹ yr ⁻¹]											
1	1	3.57	3.57	3.57	3.57	3.57	3.57	3.57	3.57		
1	2	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25		
1	3	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13		
2	1	4.51	4.51	4.51	4.51	4.51	4.51	4.51	4.51		
2	2	4.82	4.82	4.82	4.82	4.82	4.82	4.82	4.82		
2	3	4.82	4.82	4.82	4.82	4.82	4.82	4.82	4.82		
3	1	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20		
3	2	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20		
3	3	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37		
4	1	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.48		
4	2	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56		
4	3	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12		
5	1	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70		
5	2	2.07	2.07	2.07	2.07	2.07	2.07	2.07	2.07		
5	3	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93		

(Table 6-18 continued)

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CC12: loss of 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 of living biomass (lossCl,i) [t C ha ⁻¹ yr ⁻¹]											
1	1	-5.03	-3.41	-3.35	-3.51	-3.67	-4.05	-3.46	-3.67	-3.65	-3.42
1	2	-3.43	-2.02	-1.99	-2.21	-2.41	-2.56	-3.02	-3.24	-3.05	-2.74
1	3	-1.70	-0.89	-0.88	-1.03	-1.16	-1.20	-2.06	-2.21	-2.03	-1.78
2	1	-10.04	-5.54	-4.12	-4.67	-4.85	-5.23	-6.08	-5.66	-5.02	-4.63
2	2	-10.20	-5.52	-4.03	-4.62	-4.83	-5.14	-6.62	-6.14	-5.40	-4.97
2	3	-2.77	-1.47	-1.05	-1.22	-1.29	-1.34	-2.86	-2.66	-2.34	-2.16
3	1	-4.72	-3.24	-2.54	-2.74	-2.82	-2.80	-3.74	-3.79	-3.55	-3.34
3	2	-7.44	-4.99	-3.77	-4.10	-4.00	-3.77	-4.97	-5.07	-4.60	-4.11
3	3	-4.72	-3.12	-2.31	-2.53	-2.38	-2.16	-1.88	-1.93	-1.72	-1.49
4	1	-1.37	-1.50	-1.57	-1.62	-1.63	-1.67	-3.12	-3.24	-3.37	-3.53
4	2	-1.28	-1.44	-1.50	-1.61	-1.48	-1.53	-2.01	-2.11	-2.21	-2.30
4	3	-1.00	-1.16	-1.20	-1.33	-1.12	-1.18	-1.05	-1.14	-1.22	-1.25
5	1	-1.29	-1.32	-1.32	-1.31	-1.31	-1.24	-1.95	-1.81	-1.81	-1.75
5	2	-0.56	-0.58	-0.59	-0.60	-0.59	-0.57	-0.73	-0.71	-0.70	-0.68
5	3	-0.29	-0.31	-0.40	-0.46	-0.38	-0.44	-0.50	-0.64	-0.56	-0.58

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017		
CC12: loss of living biomass (lossCl,i) [t C ha ⁻¹ yr ⁻¹]											
1	1	-3.68	-3.71	-3.49	-3.66	-3.83	-3.48	-3.55	-3.56		
1	2	-2.96	-2.91	-2.71	-2.81	-2.97	-2.63	-2.70	-2.70		
1	3	-1.92	-1.86	-1.72	-1.77	-1.89	-1.65	-1.70	-1.70		
2	1	-4.56	-4.54	-4.26	-4.27	-4.37	-4.26	-4.05	-4.44		
2	2	-4.88	-4.85	-4.55	-4.54	-4.64	-4.53	-4.30	-4.73		
2	3	-2.12	-2.11	-1.98	-1.98	-2.02	-1.97	-1.87	-2.06		
3	1	-3.72	-3.76	-3.27	-3.55	-3.64	-3.33	-3.28	-3.39		
3	2	-4.62	-4.61	-3.93	-4.09	-4.21	-3.76	-3.77	-3.93		
3	3	-1.68	-1.66	-1.40	-1.42	-1.46	-1.28	-1.30	-1.37		
4	1	-3.83	-3.76	-3.57	-3.99	-3.82	-3.49	-3.45	-3.41		
4	2	-2.48	-2.42	-2.31	-2.52	-2.43	-2.24	-2.17	-2.17		
4	3	-1.33	-1.27	-1.23	-1.25	-1.22	-1.16	-1.06	-1.11		
5	1	-2.13	-2.18	-2.06	-2.10	-2.04	-2.19	-2.47	-2.26		
5	2	-0.82	-0.84	-0.78	-0.81	-0.84	-0.84	-0.94	-0.88		
5	3	-0.65	-0.66	-0.57	-0.68	-0.91	-0.67	-0.71	-0.75		

6.4.2.6 Productive forests (CC12): carbon stocks in dead wood, litter and in mineral soils

Carbon stocks in dead wood

Carbon stock in dead wood depends on the available volume in different decay stages, and on the associated wood density and carbon content. The influence of wood decay on wood density and on carbon content of dead wood was investigated by Dobbertin and Jüngling (2009). For the two dominant tree species in Swiss forests, Norway spruce (*Picea abies*) and European beech (*Fagus sylvatica*), a significant decrease in wood density from alive trees to wood in advanced decay (duff wood) was found, i.e., Norway spruce (0.39 to 0.247 g cm⁻³) and beech (0.56 to 0.233 g cm⁻³; cf. Table 1 in Didion et al. 2014a). Carbon content varied very little (± 1.2 – 1.4%) between alive trees and dead wood in different decay stages. The findings by Dobbertin and Jüngling (2009) are consistent with recent data from Switzerland for Norway spruce (Wunder and Bont 2015).

The total amount of carbon in the dead wood pool (henceforth dead wood) in Switzerland is estimated as the sum of carbon in

- Stemwood including stump originating from standing dead trees with DBH ≥ 12 cm
- lying dead trees with DBH ≥ 7 cm
- large branches ≥ 7 cm in diameter originating from standing dead trees with DBH ≥ 12 cm
- coarse roots > ca. 5 mm in diameter of dead trees with DBH ≥ 12 cm.

The biomass elements of dead trees were estimated according to Table 6-16.

A time series of carbon stocks in dead wood was simulated with the soil carbon model Yasso07 (Didion and Thürig 2018; see description in chp. 6.4.2.7). Stratified estimated dead wood stocks for 1990 are shown in Table 6-19. Annual values for dead wood stocks since 1990 are displayed in Table 6-20.

Carbon stocks in litter (organic soil horizons) and in mineral soils

Soil carbon stocks were estimated by Nussbaum et al. (2012, 2014) based on soil profiles and robust geostatistical methods. The soil profiles are part of a pedothek maintained at the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL). The data used by Nussbaum et al (2012, 2014) were collected over the past 30 years (n=1033 sites) distributed among different forest types throughout Switzerland. The same dataset was re-analysed (n=1030; Nussbaum et al. 2012) to update estimates of carbon stocks in litter (organic soil horizons L - litter, F - fermentation and H - humus) prepared by Moeri (2007).

The data for litter and soil carbon stocks were stratified by the five NFI production regions and three elevation levels (Table 6-19). The estimated national average carbon stocks in mineral forest soils calculated by Nussbaum et al. (2012) were 79.9 t C ha⁻¹ (0–30 cm topsoil) and 125.8 t C ha⁻¹ (0–100 cm), respectively, and 16.7 t C ha⁻¹ in the organic soil horizons (litter) of mineral forest soils.

The sites in the WSL soil database which were used by Nussbaum et al. (2012, 2014) and by Moeri (2007) were visited mostly between 1990 and 2005. Hence, it is not possible to

attribute the national estimates of carbon stocks in mineral forest soils and in litter to one single year. Consequently, a combination of these carbon stocks and the carbon stock changes derived from the Yasso07 model (Didion and Thürig 2018; see chp. 6.4.2.7) would not result in a consistent time series for litter and soil carbon stocks. Thus, it was assumed that the values from Nussbaum et al. (2012, 2014) are representative for current conditions of Swiss forests soils and is therefore used for the period 1990 until the latest inventory year.

Table 6-19 Dead wood stocks (stockC_d) in Swiss productive forests (CC12) by spatial stratum in t C ha^{-1} for 1990 (Tables A-23 (means) and A-25 (SE) in Didion and Thürig 2018). Carbon stocks in organic soil horizons (litter; stockC_h ; Table 3 in Nussbaum et al. 2012; used for CC12, CC13) and carbon stocks in mineral soil (0–30 cm; stockC_s ; Table 5 in Nussbaum et al. 2012, Nussbaum et al. 2014; used for CC11, CC12, CC13) were assumed to be representative for 1990–2017. The data were stratified for NFI production regions and elevation zones. Dead wood and litter stocks in NFI production region 2, 601–1200 and >1200 m were aggregated due to the low number of samples >1200 m. Average values \pm single standard errors are given.

NFI region	Elevation [m]	Carbon stock in dead wood 1990 ($\text{stockC}_{d,i,CC12}$) [t C ha^{-1}]	Carbon stock in litter ($\text{stockC}_{h,i,CC12}$, $\text{stockC}_{h,i,CC13}$) [t C ha^{-1}]	Carbon stock in mineral topsoil 0–30 cm ($\text{stockC}_{s,i,CC11}$, $\text{stockC}_{s,i,CC12}$, $\text{stockC}_{s,i,CC13}$) [t C ha^{-1}]
1	<601	4.86 ± 0.05	9.51 ± 1.57	82.65 ± 3.34
1	601–1200	5.24 ± 0.03	7.53 ± 0.70	102.03 ± 3.56
1	>1200	4.54 ± 0.08	7.76 ± 1.74	121.34 ± 5.39
2	<601	8.10 ± 0.05	8.70 ± 0.68	55.40 ± 1.55
2	601–1200	7.79 ± 0.06	11.42 ± 1.45	62.12 ± 1.68
2	>1200	7.79 ± 0.06	11.42 ± 1.45	122.00 ± 7.07
3	<601	7.61 ± 0.05	7.51 ± 1.25	66.10 ± 2.06
3	601–1200	7.61 ± 0.05	16.29 ± 1.55	57.91 ± 2.00
3	>1200	6.00 ± 0.07	26.21 ± 4.77	95.78 ± 3.27
4	<601	5.67 ± 0.06	3.15 ± 0.47	66.47 ± 2.44
4	601–1200	5.67 ± 0.06	19.99 ± 2.64	74.39 ± 2.42
4	>1200	5.14 ± 0.04	33.37 ± 3.53	69.48 ± 1.85
5	<601	2.22 ± 0.09	8.22 ± 1.62	102.37 ± 4.07
5	601–1200	2.08 ± 0.05	11.03 ± 2.11	108.99 ± 4.09
5	>1200	1.76 ± 0.03	30.77 ± 5.43	107.08 ± 4.11
Switzerland		5.76 ± 0.02	16.73 ± 0.83	79.93 ± 1.52

Table 6-20 Carbon stock in dead wood for CC12 stratified for NFI production region (NFI) and elevation zone (Elev.). Highlighted data for 1990 are displayed in Table 6-4 and Table 6-19.

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	4.86	4.92	4.95	4.97	4.97	4.99	5.30	5.64	5.92	6.16
1	2	5.24	5.30	5.33	5.36	5.37	5.40	5.42	5.49	5.56	5.61
1	3	4.54	4.54	4.51	4.50	4.47	4.46	4.23	4.13	4.05	3.98
2	1	8.10	8.18	8.23	8.27	8.26	8.29	8.59	8.92	9.19	9.41
2	2	7.79	7.86	7.90	7.93	7.93	7.95	8.28	8.64	8.95	9.22
2	3	7.79	7.86	7.90	7.93	7.93	7.95	8.28	8.64	8.95	9.22
3	1	7.61	7.73	7.81	7.90	7.94	8.02	8.44	8.82	9.17	9.49
3	2	7.61	7.73	7.81	7.90	7.94	8.02	8.44	8.82	9.17	9.49
3	3	6.00	6.04	6.06	6.09	6.09	6.12	5.94	6.00	6.07	6.14
4	1	5.67	5.77	5.85	5.93	5.99	6.07	5.94	5.93	5.93	5.92
4	2	5.67	5.77	5.85	5.93	5.99	6.07	5.94	5.93	5.93	5.92
4	3	5.14	5.26	5.36	5.46	5.53	5.63	5.39	5.38	5.38	5.37
5	1	2.22	2.29	2.34	2.39	2.44	2.49	2.47	2.51	2.55	2.58
5	2	2.08	2.15	2.20	2.25	2.30	2.35	2.14	2.04	1.95	1.87
5	3	1.76	1.78	1.80	1.82	1.84	1.86	1.74	1.72	1.71	1.70

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	6.39	6.59	6.76	6.99	7.16	7.33	7.32	7.37	7.45	7.54
1	2	5.65	5.69	5.72	5.78	5.82	5.88	6.34	6.51	6.68	6.84
1	3	3.90	3.84	3.77	3.72	3.67	3.63	3.11	3.29	3.46	3.62
2	1	9.61	9.78	9.94	10.18	10.34	10.51	10.63	10.64	10.68	10.74
2	2	9.45	9.67	9.85	10.10	10.29	10.49	9.85	9.96	10.09	10.23
2	3	9.45	9.67	9.85	10.10	10.29	10.49	9.85	9.96	10.09	10.23
3	1	9.77	10.04	10.26	10.51	10.73	10.96	10.72	10.97	11.22	11.46
3	2	9.77	10.04	10.26	10.51	10.73	10.96	10.72	10.97	11.22	11.46
3	3	6.19	6.24	6.28	6.32	6.37	6.43	6.60	6.50	6.42	6.36
4	1	5.91	5.91	5.89	5.90	5.91	5.94	5.42	5.73	6.01	6.28
4	2	5.91	5.91	5.89	5.90	5.91	5.94	5.42	5.73	6.01	6.28
4	3	5.36	5.35	5.34	5.34	5.36	5.38	5.06	5.07	5.09	5.12
5	1	2.61	2.64	2.66	2.70	2.72	2.76	3.00	3.21	3.40	3.58
5	2	1.79	1.73	1.67	1.62	1.58	1.54	1.54	1.56	1.58	1.60
5	3	1.69	1.68	1.67	1.67	1.67	1.67	1.20	1.27	1.34	1.41

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017		
CC12: carbon stock in dead wood (stockCd,i) [t C ha ⁻¹]											
1	1	7.65	7.71	7.77	7.84	7.86	7.94	7.97	8.03		
1	2	7.02	7.14	7.26	7.39	7.45	7.55	7.62	7.71		
1	3	3.78	3.89	4.01	4.13	4.21	4.30	4.37	4.45		
2	1	10.83	10.87	10.91	10.96	10.94	11.00	11.00	11.05		
2	2	10.39	10.49	10.59	10.70	10.72	10.81	10.86	10.94		
2	3	10.39	10.49	10.59	10.70	10.72	10.81	10.86	10.94		
3	1	11.72	11.88	12.07	12.27	12.36	12.49	12.59	12.72		
3	2	11.72	11.88	12.07	12.27	12.36	12.49	12.59	12.72		
3	3	6.33	6.24	6.19	6.16	6.09	6.03	5.98	5.94		
4	1	6.55	6.75	6.96	7.16	7.30	7.45	7.60	7.73		
4	2	6.55	6.75	6.96	7.16	7.30	7.45	7.60	7.73		
4	3	5.17	5.17	5.18	5.21	5.21	5.21	5.23	5.24		
5	1	3.75	3.89	4.02	4.15	4.25	4.35	4.44	4.54		
5	2	1.62	1.63	1.65	1.67	1.67	1.68	1.70	1.71		
5	3	1.47	1.53	1.58	1.63	1.67	1.71	1.75	1.78		

6.4.2.7 Productive forests (CC12): changes in carbon stocks in dead wood, in litter and in mineral soils

Switzerland uses the soil carbon model Yasso07 to estimate temporal changes in carbon stocks in mineral forest soil (0–100 cm), organic soil horizons (LFH; litter) and in dead wood for productive forests (CC12). The implementation of Yasso07 (Tuomi et al. 2009, 2011) in the Swiss GHG inventory is described in detail in Didion et al. (2012) and, for the current submission, in Didion and Thürig (2018). Didion et al. (2014a) demonstrated the validity of the model for application in Swiss forests.

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 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).

By default, Yasso07 does not provide separate estimates of carbon pool sizes for dead wood, litter and soil. In order to report estimates for each pool, the structure of Yasso07 was examined for deriving separate estimates. Dead wood, litter and soil pools could be correlated with modeled 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 (see Didion et al. 2012).

Using annual data for climate and for carbon inputs obtained from the Swiss NFIs, Yasso07 was used for estimating the annual carbon stock changes in mineral soil, litter and dead wood. Table 6-19 shows the carbon stocks in Swiss forests by stratum for the pools mineral soil, litter (both based on Nussbaum et al 2012, 2014) and dead wood (based on Didion and Thürig 2018). Annual stratified values of carbon stock changes for dead wood, litter and mineral soils are calculated for the plots in Table 6-13 and results are given in Table 6-21. Carbon stocks and carbon stock changes were validated as described in Didion and Thürig (2018).

Table 6-21 Net carbon stock change in dead wood, in litter and in mineral soils 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	0.02	0.06	0.03	0.03	0.00	0.02	0.39	0.34	0.28	0.24
1	2	0.03	0.06	0.03	0.03	0.01	0.03	0.10	0.07	0.07	0.05
1	3	-0.03	-0.01	-0.02	-0.01	-0.03	-0.01	-0.08	-0.10	-0.08	-0.08
2	1	0.03	0.09	0.04	0.04	-0.01	0.03	0.37	0.33	0.27	0.22
2	2	0.03	0.07	0.04	0.03	-0.01	0.03	0.41	0.35	0.31	0.27
2	3	0.03	0.07	0.04	0.03	-0.01	0.03	0.41	0.35	0.31	0.27
3	1	0.09	0.12	0.09	0.08	0.04	0.08	0.45	0.38	0.35	0.32
3	2	0.09	0.12	0.09	0.08	0.04	0.08	0.45	0.38	0.35	0.32
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	0.11	0.08	0.08	0.05	0.08	0.01	-0.01	0.00	-0.01
4	2	0.09	0.11	0.08	0.08	0.05	0.08	0.01	-0.01	0.00	-0.01
4	3	0.11	0.12	0.10	0.10	0.07	0.10	0.01	-0.02	0.00	-0.01
5	1	0.07	0.06	0.05	0.05	0.04	0.05	0.05	0.03	0.04	0.03
5	2	0.07	0.07	0.05	0.05	0.04	0.05	-0.11	-0.11	-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	0.22	0.20	0.17	0.24	0.17	0.17	0.09	0.05	0.08	0.09
1	2	0.04	0.04	0.03	0.07	0.04	0.06	0.20	0.16	0.17	0.17
1	3	-0.08	-0.06	-0.07	-0.05	-0.05	-0.04	0.21	0.18	0.17	0.16
2	1	0.20	0.18	0.15	0.24	0.16	0.18	0.06	0.00	0.04	0.06
2	2	0.23	0.22	0.18	0.25	0.18	0.20	0.17	0.11	0.13	0.14
2	3	0.23	0.22	0.18	0.25	0.18	0.20	0.17	0.11	0.13	0.14
3	1	0.28	0.27	0.22	0.25	0.22	0.23	0.30	0.24	0.25	0.24
3	2	0.28	0.27	0.22	0.25	0.22	0.23	0.30	0.24	0.25	0.24
3	3	0.05	0.06	0.03	0.04	0.05	0.06	-0.10	-0.10	-0.07	-0.07
4	1	-0.01	0.00	-0.02	0.01	0.01	0.03	0.35	0.31	0.28	0.27
4	2	-0.01	0.00	-0.02	0.01	0.01	0.03	0.35	0.31	0.28	0.27
4	3	-0.01	0.00	-0.02	0.01	0.01	0.03	0.02	0.02	0.02	0.03
5	1	0.03	0.03	0.02	0.04	0.02	0.04	0.25	0.21	0.19	0.17
5	2	-0.07	-0.06	-0.06	-0.05	-0.05	-0.04	0.03	0.02	0.02	0.02
5	3	-0.01	-0.01	-0.01	0.00	0.00	0.01	0.09	0.08	0.07	0.07

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017		
CC12: net change in dead wood (changeCd,i) [t C ha ⁻¹ yr ⁻¹]											
1	1	0.11	0.06	0.06	0.07	0.01	0.08	0.03	0.06		
1	2	0.18	0.11	0.12	0.13	0.06	0.10	0.07	0.09		
1	3	0.16	0.11	0.12	0.12	0.08	0.08	0.08	0.08		
2	1	0.09	0.04	0.04	0.05	-0.03	0.06	0.00	0.05		
2	2	0.17	0.09	0.10	0.11	0.02	0.09	0.04	0.08		
2	3	0.17	0.09	0.10	0.11	0.02	0.09	0.04	0.08		
3	1	0.27	0.16	0.19	0.20	0.09	0.13	0.11	0.13		
3	2	0.27	0.16	0.19	0.20	0.09	0.13	0.11	0.13		
3	3	-0.03	-0.08	-0.05	-0.03	-0.07	-0.06	-0.05	-0.04		
4	1	0.27	0.20	0.20	0.20	0.14	0.15	0.14	0.14		
4	2	0.27	0.20	0.20	0.20	0.14	0.15	0.14	0.14		
4	3	0.04	0.00	0.01	0.03	0.00	0.01	0.01	0.01		
5	1	0.17	0.14	0.13	0.13	0.10	0.11	0.09	0.09		
5	2	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01		
5	3	0.07	0.05	0.05	0.05	0.04	0.04	0.04	0.04		

(Table 6-21 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	-0.11	0.13	-0.06	-0.02	-0.17	-0.04	0.31	0.16	0.03	-0.04
1	2	-0.06	0.12	-0.03	0.00	-0.14	0.01	0.35	0.14	0.12	0.05
1	3	-0.16	-0.03	-0.11	-0.06	-0.16	-0.01	0.26	0.07	0.11	0.07
2	1	-0.13	0.13	-0.05	-0.04	-0.19	-0.03	0.25	0.14	0.03	-0.05
2	2	-0.09	0.12	-0.03	-0.02	-0.18	0.01	0.25	0.10	0.06	-0.01
2	3	-0.09	0.12	-0.03	-0.02	-0.18	0.01	0.25	0.10	0.06	-0.01
3	1	-0.01	0.15	-0.01	0.02	-0.15	0.06	0.33	0.08	0.12	0.08
3	2	-0.01	0.15	-0.01	0.02	-0.15	0.06	0.33	0.08	0.12	0.08
3	3	-0.03	0.10	-0.05	0.04	-0.13	0.08	0.31	0.04	0.16	0.11
4	1	0.01	0.12	-0.02	0.03	-0.09	0.07	0.36	0.15	0.19	0.10
4	2	0.01	0.12	-0.02	0.03	-0.09	0.07	0.36	0.15	0.19	0.10
4	3	0.11	0.21	0.02	0.12	-0.07	0.15	0.41	0.17	0.24	0.11
5	1	0.02	0.05	-0.01	-0.01	-0.04	0.06	0.31	0.16	0.17	0.13
5	2	0.14	0.16	0.06	0.07	-0.01	0.12	0.50	0.25	0.25	0.21
5	3	0.15	0.20	0.05	0.11	-0.02	0.16	0.63	0.32	0.32	0.27

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	0.29	0.00	0.09	0.06	-0.09	0.03	0.09
1	2	0.03	0.05	-0.05	0.19	0.04	0.13	0.05	-0.06	0.06	0.09
1	3	0.01	0.06	-0.03	0.06	0.05	0.11	0.20	0.11	0.16	0.14
2	1	-0.05	-0.04	-0.07	0.25	0.00	0.10	-0.10	-0.22	-0.07	0.00
2	2	-0.04	0.00	-0.07	0.20	0.02	0.12	-0.01	-0.13	0.00	0.05
2	3	-0.04	0.00	-0.07	0.20	0.02	0.12	-0.01	-0.13	0.00	0.05
3	1	0.00	0.07	-0.06	0.11	0.07	0.13	0.04	-0.06	0.05	0.06
3	2	0.00	0.07	-0.06	0.11	0.07	0.13	0.04	-0.06	0.05	0.06
3	3	0.03	0.10	-0.04	0.03	0.10	0.15	-0.17	-0.14	-0.04	-0.04
4	1	0.04	0.10	-0.04	0.15	0.12	0.19	0.20	0.07	0.11	0.15
4	2	0.04	0.10	-0.04	0.15	0.12	0.19	0.20	0.07	0.11	0.15
4	3	0.03	0.13	-0.04	0.18	0.19	0.25	0.26	0.14	0.16	0.21
5	1	0.05	0.11	0.03	0.14	0.03	0.18	0.13	0.00	0.01	0.03
5	2	0.11	0.16	0.04	0.17	0.07	0.24	0.22	0.06	0.09	0.09
5	3	0.16	0.21	0.07	0.19	0.13	0.32	0.44	0.27	0.27	0.23

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017		
CC12: net change in litter (changeCh,i) [t C ha ⁻¹ yr ⁻¹]											
1	1	0.16	-0.03	-0.01	0.05	-0.17	0.13	-0.07	0.08		
1	2	0.20	-0.09	0.02	0.08	-0.17	0.03	-0.06	0.06		
1	3	0.24	-0.05	0.08	0.12	-0.10	-0.01	-0.02	0.04		
2	1	0.09	-0.06	-0.04	0.01	-0.19	0.08	-0.10	0.05		
2	2	0.15	-0.07	0.01	0.05	-0.20	0.06	-0.08	0.05		
2	3	0.15	-0.07	0.01	0.05	-0.20	0.06	-0.08	0.05		
3	1	0.20	-0.14	0.05	0.10	-0.22	-0.03	-0.06	0.03		
3	2	0.20	-0.14	0.05	0.10	-0.22	-0.03	-0.06	0.03		
3	3	0.11	-0.21	-0.01	0.04	-0.17	-0.10	-0.05	-0.01		
4	1	0.25	-0.06	0.06	0.12	-0.12	0.00	-0.01	0.03		
4	2	0.25	-0.06	0.06	0.12	-0.12	0.00	-0.01	0.03		
4	3	0.34	-0.06	0.04	0.15	-0.08	-0.03	0.06	0.04		
5	1	0.12	-0.02	0.02	0.02	-0.10	0.02	-0.01	0.03		
5	2	0.22	-0.05	0.03	0.06	-0.09	-0.01	0.00	0.02		
5	3	0.34	0.01	0.09	0.14	-0.01	0.00	0.05	0.05		

(Table 6-21 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	0.000	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	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001
2	3	0.000	0.000	0.000	0.000	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	0.001	0.002	0.002
4	2	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002
4	3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
5	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002
5	2	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.004
5	3	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.004

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	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002
1	2	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002
1	3	-0.002	-0.002	-0.002	-0.002	-0.002	-0.001	-0.001	-0.001	-0.001	-0.001
2	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000
2	2	0.001	0.001	0.001	0.002	0.002	0.002	0.001	0.001	0.001	0.001
2	3	0.001	0.001	0.001	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	0.000	0.001	0.001	0.001	0.001	0.001	-0.001	-0.001	-0.001	-0.001
4	1	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002
4	2	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002
4	3	0.003	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003
5	1	0.002	0.002	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.003
5	2	0.004	0.004	0.004	0.004	0.004	0.004	0.005	0.006	0.006	0.006
5	3	0.004	0.004	0.004	0.004	0.004	0.004	0.003	0.003	0.004	0.004

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017		
CC12: net change in mineral soil (changeCs,i) [t C ha ⁻¹ yr ⁻¹]											
1	1	0.002	0.002	0.002	0.002	0.003	0.002	0.003	0.002		
1	2	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.003		
1	3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
2	1	0.001	0.001	0.001	0.001	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		
2	3	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		
3	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004		
3	3	-0.001	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002		
4	1	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.003		
4	2	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.003		
4	3	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003		
5	1	0.003	0.003	0.003	0.003	0.004	0.003	0.003	0.004		
5	2	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006		
5	3	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005		

Carbon stock changes in the soil pool are small (Table 6-21). The Yasso07 data are supported by measurements of the Swiss Soil Monitoring Network (see chp. 6.4.4). 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 there is a higher interannual variability in the production of foliage (Etzold et al. 2011). The carbon stock change in the dead wood pool is to a large extent 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 winterstorm Lothar which occurred in 1999, i.e. between the NFI2 (1993–1995) and NFI3 (2004–2006), strongly affects the results of the change analysis for dead wood volume in the period NFI2 to NFI3.

Although the majority of the windthrown 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 storm resulted in a sustained carbon sink. The trend of decreasing harvesting rates for several years after NFI3 (see Table 6-17) further sustained the carbon sink of dead wood as mature trees, which could be harvested, remain in the forest to potentially contribute to the dead wood pool. Large-scale disturbance events like Lothar that occur between two consecutive NFIs can strongly affect the estimates of annually accumulating mass of carbon in dead wood that drives the Yasso07 simulation. Preliminary results of the NFI4 indicate that dead wood volume is still increasing.

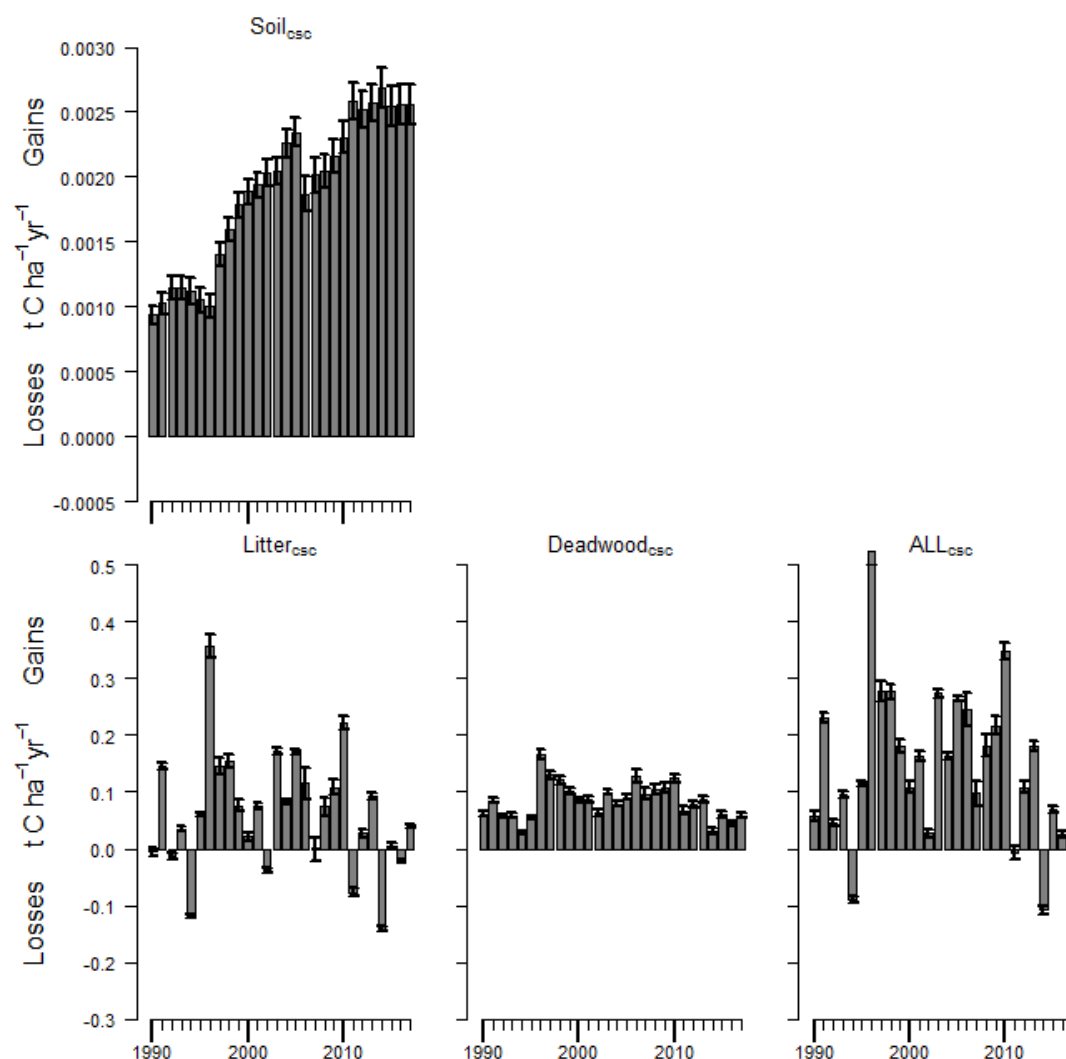


Figure 6-6 Mean carbon stock change (CSC) for three pools soil (0–100 cm), litter, dead wood and their sum (ALL) in $\text{t C ha}^{-1} \text{yr}^{-1}$. Note the difference of the y-axis scale between Soil_{CSC} and $\text{Litter}_{\text{CSC}}$, $\text{Deadwood}_{\text{CSC}}$ and ALL_{CSC} , respectively. Negative values indicate losses in carbon stock, positive values gains in carbon stock. The error bars indicate the double standard error.

6.4.2.8 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 (e.g. wood log blocks a hiking trail) there can be an intervention where the log is moved, but not removed from the stand. Moreover, since yearly harvesting amounts from forest statistics (Table 6-17) are distributed over the productive forests, total harvesting in Swiss forests was accounted for under productive forests (CC12), and thus all harvesting amounts were accounted for.

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: 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 (Table 1 in Duggelin and Abegg 2011). Following the NFI definition, brush forests are dominated by more than two thirds by shrubs. For brush forests, no NFI data are available to derive their growing stock. In a case study, Duggelin and Abegg (2011) analysed the carbon stock of total living biomass 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 m³ 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. 6.4.2.4).

The carbon stock of living biomass (C_i) 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:

$$\text{stock}C_{i,i,CC13} = F_i * \text{stock}C_{i,i,CC13bi} + (1 - F_i) * \text{stock}C_{i,i,CC13u}$$

where F_i is the fraction of the brush and inaccessible forest per spatial stratum i ,

$\text{stock}C_{i,i,CC13bi}$ is the carbon stock of brush and inaccessible forest (20.45 t C ha⁻¹),

$\text{stock}C_{i,i,CC13u}$ is the carbon stock of forest on unproductive areas (51.38 t C ha⁻¹).

Table 6-22 shows the resulting carbon stocks in living biomass of unproductive forest per spatial stratum in t C ha⁻¹.

Table 6-22 Area of brush forest, inaccessible 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 ($\text{stock}C_{i,i,CC13}$).

NFI region	Altitude [m]	Brush forest [ha]	Inaccessible 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 ($\text{stock}C_{i,i,CC13}$) [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, litter, and mineral soil

As stated above, CC13 consists of different types of forests and data are hardly 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 in litter and in mineral soil under unproductive forests reveal a high spatial heterogeneity, and specific data are not available. Both carbon stocks of soil carbon and litter were assumed to be the same as for productive forests, which were derived from Nussbaum et al. (2012, 2014) (see Table 6-19).

Values for carbon stocks in dead wood, litter, and in mineral soil for CC13 are listed in Table 6-4.

Changes in carbon stocks of living biomass

There are a few case studies on carbon stocks, but similarly to neighbouring countries with forests in mountainous regions, there are no repeated forest inventory data available for these unproductive 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 m² ha⁻¹ in 2006 to 5.47 m² ha⁻¹ in 2012.
- 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 reported to be in equilibrium. In Table 6-4 and in CRF Table4.A, this approach is transcribed into “gains (gainC_{l,i,13}) = losses (lossC_{l,i,13}) = 0”.

Changes in carbon stocks of dead wood, litter, and 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 increasing. 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 reported to be in equilibrium. In Table 6-4 and in CRF Table 4.A, this approach is transcribed into “ $\text{changeC}_{d,i,11} = \text{changeC}_{h,i,11} = \text{changeC}_{s,i,13} = 0$ ”. 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 litter and soil carbon of mineral soils were calculated because carbon stocks of litter and mineral soil are the same for CC12 and CC13.

With the exception of brush forests, it is very likely that carbon stocks in litter and 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 litter and mineral soil under productive and unproductive forest, the resulting emissions are not underestimated.

6.4.2.9 Afforestations (CC11)

Carbon stock and changes in carbon stocks of 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). 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 stock and changes in carbon stocks of dead wood and litter

On afforestations, carbon stocks in litter and dead wood 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 litter and dead wood pool after a afforestation were rather small 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 stock and changes in carbon stocks of mineral soil

The estimates for soil carbon stocks from Nussbaum et al. (2012, 2014) were used for afforestations (see Table 6-4 and Table 6-19), i.e. the same as for productive forest (CC12). Carbon stock changes of afforestations (≤ 20 years) were calculated with the stock-difference method (see Table 6-3).

6.4.2.10 Organic soils

Carbon stock in organic soils

The mean soil organic carbon stock (0–30 cm) for organic soils under forest land is $145.6 \pm 24.1 \text{ t C ha}^{-1}$ (Wüst-Galley et al. 2016). This value was used for CC11, CC12, and CC13 (cf. 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 intersecting information on drainage from NFI plots with the shapefile 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 soils, the default emission factor of $2.6 \text{ t C ha}^{-1} \text{ yr}^{-1}$ was applied for all forest stands (CC11, CC12, and CC13; cf. Table 6-4) according to the Wetlands Supplement (IPCC 2014a: Table 2.1).

6.4.2.11 N₂O 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 Ordinance on Chemical Risk Reduction (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 N₂O 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”).

N₂O emissions from drainage of organic soils was calculated for Forest land with an emission factor of 2.8 kg N₂O-N ha⁻¹ for 3% of the area of organic soils (see chp. 6.4.2.10) 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 N₂O emissions from nitrogen mineralisation in mineral soils and indirect N₂O emissions from managed soils, is described in chp. 6.10.

6.4.2.12 Emissions from wildfires

Data on wildfires affecting Swiss forest land were obtained from cantonal authorities and were compiled by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL, [Swissfire database](#)). Table 6-23 shows the time series 1990 to 2017 of the area affected 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.

CO₂ emissions from wildfires were noted “IE” in the CRF Table4(V) and are encompassed in the data in CRF Table4.A. Losses in living biomass are reflected in the NFI dataset. Carbon changes in dead wood, litter and soil carbon 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 and Thürig 2018).

CH₄ and N₂O emissions from wildfires (Table 6-23) were calculated using equation 2.27 in Volume 4 of IPCC (2006) with the following parameters:

- For CH₄ the default emission factor of 4.7 g kg⁻¹ dry matter burned and for N₂O, the default emission factor of 0.26 g (kg combusted biomass)⁻¹ 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 95.19 t C ha⁻¹ or 190.39 t

biomass ha^{-1} . This value was derived from the mean growing stock in NFI1, NFI2, NFI3 and NFI4 2013–2017 (Brassel and Brändli 1999; Brändli 2010; Thürig et al. 2018) as a weighted value of the regions affected by forest fires (82% of the fires occur in the southern Alps, 15% in the Central Alps). The average amount of litter in Swiss forests was $16.73 \text{ t C ha}^{-1}$ (see Table 6-19) or $33.46 \text{ t biomass ha}^{-1}$ and average stocks of dead wood were calculated per NFI period based on data from Didion and Thürig 2018 (see Table 6-20).

- The fraction of the biomass combusted was 0.45 (IPCC 2006, Volume 4, Table 2.6).

CH_4 and N_2O emissions caused by wildfires were 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 6-23 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	1'067.1	70.5	27.9	17.7	233.2	362.8	232.6	1'389.5	197.7	11.2
CH_4	t	538.7	35.6	14.1	8.9	117.7	183.1	117.4	701.5	99.8	5.7
N_2O	t	29.8	2.0	0.8	0.5	6.5	10.1	6.5	38.8	5.5	0.3

Forest land	Unit	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Area burnt	ha	47.4	12.9	418.0	527.0	24.5	41.1	112.2	238.2	38.5	50.3
CH_4	t	23.9	6.5	211.0	266.1	12.4	20.8	56.6	120.3	19.4	25.4
N_2O	t	1.3	0.4	11.7	14.7	0.7	1.1	3.1	6.7	1.1	1.4

Forest land	Unit	2010	2011	2012	2013	2014	2015	2016	2017
Area burnt	ha	26.1	168.7	23.7	24.2	43.2	42.3	254.8	101.6
CH_4	t	13.2	85.1	12.0	12.2	21.8	21.4	128.6	51.3
N_2O	t	0.7	4.7	0.7	0.7	1.2	1.2	7.1	2.8

6.4.2.13 Emissions from controlled burning

Emissions from controlled burning covers the burning of residues in forestry; controlled burning of forest stands is not allowed in Switzerland.

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 are calculated by multiplying the annual estimate of branches burnt (in kt) by emission factors (IPCC default values).

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.

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 dataset.

The emission factors of CH₄, N₂O and NMVOC of burning of branches in forestry were calculated based on EMEP/CORINAIR (EMEP/EEA 2013), see also documentation in EMIS (2019/5C2 *Abfallverbrennung in der Land- und Forstwirtschaft*).

6.4.2.14 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.

The biogenic NMVOC emissions from forest stands were calculated for the years 1990-2016 on the basis of monthly maps for the parameters temperature, vegetation period and for 12 different tree species (Meteotest 2019a). This corresponds to the simplified method according to chapter 11C in EMEP/EEA (2016). The values after 2016 are interpolated between the modelled years 2016 and 2050. In 1990, the NMVOC emission from forest stands was 60.83 kt.

The methods for calculating the NMVOC emissions from wildfires and from burning of residues in forestry are presented in FOEN 2019d (chapter 7). In 1990, these emissions amounted to 0.98 kt.

6.4.3 Uncertainties and time-series consistency

6.4.3.1 Uncertainties

Activity data

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.

Living biomass

For living biomass, the uncertainty was estimated based on the following information:

- Stem wood of growth (gains of living biomass) and cut & mortality (losses of living biomass) in NFI4 2009–2013 and differences between NFI3 and NFI4 2009–2013 (Abegg et al. 2014):
- mean gain 8.95 m³ ha⁻¹ yr⁻¹, mean loss -7.64 m³ ha⁻¹ yr⁻¹, resulting mean net change in stem volume 1.31 m³ ha⁻¹ yr⁻¹
- relative uncertainty of mean net change in volume: 54% (double standard error (2SE); for calculation see Thürig et al. 2015).
- Carbon content in solid wood: The uncertainty was estimated to be 2% (2SE) based on Monni et al. (2007) (2% relative standard deviation; RSD), and Lamlo and Savidge (2003) (4-8% RSD).
- 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: The uncertainty related to the expansion and conversion of stem volume to whole tree

biomass was based on Lehtonen and Heikkinen (2016) including 21.2% (2SE) sampling uncertainty and 22.2% (2SE) model uncertainty.

Thus, the total uncertainty of net carbon stock change in living biomass ($U_{\text{liv.biom}}$) in terms of carbon per unit area can be calculated following equation 3.1 in chp. “Quantifying Uncertainties” (Volume 1 of IPCC 2006):

$$U_{\text{liv.biom}} = \sqrt{54^2 + 2^2 + 21.2^2 + 22.2^2} = 62.15\%$$

Dead wood, litter, soil

The uncertainty in the estimates of annual carbon stock changes derived with the Yasso07 model originates from the following sources:

- carbon input estimates obtained from the NFI (measurement errors, allometries, etc.) (chp. 2.3.3 in Didion and Thürig 2018);
- decomposition parameters used in the Yasso07 model (chp. 2.3.1 in Didion and Thürig 2018).

The uncertainty associated with carbon inputs (dead wood production and litterfall) was estimated based on estimates of uncertainty in (a) litter turnover rates (Wutzler and Mund 2007), (b) wood densities of dead wood in different decay stages (Dobbertin and Jüngling 2009), and (c) spatial uncertainty in the NFI data approximated based on the estimation error for tree volume reported for the NFI (see chp. 1.4 in Brändli 2010). Based on the mean carbon inputs and the estimated uncertainty, a distribution of possible values was obtained. Finally, the combined uncertainty from these sources was calculated. The uncertainty in the Yasso07 parameters was estimated based on a Markov Chain Monte Carlo approach (see also Tuomi et al. 2011). A distribution of possible parameter values was provided by A. Lehtonen, Natural Resources Institute Finland. The uncertainty of Yasso07 estimates on carbon stocks and carbon stock changes in different pools, resulting from the uncertainty of carbon inputs and of model parameters, was obtained through Monte Carlo simulations: 10 values for carbon inputs and 10 parameter combinations were selected randomly and the combined uncertainty in Yasso07 estimates of carbon stocks and carbon stock changes in the soil, litter, and dead wood pools was calculated as described in Didion and Thürig (2018).

Based on this approach, the absolute uncertainty (double standard error) of the estimates of C stock changes are:

- $U_{\text{Soil.abs}} = 0.00014 \text{ t C ha}^{-1} \text{ yr}^{-1}$
- $U_{\text{Litter.abs}} = 0.00371 \text{ t C ha}^{-1} \text{ yr}^{-1}$
- $U_{\text{Dead wood.abs}} = 0.00708 \text{ t C ha}^{-1} \text{ yr}^{-1}$

which correspond to the relative uncertainties (2SE) of

- $U_{\text{Soil}} = 13.18\%$
- $U_{\text{Litter}} = 2.31\%$

- $U_{\text{Dead wood}} = 679.46\%$.

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” (Volume 1 of IPCC 2006):

$$U_{tot} = \frac{\sqrt{(U_{\text{liv.biom}} * X_{\text{liv.biom}})^2 + (U_{\text{soil}} * X_{\text{soil}})^2 + (U_{\text{Litter}} * X_{\text{Litter}})^2 + (U_{\text{Deadwood}} * X_{\text{Deadwd}})^2}}{|X_{\text{liv.biom}} + X_{\text{soil}} + X_{\text{Litter}} + X_{\text{Deadwood}}|}$$

With mean carbon stock changes in 2014 in

living biomass ($X_{\text{liv.biom}}$): $0.53 \text{ t C ha}^{-1} \text{ yr}^{-1}$,

soil (X_{Soil}): $0.001 \text{ t C ha}^{-1} \text{ yr}^{-1}$,

litter (X_{Litter}): $-0.160 \text{ t C ha}^{-1} \text{ yr}^{-1}$, and

dead wood ($X_{\text{Dead wood}}$): $0.001 \text{ t C ha}^{-1} \text{ yr}^{-1}$,

where positive values refer to gains in carbon stock; negative values refer to losses in carbon stock. Thus,

$$U_{tot} = \frac{\sqrt{(62.15 * -0.53)^2 + (13.18 * -0.001)^2 + (2.31 * 0.160)^2 + (679.46 * -0.001)^2}}{|(-0.53) + (-0.001) + 0.160 + (-0.001)|}$$

Thus, the resulting relative uncertainty of the total carbon stock change for Forest land is 88.6%. This value is used for the whole inventory period, i.e. explicitly for 1990 and 2017 (see Table 6-5). It should be noted that this value is an overestimation. Responsible for the high value is the high uncertainty estimate for the mean net change in volume of living biomass (54%) which is the result of the calculation of the relative uncertainty for a small net change in volume of living biomass of $1.31 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$. In fact, the uncertainties of mean gains and losses in living biomass from which the net change is calculated are only $\pm 2\%$ and $\pm 4\%$, respectively. For the combined stock change from soil, litter and dead wood the uncertainty is 5%.

Drainage of organic soils (CO_2 ; pool Organic soils in CRF Table4.A)

The CO_2 emissions from drained organic forest soils are very small ($<0.1\%$ of category 4A total) and was 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 (CH₄, N₂O; category 4(V))

The emission factor uncertainty for category 4(V) (biomass burning, wildfires) is 70%. This is the default value given for non-CO₂ emissions in IPCC (2003, chp. 3.2.1.4.2.4) and also corresponds to 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 of living biomass were calculated backward or forward starting from the growing stock 2005, as derived from NFI3 (see chp. 6.4.2.5).

Consistent time series of dead wood, litter and soil carbon were calculated with the model Yasso07 (see Didion and Thürig 2018 and chp. 6.4.2.7).

6.4.4 Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

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 analyzed, 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.

Afforestation – Growing stock and changes in growing stock

A comparison of Swiss carbon data for living biomass in afforestations with IPCC 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.

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.

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. During 2005 to 2009 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 removals for 4A1 amounted to -218 g C m⁻² yr⁻¹ in 2017 (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).

Changes in soil carbon stocks – Soil organic carbon (SOC) dataset 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. Most of them were sampled for the first time between 1985 and 1989 and resampled every five years ever since. 28 sites are located in forests (SAEFL 1993).

The long-term soil monitoring sites are resampled every 5 years. 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 5 are available for Forest land. For Cropland and Grassland, additionally the results of sampling campaign 6 were already processed.

The spatial variation of bulk density was included in calculating the carbon pools. 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 pools 0–20 cm [t/ha] were calculated by D [g/cm³] * 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 SOC pools for the forest top soils (0–20 cm) ranged between 35.4 t C ha⁻¹ (min) and 135.8 t C ha⁻¹ (max) and were on average 70.6 t C ha⁻¹. In these numbers one coniferous forest site was excluded as it revealed large SOC pools up to 191 t C ha⁻¹. For comparison, the mean carbon stock in Swiss forest soils from Nussbaum et al. (2012; 2014) amounts to 79.9 t C ha⁻¹ (Table 6-18).

Figure 6-7 shows that on average, SOC pools did not change monotonously during the measurement period between 1989 and 2009 in the sampled forest soils. At some of the forest monitoring sites higher values were found in the third resampling campaign.

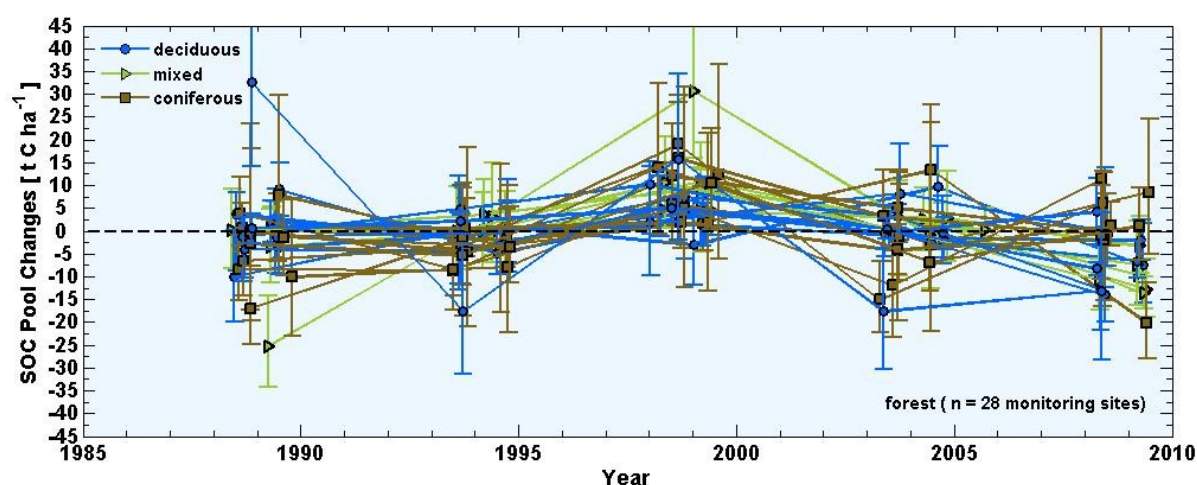


Figure 6-7 Time series of measured SOC pool changes in the top soil (0–20 cm) at the 28 NABO forest sites from the 1st to the 5th resampling campaigns. SOC pools were centred by the median SOC pool of all resamplings of the monitoring site. Each pool value presents the median of four bulked soil samples per campaign with measured SOC and bulk density. The error bars indicate the 25% and 75% percentiles resulting from the spatial variation of the sites and the errors along the measurement chain. The elevation of the forest sites ranges between 380 and 1690 m a.s.l.

Detailed studies at monitoring sites showed that short-term temporal variation of soil properties can result from different site conditions at the sampling date, e.g. regarding soil moisture, soil temperature and bulk density (Keller et al. 2006). For instance, at two forest sites six resamplings within three years revealed short-term variation of the SOC content between $\pm 1.8\%$ and $\pm 0.6\%$ (simple standard error). Therefore, the majority of the measured temporal variation for all forest sites was interpreted as natural variation (noise) and not as real SOC changes (signal). This hypothesis is also supported by the fact that the soil samples in the third resampling campaign were taken earlier in spring time as in the other sampling campaigns and hence, soil moisture content of the samples was higher on average. This might explain the large temporal variation, in particular at coniferous forest sites with a pronounced organic layer. Using a robust linear regression approach for the SOC pool data of the forest soils, the 95% confidence interval for the SOC pool was ± 1.5 t C ha⁻¹. In order to capture as good as possible the natural variation of these site-specific characteristics, standard operation procedures and quality assurance were implemented since the 4th soil campaign. Further work will focus on the correction of the measured carbon

pools to equivalent mass of the fine earth <2 mm. In this way, the 95% confidence interval of the mean SOC pool can probably be reduced to some degree.

In comparison, the mean change in SOC which was obtained with Yasso07 for the period 1991–2010 was $-0.00075 \pm 0.00002 \text{ t C ha}^{-1} \text{ yr}^{-1}$ (2SE; based on data in Didion and Thürig 2017). This value would correspond to $-0.015 \pm 0.00053 \text{ t C ha}^{-1}$ for the monitoring period of the NABO network (20 years). The analysis strongly suggests that modelled SOC pool changes are not inconsistent with the repeated soil inventories in the NABO network. As indicated by the 95% confidence interval for the 28 forest monitoring sites, the noise is two orders of magnitude higher than the modelled signal.

Uncertainty Estimates

The uncertainty for carbon stock changes in dead wood, 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 in the change of living biomass, Finland reported 20% (Statistics Finland 2017: chp. 6.4.3.1).

6.4.5 Category-specific recalculations

The following recalculations were implemented in this submission. Major recalculations which contribute significantly to the total differences emissions of sector 4A between the latest and the previous submission are presented also in chp. 10.1.2.4.

4A: Activity data 1990–2016 were updated (see chp. 6.3.5).

4A: Based on the new NFI data delivery NFI4 (2013–2017), the time series of stocks, gains and losses of living biomass were recalculated from 2006 onwards (Thürig et al. 2018). The consequences following the use of NFI4 data (2013–2017) instead of NFI4 data (2011–2015; FOEN 2018) were described in chp. 6.4.2.1.

4A: In addition to the new NFI data delivery, the time series of losses in living biomass was recalculated from 2006 onwards since values of cut and mortality from the NFI were recalibrated with relative harvesting amounts taken from the forest statistics (see chp. 6.4.2.5) over a different time span (2006–2017 instead of 2006–2016 in FOEN 2018).

4A: Estimates of annual litter and dead wood production that drive the Yasso07 simulations (cf. ch. 6.4.2.7) between NFI3 and NFI4 were obtained based on the new inventory period NFI4 (2013–2017) instead of NFI4 (2011–2015) (see chp. 6.4.2.1). Further, the estimates of carbon stock changes in dead wood, litter, and mineral soil in productive forests simulated with Yasso07 were recalculated to reflect methodological improvements, including consideration of (effect of recalculations are described in ch. 2.4.1 in Didion and Thuerig 2018):

- all sample plots with productive forest in any NFI inventory period including newly afforested and temporarily unstocked plots instead of plots classified as productive forest throughout all NFIs. Due to this methodological change the sample plot selection is fully consistent with the sample plot selection for estimating growth and mortality of living biomass in Swiss forests (see chp. 6.4.2.5);

- 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.

4A1: The model for calculating NMVOC emissions from forest stands has been fundamentally revised (MeteoTest 2019a). The biogenic NMVOC emissions reported in CRF Table4 were recalculated for the time period 1990-2016. The NMVOC values in CRF Table4 now include also the NMVOC emissions from wildfires controlled burning of residues in forestry.

4(V)A1: The time series 1990-2016 of activity data in the Swissfire database was updated by the database administrators. Also the amount of "available fuel" was recalculated, incorporating the new NFI 4 (2013-2017) data.

6.4.6 Category-specific planned improvements

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:

- Investigating the validity of the further development of Yasso07 for application in Switzerland. The new model version Yasso15 includes, among other, a new parameter set that improves the sensitivity of the simulated decomposition to temperature and precipitation. Preliminary results from Switzerland using a beta-version of Yasso15 indicate improvements over Yasso07, particularly with regards to soil carbon stocks. Status of the project: ongoing.
- Evaluating available data to improve the completeness of the litter inputs by accounting for the contribution of (a) fine-woody litter <7 cm and (b) litter from the herb- and shrub layer. A field study was recently completed which will provide estimates on biomass turnover of plants in the herb- and shrub layer of NFI plots. These activities may also further improve the accuracy of the simulated estimates. Status of the project: ongoing.
- Implementing knowledge gained in the project "Drivers of C stabilization in Swiss Forest soils" (Gosheva et al. 2018; anticipated for GHG inventory submission 2021).
- Review of the litter production estimates, including turnover rates (for GHG inventory submission 2021).

6.5 Category 4B – Cropland

6.5.1 Description

Table 6-24 Key categories in category 4B. Combined KCA results, level for 2017 and trend for 1990–2017, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
4B1	Cropland remaining cropland	CO ₂	L1, L2, T1, 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 in above-ground living biomass and carbon stocks in mineral and organic soils were considered.

In 2017, category 4B1 Cropland remaining cropland was a net source of 764.06 kt CO₂ due to emissions from living biomass, mineral and organic soils. Average living biomass in 4B1 increased slightly over the period 1990–2017. However, annual fluctuations in carbon stocks of living biomass were considerable (see chp. 6.5.2.1).

Over all inventory years the emissions in category 4B1 were dominated by carbon mineralisation in organic soils in the lowest elevation zone (z1: 86%), although overall, organic soils accounted only for 2.7% of cropland area in Switzerland (Table 6-7). However, contributions of the individual processes display high annual variations.

Category 4B2 Land converted to cropland was a small net source of 40.06 kt CO₂ in 2017 mainly due to carbon losses in mineral soils under Grassland converted to cropland.

6.5.2 Methodological issues

Carbon in living biomass, annual carbon stocks and carbon stock changes in mineral soils estimated with a Tier 3 approach using the model RothC (Wüst-Galley et al. 2019). The results were integrated in the GHG inventory by calculating area-weighted average values per elevation zone and the difference in carbon stock between a specific year and the preceding year was reported as net change for mineral soils.

6.5.2.1 Carbon in living biomass

Annual biomass carbon stocks per elevation zone (cf. chp. 6.2.2) are shown in Table 6-25. 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 1990–2017 for harvested biomass were published by the Swiss Farmers Union (SBV 2018 and former editions). For the year 2017 provisional values were calculated (mean of time span 2006-2016). A carbon fraction of 0.45 was assumed based on Bolinder et al. (2007).

The resulting area-weighted mean biomass stock for Swiss cropland over the inventory time period was 3.83 ± 0.22 (1 SD) t C ha⁻¹.

Carbon stock and carbon stocks 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 idea behind this approach is that due to stockpiling the consumption (and thus oxidation) of the biomass is levelled out between individual years (see Figure 6-8).

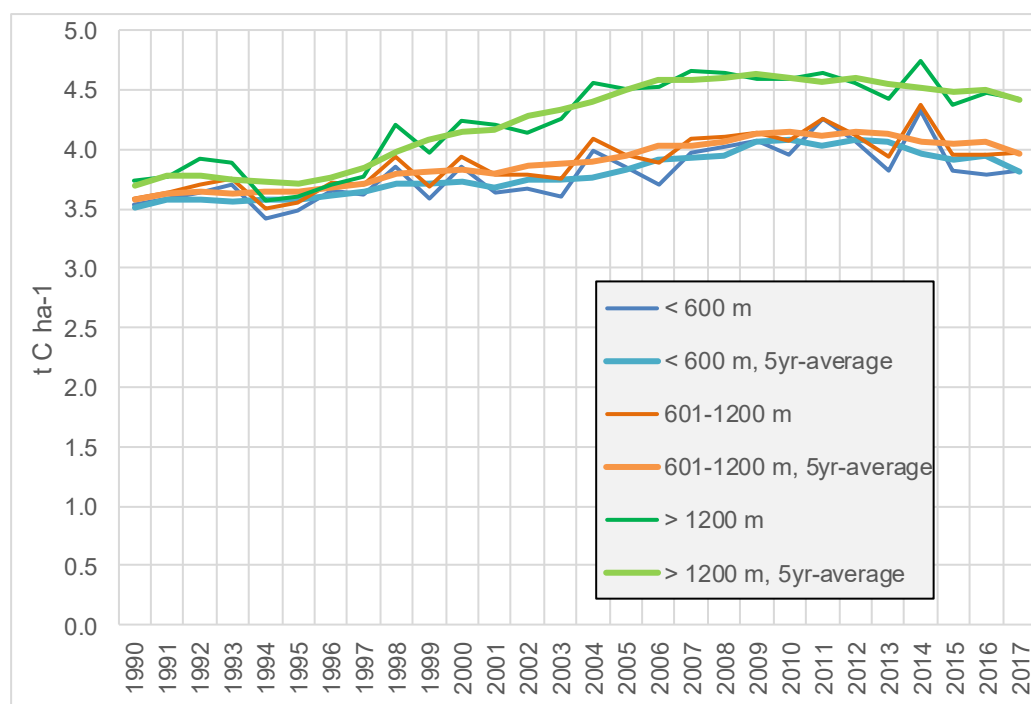


Figure 6-8 Carbon stocks in living biomass of cropland for three elevation zones (SBV 2018 and former editions) and corresponding moving averages over five years. Elevation zone >1200 m is less important as it covers only 0.1% of the total cropland area.

Table 6-25 Area-weighted carbon stocks (t C ha⁻¹) and carbon stock changes (gain/loss) (t C ha⁻¹ yr⁻¹) in arable crop yields (living biomass of CC21) reported as moving average over five years, stratified for elevation zone (Elev.; cf. chp. 6.2.2). A carbon fraction of 0.45 was assumed. 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	3.51	3.58	3.58	3.57	3.58	3.58	3.60	3.64	3.71	3.71
Stock	2	3.57	3.63	3.64	3.63	3.64	3.64	3.68	3.72	3.80	3.81
Stock	3	3.70	3.77	3.78	3.75	3.74	3.71	3.77	3.85	3.98	4.08
Gain/loss	1	0.06	0.06	0.00	-0.01	0.01	0.00	0.03	0.03	0.08	0.00
Gain/loss	2	0.06	0.06	0.01	-0.01	0.01	0.00	0.04	0.04	0.08	0.01
Gain/loss	3	0.08	0.07	0.00	-0.03	-0.01	-0.03	0.06	0.08	0.13	0.10

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	3.72	3.67	3.75	3.75	3.76	3.83	3.91	3.93	3.95	4.06
Stock	2	3.83	3.79	3.87	3.88	3.89	3.96	4.03	4.04	4.06	4.13
Stock	3	4.15	4.16	4.28	4.33	4.40	4.50	4.58	4.59	4.60	4.63
Gain/loss	1	0.01	-0.05	0.08	0.00	0.01	0.06	0.08	0.02	0.02	0.11
Gain/loss	2	0.01	-0.03	0.08	0.01	0.02	0.06	0.07	0.01	0.02	0.08
Gain/loss	3	0.07	0.01	0.12	0.05	0.06	0.11	0.08	0.01	0.02	0.03

Living biomass	Elev.	2010	2011	2012	2013	2014	2015	2016	2017		
CC21: carbon stock [t C ha ⁻¹] and gain/loss in living biomass [t C ha ⁻¹ yr ⁻¹]											
Stock	1	4.08	4.04	4.09	4.06	3.97	3.92	3.94	3.81		
Stock	2	4.14	4.11	4.16	4.13	4.07	4.04	4.07	3.97		
Stock	3	4.61	4.57	4.60	4.55	4.52	4.49	4.50	4.42		
Gain/loss	1	0.02	-0.04	0.05	-0.03	-0.09	-0.05	0.02	-0.13		
Gain/loss	2	0.01	-0.03	0.05	-0.02	-0.06	-0.03	0.03	-0.10		
Gain/loss	3	-0.02	-0.04	0.03	-0.04	-0.03	-0.03	0.01	-0.08		

6.5.2.2 Carbon in dead organic matter

Applying a Tier 1 approach carbon stocks in dead organic matter were not assessed.

6.5.2.3 Carbon in soils

6.5.2.3.1 Mineral soils

Initial carbon stocks

Soil carbon stocks in mineral soils under cropland were calculated based on Leifeld et al. (2003, 2005), as described in Wüst-Galley et al. (2019). 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. Average stocks were calculated as weighted means using the location of arable land and leys, according to the Swiss Land Use Statistics AREA (see chp. 6.1.1). 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 area is 9.1 t C ha^{-1} (1 SD). These 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 & Jenkinson 1999) to estimate carbon stocks in mineral soil (0–30 cm) under cropland for the period 1990 to 2017. The implementation of RothC in the Swiss GHG inventory is described in detail in Wüst-Galley et al. (2019).

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). Plant inputs were derived using an allometric function, adapted from Bolinder et al. (2007) as described in Wüst-Galley et al. (2019), using annual harvest information as input data. Calibration and validation of RothC are described in Wüst-Galley et al. (2019).

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 using these two data sets as well as monthly surface incoming shortwave radiation (SIS), also obtained from MeteoSwiss. The most important 19 crops (as introduced in chp. 6.5.2.1, covering over 99% of Swiss cropland area) were considered. Annual crop yields were obtained from the Swiss Farmers Union (SBV 2018 and former editions). Based on yield data from crops, plant carbon inputs to the soil from crop residues, roots and rhizodeposition were estimated according to a modified version of Bolinder et al. (2007) as described in Wüst-Galley et al. (2019). Annual carbon inputs from organic manures to different crops or grassland management types were calculated based

on: (i) organic manure production, calculated as a function of excretion rate of volatile solids (VS), using the method described in chp. 5.3.2.2.1; (ii) animal herd size, described in chp. 5.3.2.5.1; (iii) manure management systems, described in chp. 5.3.2.2.4 (using the data for VS); (iv) 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. 2013, Kupper et al. 2018); (v) 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); (vi) straw production, using annual values published by the Swiss Farmers Union; (vii) the amount of manure digested anaerobically in biogas plants, as described in chp 5.3.2.2.3; (viii) the amount of liquid and solid digestates, as described in chp 5.5.2.2.2; (ix) the number of livestock units moving annually to the summer pasture regions, using annual data (1999 to present, years prior using extrapolation) from the Swiss Federal Office for Agriculture. Clay content was derived from the Swiss Soil Suitability Map (Bodeneignungskarte) from the Swiss Federal Statistics Office (SFSO 2002) as described in Wüst-Galley et al. (2019). 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. (2019).

Up-scaling

The RothC modelling was carried out for 4560 different combinations (19 crops x 240 regions) representing similar climate, crop type, management systems and clay content, as described in Wüst-Galley et al. (2019).

Area-weighted average values, accounting for the extent of cropland (according to the AREA Land Use Statistics) and different crops were used to up-scale the RothC results to Switzerland. These results were integrated in the GHG inventory by calculating area-weighted average values per elevation zone, accounting for the distribution of cropland in each elevation zone. See Table 6-26.

Table 6-26 Area-weighted carbon stock means (t C ha^{-1}) and carbon stock changes ($\text{t C ha}^{-1} \text{ yr}^{-1}$) in mineral soils (0-30cm) for cropland (CC21), stratified for elevation zone (Elev.). 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 [$\text{t C ha}^{-1} \text{ yr}^{-1}$]											
Stock	1	49.91	50.07	50.10	49.89	49.73	49.56	49.62	49.66	49.87	50.04
Stock	2	49.45	49.65	49.77	49.67	49.59	49.48	49.63	49.73	49.83	49.99
Stock	3	40.38	40.77	41.01	41.05	41.11	41.13	41.43	41.91	42.07	42.49
Net change	1	0.08	0.16	0.02	-0.20	-0.16	-0.17	0.06	0.03	0.21	0.18
Net change	2	0.00	0.20	0.12	-0.10	-0.08	-0.12	0.15	0.10	0.11	0.16
Net change	3	0.18	0.39	0.24	0.04	0.05	0.02	0.31	0.48	0.16	0.42

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 [$\text{t C ha}^{-1} \text{ yr}^{-1}$]											
Stock	1	49.61	49.48	49.33	49.91	50.29	50.06	50.24	50.38	50.48	50.66
Stock	2	49.73	49.68	49.65	50.06	50.40	50.18	50.41	50.59	50.71	50.86
Stock	3	42.91	43.33	43.51	44.32	45.21	45.43	45.88	45.96	45.97	46.10
Net change	1	-0.44	-0.13	-0.15	0.58	0.38	-0.23	0.18	0.14	0.10	0.18
Net change	2	-0.26	-0.05	-0.02	0.41	0.34	-0.22	0.22	0.19	0.11	0.15
Net change	3	0.41	0.43	0.18	0.81	0.89	0.22	0.45	0.08	0.02	0.13

Mineral soil	Elev.	2010	2011	2012	2013	2014	2015	2016	2017		
CC21: carbon stock [t C ha^{-1}] and net change in mineral soil [$\text{t C ha}^{-1} \text{ yr}^{-1}$]											
Stock	1	50.66	50.90	50.77	50.68	50.70	50.67	50.34	50.14		
Stock	2	50.92	51.07	50.91	50.87	50.94	50.87	50.68	50.49		
Stock	3	46.32	46.40	46.20	46.05	45.96	45.84	45.90	45.60		
Net change	1	0.00	0.24	-0.13	-0.09	0.02	-0.03	-0.32	-0.20		
Net change	2	0.06	0.15	-0.16	-0.04	0.07	-0.06	-0.20	-0.19		
Net change	3	0.22	0.09	-0.20	-0.15	-0.09	-0.13	0.06	-0.30		

6.5.2.3.2 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 $240 \pm 48 \text{ t C ha}^{-1}$ (uncertainty 20%).

6.5.2.4 Changes in carbon stocks

6.5.2.4.1 Living biomass

Carbon stocks in living biomass intermittently increased from 1990 to 2017 (Figure 6-8; SBV 2018). The difference in biomass stock between a specific year and the preceding year was reported as gain or loss of carbon (see Table 6-25). The resulting values are in the range between -0.13 and $0.13 \text{ t C ha}^{-1} \text{ yr}^{-1}$ with an average of $0.019 \text{ t C ha}^{-1} \text{ yr}^{-1}$ for the inventory time period.

6.5.2.4.2 Dead organic matter

Applying a Tier 1 approach, carbon stocks in dead organic matter were assumed to be in equilibrium for Cropland remaining cropland.

6.5.2.4.3 Mineral soils

The difference in carbon stock between a specific year and the preceding year was reported as net change for mineral soils (Table 6-26 and Figure 6-9). Mean annual carbon stock

change for this period for elevation zone 1 is $+0.011 \text{ t C ha}^{-1}$ and for elevation zone 2 is $+0.037 \text{ t C ha}^{-1}$ (elevation zone 3 represents $<1\%$ of cropland). The weighted average annual stock change across all elevation zones is $+0.020 \text{ t C ha}^{-1}$. Annual carbon stocks in croplands on a per hectare basis deviate from the stocks predicted by linear regression across the inventory time period (i.e. accounting for the long-term trend) by -1.52 to $+0.95\%$ (or -0.75 to $+0.48 \text{ t C ha}^{-1}$) across the 1990 to 2017 period.

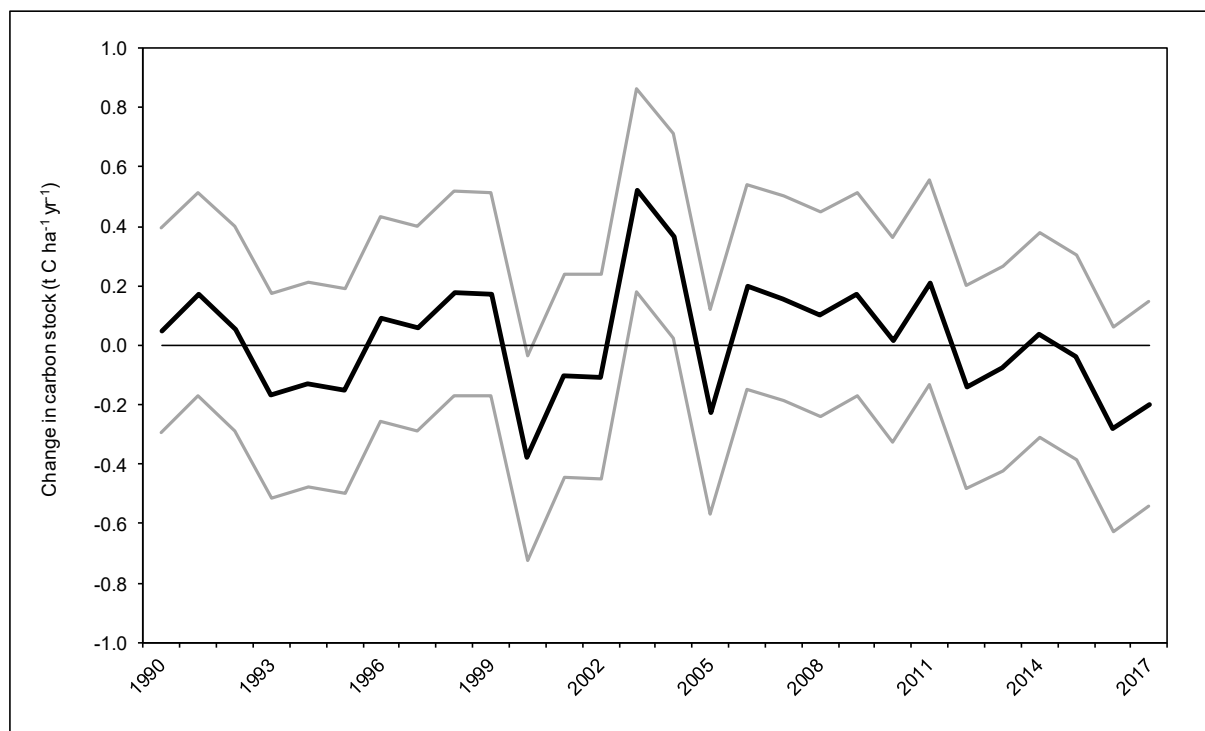


Figure 6-9 Area-weighted carbon stock changes ($\text{t C ha}^{-1} \text{ yr}^{-1}$) in mineral soils (0-30 cm) for cropland averaged across three elevation zones (black line) plus upper and lower confidence intervals (grey lines; see chp. 6.5.3).

6.5.2.4.4 Organic soils

The annual net carbon stock change in organic soils was estimated to $-9.52 \text{ t C ha}^{-1}$ 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).

6.5.2.4.5 Land-use change

In the case of land-use change, the net carbon changes in biomass and soil were calculated as described in chp. 6.1.3.

6.5.2.5 N₂O emissions from cropland

N₂O emissions from drainage of organic soils (category 4(II)) on cropland are reported in the agriculture sector (CRF Table3.D).

The calculation of emissions for categories 4(III) and 4(IV) (direct N₂O emissions from nitrogen mineralisation in mineral soils and indirect N₂O 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 2019).

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 2017, are 0.016 t C ha⁻¹ yr⁻¹ for 4B1 and 0.010 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 4B1 and 4B2. This value was calculated by a Monte-Carlo analysis (Wüst-Galley et al. 2019). 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.

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 37.8% (see chp. 6.3.3), resulting in a combined uncertainty of 44.2%. Thus, the absolute uncertainties of the total organic soil emissions in 2017 are 42.21 kt C for 4B1 and 1.22 kt C for 4B2. By dividing those uncertainties with the total area of 4B1 and 4B2, respectively, the absolute uncertainties per hectare result in 0.117 t C ha⁻¹ yr⁻¹ for 4B1 and 0.040 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 0.346 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 mean net carbon stock change per hectare of 4B1 and 4B2, respectively. In 2017, the mean net carbon stock changes were -0.578 t C ha⁻¹ for 4B1 and -0.356 t C ha⁻¹ for 4B2 (calculated from CRF Table 4.B). The resulting relative uncertainties are 62.8% for 4B1 and 97.1% for 4B2, respectively (see Table 6-5).

In the same way the uncertainties for the year 1990 were calculated. They are 228.9% (4B1) and 68.9% (4B2) (Table 6-5).

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. Small inconsistencies in the input data for the RothC model (related to livestock husbandry, compare chp. 5.2.3 and 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 in mineral soils

6.5.4.2 The initial SOC stocks for this submission are modelled, using the calculation of Leifeld et al. (2003, 2005), as described in Wüst-Galley et al. (2019). The calculation differs from that of previous submissions in that the spatial resolution of the new calculation is higher. 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 project described in chp. 6.5.6.

6.5.4.3 Changes in living biomass

In 2012 an assessment of the appropriateness of the estimated pools of carbon in living biomass was conducted (ART 2012a). It came to the conclusion that almost all carbon stocks and carbon stock changes are in the range of the respective default values provided in the guidelines (IPCC 2006). Nevertheless, there is room for improvements. Consequently, the biomass carbon pools were recalculated for the GHG inventory submission 2019 in the course of the Tier 3 approach for quantification of carbon stocks and carbon stock changes in agricultural soils (see chp. 6.5.2.3). As far as possible, the input data for the simulations were consistent with input data in the Agriculture sector. The new assessment methodology resulted in lower estimates, probably due to the consideration of minor crop cultures with lower yields, a new assessment of the yields for leys and a lower carbon fraction of 0.45 (compared to 0.50 in the previous submission). Furthermore, root biomass is not yet considered in the living biomass.

6.5.4.4 Changes in soil carbon stocks

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). High increases in SOC stocks as e.g. in 2003 (see Figure 6-9) might possibly be explained by reduced SOC decomposition caused by warmer temperatures and associated higher soil moisture deficits (the summer of 2003 was exceptionally warm in Switzerland). A comparison of these increases in SOC stocks and measured values from field experiments are made by Wüst-Galley et al. (2019).

The SOC pools measured at 29 cropland monitoring sites of the Swiss Soil Monitoring Network (NABO; see chp. 6.4.4) 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 pools. The range of the calculated SOC pools 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 stocks of roughly 3.3% per 10 years for mineral cropland soils (minimum detectable change for about 30 monitoring sites including three or more sampling campaigns). Regarding the measured SOC pools (mean \approx 47 t ha⁻¹) this corresponds to a minimum detectable change of roughly 0.15 t C ha⁻¹ yr⁻¹ for SOC pools.

The mean change in SOC which was calculated with RothC for the years 1990-2017 was 0.02 ± 0.344 t C ha⁻¹ yr⁻¹ (weighted average change across three elevation zones \pm absolute uncertainty based on a Monte Carlo analysis; see Figure 6-9 and chp. 6.5.3). In comparison, the modelled change is one order of magnitude smaller than the detectable change by NABO and suggests that modelled SOC pool changes agree with the repeated soil inventories in the NABO network.

The SOC pools 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 pools 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).

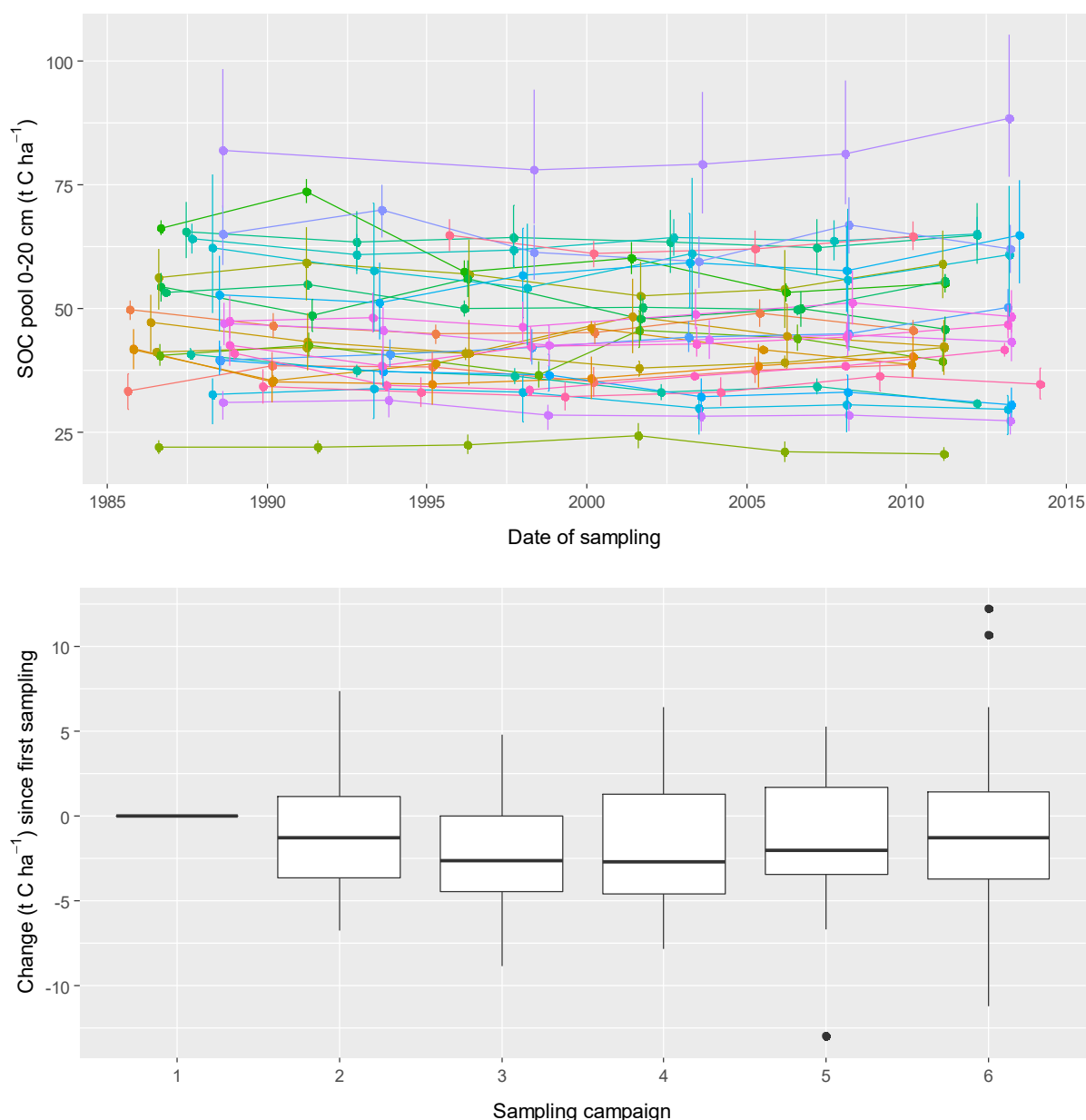


Figure 6-10 Measured SOC pools for topsoils (0–20 cm) and their changes for 29 NABO long-term monitoring sites featuring mineral soils and used as cropland during the time period 1985–2014. The elevation of the sites ranges from 324 to 945 m a.s.l. Top panel: SOC pools 0–20 cm per site and sampling; 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 pools since first sampling (boxes indicate the lower and 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). Furthermore, only long-term changes between cropland and grassland are considered relevant for carbon stock changes in soils. 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

Major recalculations which contribute significantly to the total differences emissions of sector 4B between the latest and the previous submission are presented also in chp. 10.1.2.4. The following recalculations were implemented in this submission:

- 4B: Activity data (areas) 1990–2016 were updated (see chp. 6.3.5).
- 4B: The biomass carbon pools for cropland were recalculated based on harvest data from the Swiss Farmers Union (SBV 2018 and former editions) in the course of the new Tier 3 approach for cropland mineral soils. The harvested biomass was calculated including 19 relevant annual crops instead of seven like in previous submissions. The carbon fraction was changed from 0.50 to 0.45 (Bolinder et al. 2007). Data were reported as moving averages over five years.
- 4B: Carbon stocks and carbon stock changes in mineral soils were recalculated. Instead of a Tier 1 approach assuming constant carbon pools, annual changes of carbon stocks in mineral soils were modelled using a Tier 3 approach (application of the RothC model by Wüst-Galley et al. 2019).

6.5.6 Category-specific planned improvements

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). 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 1500 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 further evaluation.

A pilot study to evaluate possible Tier 3 methodological approaches for quantification of carbon stocks and carbon stock changes in agricultural soils was completed by Köck et al. (2013). Based on this, four soil carbon models were evaluated 2015–2017, using data from Swiss long-term experiments. In this inventory submission, the model results were implemented for the first time (Wüst-Galley et al. 2019). For future submissions improvement of the calculations of the initial carbon stocks will be carried out, as there are indications that

the soil depth of some mountain soils has been underestimated. It is not anticipated that carbon stock changes in cropland soils will be altered significantly by this improvement.

A digital soil modeling project at Agroscope (funded by FOEN 2017-2020) builds on the outcomes of the recently completed national research programme “Sustainable Use of Soil as a Resource” (www.nfp68.ch/en). It addresses the shortcomings of missing spatially inclusive and comprehensive soil information in Switzerland. A LULUCF module aims at improving the estimates of soil carbon contents in Swiss non-forest soils.

6.6 Category 4C – Grassland

6.6.1 Description

Table 6-27 Key categories in category 4C. Combined KCA results, level for 2017 and trend for 1990–2017, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
4C1	Grassland remaining grassland	CO ₂	L1, L2, T1, T2
4C2	Land converted to grassland	CO ₂	L1, L2, T1, T2

Swiss grasslands belong to the cold temperate wet climatic zone.

Carbon stocks in living biomass and carbon stocks 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 Table 4.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 2017, category 4C1 Grassland remaining grassland was a net source of 316.32 kt CO₂. Carbon stocks in living biomass are assumed to be in balance (i.e. no carbon stock changes occur). Most CO₂ emissions of category 4C1 were generated by carbon stock changes in mineral soils and by carbon mineralisation in organic soils under permanent grasslands (CC31), although only 0.6% of CC31 soils in Switzerland are organic soils (Table 6-7). Contributions of other Grassland remaining grassland categories (CC32-CC37) were of minor importance, although there is a noticeable gain in living biomass for shrub vegetation (CC32). The gain can be explained by abandoned pastures (CC31) that change to CC32 (approximately 1 kha per year, see Table 6-9).

Category 4C2 Land converted to grassland was a net source of 225.84 kt CO₂ in 2017. The highest individual contribution came from subcategory 4C2.1 Forest land converted to grassland being responsible for a net source of 429.26 kt CO₂. Most of this source was due to net changes in living biomass from deforestation. Subcategories 4C2.2 to 4C2.5 were net

sinks due to sequestration of CO₂ in biomass and in mineral soils in the course of the conversion to grassland.

6.6.2 Methodological issues

Annual carbon stocks and carbon stock changes in mineral soils were estimated by a Tier 3 approach, using the model RothC (Wüst-Galley et al. 2019). In the course of this recalculation carbon in living biomass was also reassessed. The results were integrated in the GHG inventory by calculating area-weighted average values per elevation zone (see chp.6.5.2.3) and the difference in carbon stock between a specific year and the preceding year was reported as net change for mineral soils.

6.6.2.1 Carbon 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 rely on the prevailing climatic and pedogenic conditions, grassland stocks were calculated separately for three elevation zones (corresponding to those used in category 4A Forest Land).

Standing stocks for permanent grasslands (t C ha⁻¹) were calculated as the annual cumulative yield (C_{yield}) of six differentially managed grasslands for three elevation zones. Total harvested biomass was adopted from annual statistics of the Swiss Farmers Union (SBV 2018 and former 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:

- extensive meadow
- less intensive meadow
- intensive meadow
- extensive pasture
- intensive pasture
- summer pasture

Table 6-28 shows the average C_{yield} 1990-2017 assuming a carbon fraction of 0.45 (Bolinder et al. 2007). Data for root biomass C were compiled by ART (2011a) based on published data of Swiss grassland. Carbon stocks in roots are in the range of 1.82–5.70 t C ha⁻¹ depending on elevation. Root biomass was added to above-ground biomass to derive the total living biomass for CC31 (cf. Table 6-28).

Table 6-28 Annual yields (C_{yield}), root biomass (C_{root}) and total living biomass (C_{I}) of permanent grassland (CC31) for three elevation zones (Z1, Z2, Z3). Each value of C_{yield} represents the mean of six grassland types in the period 1990-2017 (based on SBV 2018 and former editions and Richner et al. 2017, see also Wüst-Galley et al. 2019).

Elevation [m]	C_{yield}	C_{root}	C_{I}
	[t C ha ⁻¹]		
Z1: <601	3.16	1.82	4.98
Z2: 601-1200	2.78	2.04	4.82
Z3: >1200	0.80	5.70	6.50

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. 6.4.2.8, 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 (C_{I}) for CC33 was therefore calculated as:

$$C_{\text{I}} = \frac{[(C_{\text{I}_{\text{vineyards}}} * \text{area}_{\text{vineyards}}) + (C_{\text{I}_{\text{low-stem orchards}}} * \text{area}_{\text{low-stem orchards}})]}{(\text{area}_{\text{vineyards}} + \text{area}_{\text{low-stem orchards}})}$$

C_{I} of vineyards (5.23 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 (1.62 t C ha⁻¹).

Woody biomass 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 content of the grass layer was calculated using the following information and assumptions: (i) 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. (ii) The grass layer between the vine rows has a lower carbon content than permanent grassland. It is assumed that it is 50% less than the carbon content of CC31 (elevation <600 m).

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.

$$\text{Stem wood volume} = r^2 * \pi * \text{height} = (5 \text{ cm})^2 * 3.1 * 100 \text{ cm} = 7.75 \text{ dm}^3$$

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 content of a tree of the type low-stem ('Niederstamm') was calculated as follows:

$$\begin{aligned} \text{C low-stem} &= \text{stem wood volume} * \text{BEF} * \text{wood density} * \text{carbon content} \\ &= 7.75 \text{ dm}^3 * 2.3 * 0.55 \text{ kg/dm}^3 * 0.5 = 4.9 \text{ kg C} \end{aligned}$$

The mean stand density of low-stem orchards was estimated as 2500 ha^{-1} (Widmer 2006), resulting in a CI of $12.25 \text{ t C ha}^{-1}$.

The resulting carbon in living biomass (CI) for CC33 is 5.36 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:

$$\begin{aligned} \text{CI biomass} &= (\text{carbon per fruit tree [t C]} * \text{number of fruit trees / area orchards [ha]}) \\ &+ \text{carbon in grass [t C ha}^{-1}] \end{aligned}$$

The carbon content of a large fruit tree with a DBH of 25–35 cm was calculated as follows:

$$\text{C (Hochstamm)} = \text{Stem wood volume} * \text{KE-Factor} = 225 \text{ kg C}$$

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 $17.78 \text{ t C ha}^{-1}$. Because orchards typically have a grass understory, the biomass of CC31 was added to the woody biomass. The biomass of CC31 (cf. Table 6-28) was weighted with the area of CC35 in the three elevation zones (cf. Table 6-7) – resulting in 4.95 t C ha^{-1} – and added to the woody biomass to obtain a total carbon stock of $22.73 \text{ t C ha}^{-1}$ 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 ($20.45 \text{ t C ha}^{-1}$; cf. chp. 6.4.2.8; Düggelein 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 in the three elevation zones (cf. Table 6-28) was assumed to be representative for the carbon stock on unproductive grassland CC37. Carbon in living biomass in unproductive grassland appeared to be 6.40 t C ha^{-1} .

6.6.2.2 Carbon in dead organic matter

Applying a Tier 1 approach carbon stocks in dead organic matter were not assessed.

6.6.2.3 Carbon in soils

Permanent grassland (CC31):

Mineral soils

Carbon stocks in grassland soil refer to a depth of 0–30 cm and were calculated based on Leifeld et al. (2003, 2005) as described in Wüst-Galley et al. (2019) and in chp. 6.5.2.3. Average stocks were calculated as weighted means using the location of permanent grassland, according to the AREA Land Use Statistics. The median soil organic carbon stock (0–30 cm, in 1975) for permanent grassland is 60.5 t C ha^{-1} . The Variability of carbon stocks across the area is 23.1 t C ha^{-1} (1 SD). These carbon stocks were used to initialise the RothC model (see below and chp. 6.5.2.3) which was used to estimate carbon stocks from 1990 to 2017.

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 2017, as described in chp. 6.5.2.3 and in Wüst-Galley et al. (2019). Six differently managed permanent grassland types (as introduced in chp. 6.6.2.1 covering over 99% of Swiss permanent grassland), as listed in chp. 6.6.2.1, 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. (2019). Mean carbon stock values calculated for permanent grasslands (CC31) are given in Table 6-29.

Table 6-29 Area-weighted carbon stock means (t C ha^{-1}) and carbon stock changes ($\text{t C ha}^{-1} \text{ yr}^{-1}$) in mineral soils (0-30cm) for permanent grassland (CC31), stratified for elevation zone (Elev.). Highlighted data for 1990 are displayed in Table 6-4.

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 [$\text{t C ha}^{-1} \text{ yr}^{-1}$]											
Stock	1	59.40	59.54	59.59	59.34	59.11	58.88	58.89	58.69	58.52	58.56
Stock	2	60.95	61.11	61.18	61.02	60.88	60.70	60.78	60.76	60.63	60.63
Stock	3	49.05	49.46	49.76	49.92	50.11	50.24	50.59	50.85	50.96	51.18
Net change	1	-0.01	0.14	0.06	-0.25	-0.23	-0.23	0.01	-0.20	-0.17	0.04
Net change	2	-0.09	0.15	0.07	-0.16	-0.14	-0.18	0.09	-0.03	-0.12	0.00
Net change	3	0.26	0.41	0.29	0.16	0.19	0.13	0.35	0.26	0.11	0.22

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 [$\text{t C ha}^{-1} \text{ yr}^{-1}$]											
Stock	1	58.22	57.80	57.60	57.81	57.97	57.71	57.79	57.62	57.53	57.42
Stock	2	60.46	60.27	60.18	60.15	60.15	60.05	60.06	59.91	59.96	59.92
Stock	3	51.28	51.42	51.56	51.65	51.76	51.90	52.02	52.03	52.30	52.42
Net change	1	-0.34	-0.42	-0.19	0.21	0.16	-0.26	0.07	-0.16	-0.10	-0.11
Net change	2	-0.17	-0.19	-0.09	-0.02	-0.01	-0.10	0.01	-0.15	0.05	-0.04
Net change	3	0.10	0.13	0.15	0.08	0.11	0.14	0.12	0.01	0.27	0.12

Mineral soil	Elev.	2010	2011	2012	2013	2014	2015	2016	2017		
CC31: carbon stock [t C ha^{-1}] and net change in mineral soil [$\text{t C ha}^{-1} \text{ yr}^{-1}$]											
Stock	1	57.24	57.06	56.75	56.53	56.18	56.04	56.00	55.78		
Stock	2	59.85	59.73	59.50	59.43	59.21	59.03	58.96	58.81		
Stock	3	52.56	52.66	52.58	52.68	52.75	52.75	52.82	52.81		
Net change	1	-0.19	-0.18	-0.31	-0.22	-0.35	-0.14	-0.04	-0.22		
Net change	2	-0.07	-0.12	-0.22	-0.07	-0.23	-0.18	-0.07	-0.15		
Net change	3	0.14	0.10	-0.08	0.10	0.06	0.00	0.08	-0.01		

Organic soils

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 $240 \pm 48 \text{ t C ha}^{-1}$ (uncertainty 20%).

Shrub vegetation (CC32) and Copse (CC34)

Due to the lack of more specific data, values calculated for grassland by Leifeld et al. (2003, 2005) were used for the carbon stocks of mineral soils (0–30 cm): 62.02, 67.50, and $75.18 \text{ t C ha}^{-1}$ depending on elevation zone. The approach correlated measured soil organic carbon stocks (t ha^{-1}) for arable land and leys with soil texture after correction for soil depth and stone content. Area upscaling used the Swiss digital soil map (SFSO 2000a), and average stocks were calculated as weighted means using the area of arable land and leys.

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)

The category includes carbon stocks in soils of vineyards, low-stem orchards and tree nurseries. In accordance with the estimate of carbon stocks in biomass, only vineyards and low-stem orchards were considered. Both land-use types were assumed to have at least

partially grass undercover. Therefore, the soil carbon stock may range between the values for grassland and cropland. For mineral soils, it was decided to take the soil carbon content value of cropland as calculated by Leifeld et al. (2003, 2005): 53.40 t C ha⁻¹ (0–30 cm). The approach correlated measured soil organic carbon stocks (t ha⁻¹) for arable land and leys with soil texture after correction for soil depth and stone content. Area upscaling used the Swiss digital soil map (SFSO 2000a), and average stocks were calculated as weighted means using the area of arable land and leys.

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. The mean value of shrub vegetation (CC32) and copse (CC34), respectively, from the two lower elevation zones (i.e. 64.76 t C ha⁻¹) was taken for mineral soils (0–30 cm), and the value of 240 t ha⁻¹ for organic soils (0–30 cm).

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, 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 mostly belongs to 'grassland' and 'unproductive land' and likely includes many of the former alpine grasslands (SFSO 2005). These grasslands are mainly located at elevations >1200m a.s.l. Thus, using the respective value of shrub vegetation (CC32), the carbon stock of CC36 was calculated as:

$$\text{Cs of CC36} = 0.35 * 75.18 \text{ t C ha}^{-1} = 26.31 \text{ t C ha}^{-1} \text{ (0–30 cm)}$$

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. In accordance with the procedure followed for biomass, the soil carbon stock in mineral soils of CC37 was assumed to correspond to the mean value of carbon stocks in mineral soils under shrub vegetation (CC32) for all three elevation zones. The carbon stock in soils under CC37 is thus 68.23 t C ha⁻¹.

The mean soil organic carbon stock (0–30 cm) of organic soils is 240 t C ha⁻¹.

6.6.2.4 Changes in carbon stocks

6.6.2.4.1 Living biomass

Applying a Tier 1 approach, changes in carbon stocks in living biomass were assumed to be in equilibrium for Grassland remaining grassland.

6.6.2.4.2 Dead organic matter

Applying a Tier 1 approach, changes in carbon stocks in dead organic matter were assumed to be in equilibrium for for Grassland remaining grassland.

6.6.2.4.3 Mineral soils: Permanent grassland (CC31)

The difference in carbon stock between a specific year and the preceding year was reported as net change for mineral soils (Table 6-29 and Figure 6-11). The mean annual carbon stock change for this period for elevation zone 1 is $-0.130 \text{ t C ha}^{-1}$, for elevation zone 2 is $-0.080 \text{ t C ha}^{-1}$ and for elevation zone 3 is $+0.144$. The weighted average annual stock change across all elevation zones is $+0.002 \text{ t C ha}^{-1}$. Annual carbon stocks in permanent grasslands on a per hectare basis deviate from the stocks predicted by linear regression across the inventory time period (i.e. accounting for the long-term trend) by -1.3 to $+0.56\%$ (or -0.64 to $+0.32 \text{ t C ha}^{-1}$) across the 1990 to 2017 period.

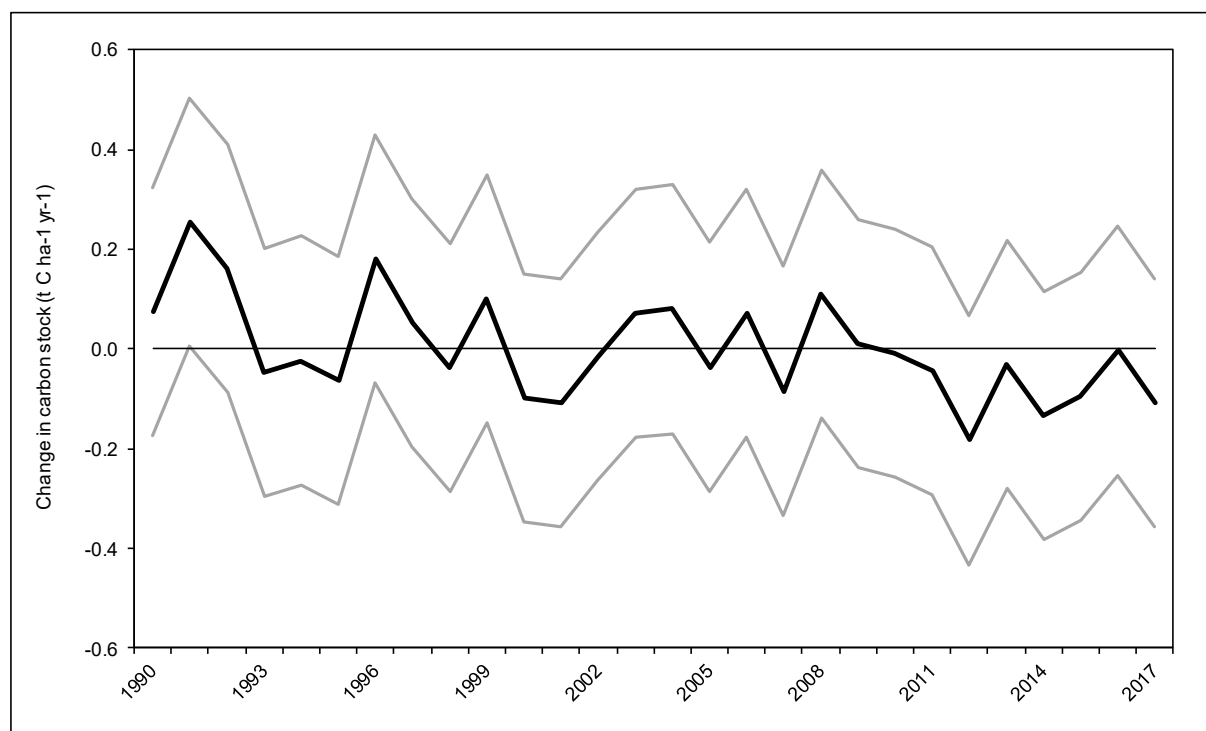


Figure 6-11 Area-weighted carbon stock changes ($\text{t C ha}^{-1} \text{ yr}^{-1}$) in 0-30 cm in mineral soils for permanent grassland (CC31) averaged across three elevation zones (black line) plus upper and lower confidence intervals (grey lines; see chp. 6.6.3).

6.6.2.4.4 Mineral soils: Remaining grassland subcategories (CC32-37)

A Tier 1 approach (changes in carbon are in equilibrium) was assumed for carbon stock changes in mineral soils in the subcategories CC32–37.

6.6.2.4.5 Organic soils

The annual net carbon stock change in organic soils on managed grassland (CC31, CC33 and CC35) was estimated as $-9.52 \text{ t C ha}^{-1}$ 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 $5.30 \text{ t C ha}^{-1} \text{ yr}^{-1}$ according to available domestic data (ART 2011b; Paul and Alewell 2018).

6.6.2.4.6 Land-use change

In the case of land-use change, the net carbon changes in biomass and soil of CC31, CC32, CC33, CC34, CC35, CC36, and CC37 were calculated as described in chp. 6.1.3.

6.6.2.5 N₂O emissions from grassland

N₂O emissions from drainage of organic soils (category 4(II)) on grassland were reported in the agriculture sector (CRF Table3.D).

The calculation of emissions for categories 4(III) and 4(IV) (direct N₂O emissions from nitrogen mineralisation in mineral soils and indirect N₂O emissions from managed soils) is described in chp. 6.10.

6.6.2.6 Emissions from wildfires

Data on wildfires affecting Swiss grassland are obtained from cantonal authorities and are compiled by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL, Swissfire database, <http://www.wsl.ch/swissfire>). Table 6-30 shows the annual burnt area from 1990 to 2017. The Swissfire database differentiates between 'grassland' and 'unproductive land'. As 'unproductive land' can partially cover the grassland categories 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 CH₄ and N₂O 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 $18.60 \text{ t biomass ha}^{-1}$. This value was derived from the carbon stocks of all grassland categories (CC31 to CC37) as an area-weighted mean using the geographical extensions in 2015 and a carbon fraction of 0.45.
- The fraction of the biomass combusted was 0.74 (IPCC 2006 Volume 4, Table 2.6, Savanna and Grassland).
- For CH₄ the default emission factor of $2.3 \text{ g (kg combusted biomass)}^{-1}$ and for N₂O, the default emission factor of $0.21 \text{ g (kg combusted biomass)}^{-1}$ was applied (IPCC 2006, Volume 4, Table 2.5, Savanna and Grassland).

The resulting annual CH₄ and N₂O emissions 1990–2017 on burnt areas in category 4C Grassland are shown in Table 6-30 and are reported in CRF Table4(V).

Table 6-30 Area of 4C Grassland affected by wildfires (WSL, Swissfire database) and resulting CH₄ and N₂O emissions.

Grassland	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Area burnt	ha	637.1	22.3	6.0	18.9	174.5	82.0	42.8	371.8	72.0	18.9
CH ₄	t	20.2	0.7	0.2	0.6	5.5	2.6	1.4	11.8	2.3	0.6
N ₂ O	t	1.8	0.1	0.0	0.1	0.5	0.2	0.1	1.1	0.2	0.1

Grassland	Unit	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Area burnt	ha	21.8	7.5	257.2	137.9	4.3	19.5	14.3	97.8	29.2	3.9
CH ₄	t	0.7	0.2	8.1	4.4	0.1	0.6	0.5	3.1	0.9	0.1
N ₂ O	t	0.1	0.0	0.7	0.4	0.0	0.1	0.0	0.3	0.1	0.0

Grassland	Unit	2010	2011	2012	2013	2014	2015	2016	2017
Area burnt	ha	1.3	56.3	4.4	3.4	2.3	3.3	198.7	12.7
CH ₄	t	0.0	1.8	0.1	0.1	0.1	0.1	6.3	0.4
N ₂ O	t	0.0	0.2	0.0	0.0	0.0	0.0	0.6	0.0

6.6.2.7 NMVOC emissions

Estimates for annual biogenic emissions of NMVOC (CRF Table4) for natural grassland in Switzerland are available in SAEFL (1996a). The value for natural grassland (unproductive vegetation) is 0.51 kt yr⁻¹.

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 2019).

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 as assessed based on SBV (2008) and Richner et al. (2017) were based on many agricultural field experiments and have a high reliability. The absolute uncertainties per hectare, calculated with the implied emission factors of 2017, are 0.002 t C ha⁻¹ yr⁻¹ for 4C1 and 0.089 t C ha⁻¹ yr⁻¹ for 4C2.

Mineral soils

0.249 t C ha⁻¹ yr⁻¹ was used as absolute uncertainty for 4C1 and 4C2. This value was calculated by a Monte-Carlo analysis (Wüst-Galley et al. 2019), see chp. 6.5.3.

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 55.9% (see chp. 6.3.3), resulting in a combined uncertainty of 60.4%. Thus, the absolute uncertainties of the total organic soil emissions in 2017 are 32.2 kt C for 4C1 and 6.1 kt C for 4C2. By dividing those uncertainties with the total area of 4C1 and 4C2, respectively, the absolute uncertainties per hectare result in 0.025 t C ha⁻¹ yr⁻¹ for 4C1 and 0.071 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 0.250 t C ha⁻¹ yr⁻¹ for 4C1 and 0.274 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 mean net carbon stock change per hectare of 4C1 and 4C2, respectively. In 2017, the mean net carbon stock changes were -0.067 t C ha⁻¹ for 4C1 and -0.713 t C ha⁻¹ for 4C2 (calculated from CRF Table 4.C). The resulting relative uncertainties are 374.7% for 4C1 and 38.4% for 4C2, respectively (see Table 6-5).

In the same way the uncertainties for the year 1990 were calculated. They are 458.7% (4C1) and 49.4% (4C2) (Table 6-5).

Wildfires

For wildfires, the emission factor uncertainties of CH₄ and N₂O 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. Small inconsistencies in the input data for the RothC model (related to livestock husbandry, compare chp. 5.2.3 and 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 in mineral soils

6.6.4.2 The initial SOC stocks for this submission are modelled, using the calculation of Leifeld et al. (2003, 2005), as described in Wüst-Galley et al. (2019). The calculation differs from that of previous submissions in that the spatial resolution of the new calculation is higher. 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 project described in chp. 6.6.6.

6.6.4.3 Changes in living biomass

In 2012 an assessment of the appropriateness of the estimated pools of carbon in living biomass was conducted (ART 2012a). It came to the conclusion that almost all carbon stocks and carbon stock changes are in the range of the respective default values provided in the guidelines (IPCC 2006). Nevertheless, there is room for improvements. Consequently, the biomass carbon pools for 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 inventory submitted in 2019. As far as possible, the input data for the simulations were consistent with input data in the Agriculture sector. Changes compared to the previous submissions are due to a more detailed consideration of different grassland types and a lower carbon fraction of 0.45 (compared to 0.50 in the previous submission).

The assumption of a constant carbon stock in living biomass was reconsidered (UNFCCC 2007: §97). According to Schneider (2010) yields on meadows and pastures did not increase since 1990. Neither management nor the share of clover did significantly change over the past 20 years. Nevertheless, there is room for improvements, for instance, annual values resulting from the RothC model could account for climatic variability.

6.6.4.4 Changes in soil carbon stocks

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).

The Swiss Soil Monitoring Network (NABO; see chp. 6.4.4) provided data from 31 monitoring sites identified as grassland 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 pools 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 6-12). The highest pools 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 for SOC. However, these minor changes were statistically non-significant. In addition, previous studies showed that the elevated SOC pools 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 pools 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 pools (mean ≈ 74 t ha⁻¹) this corresponds to a minimum detectable change of roughly 0.19 t C ha⁻¹ yr⁻¹ for SOC pools (or 0.21 t C ha⁻¹ yr⁻¹ if vineyards are excluded).

In conclusion, NABO data provide evidence that Swiss grassland mineral soils did not act as a significant net source or sink of carbon over the last 30 years.

The mean change in SOC which was calculated with RothC for the years 1990-2017 was $0.002 \pm 0.249 \text{ t C ha}^{-1} \text{ yr}^{-1}$ (weighted average change across three elevation zones \pm the absolute uncertainty based on a Monte Carlo analysis, see Figure 6-11 and chp. 6.6.3). In comparison, the modelled net change is two orders of magnitude smaller than the detectable change by NABO and suggests that modelled SOC pool changes agree with the repeated soil inventories in the NABO network.

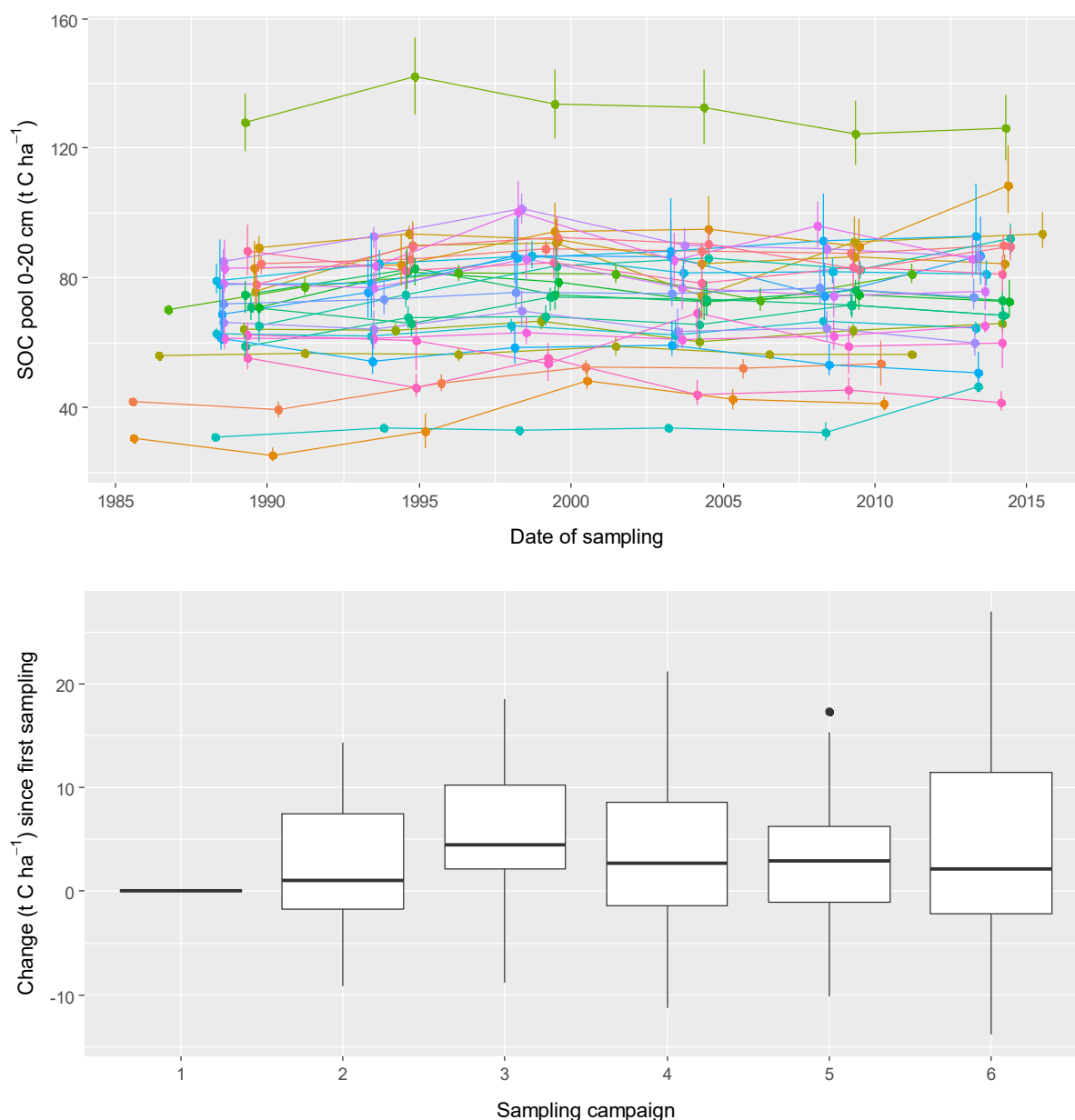


Figure 6-12 Measured SOC pools for topsoils (0–20 cm) and their changes for 31 NABO long-term monitoring sites used as grassland during the time period 1985–2014. The elevation of the sites ranges from 265 to 2400 m a.s.l. Top panel: SOC pools 0–20 cm per site and sampling; the dots indicate the mean 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 pools since first sampling (boxes indicate the lower and 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.

6.6.5 Category-specific recalculations

The following recalculations were implemented in this submission. Major recalculations which contribute significantly to the total differences emissions of sector 4C between the latest and the previous submission are presented also in chp. 10.1.2.4.

- 4C: Activity data (areas) 1990–2016 were updated (see chp. 6.3.5).
- 4C: Carbon stocks and carbon stock changes in mineral soils were recalculated for permanent grassland CC31. Instead of a Tier 1 approach assuming constant carbon pools, annual changes of carbon stocks in mineral soils were modelled using a Tier 3 approach (application of the RothC model by Wüst-Galley et al. 2019).
- 4C: In the new soil model, also new carbon stocks in living biomass (above ground) were calculated for permanent grassland CC31. For reporting, the average carbon stock in living biomass 1990-2017 was used. The assessment is based on a more detailed approach using six different grassland types (data from SBV 2018 and Richner et al. 2017). The carbon fraction was changed from 0.50 to 0.45 (Bolinder et al. 2007). The biomass of roots was not changed.
- 4C: The carbon stocks in living biomass for grassland subcategories CC33, CC35 and CC37 were adjusted according to the recalculated carbon content of living biomass of CC31.
- 4(V)C1: The area affected by wildfires in the Swissfire database was updated for the years 2005, 2007, 2009 and 2016.
- 4(V)C1: For calculating the amount of 'available fuel' consumed by wildfires recalculated carbon contents in living biomass for CC31, CC33, CC35 and CC37 (see above) were used.

6.6.6 Category-specific planned improvements

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). 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 1500 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 4C is subject to further evaluation.

A pilot study to evaluate possible Tier 3 methodological approaches for quantification of carbon stocks and carbon stock changes in agricultural soils (including meadows and pastures) was completed by Köck et al. (2013). Based on this, four soil carbon models were evaluated in 2015–2017, using data from Swiss long-term experiments. In this inventory

submission, the model results (were implemented for the first time Wüst-Galley et al. 2019). For future submissions improvement of the calculations of the initial carbon stocks will be carried out, as there are indications that the soil depth of some mountain soils has been underestimated. It is not anticipated that carbon stock changes will be altered significantly by this improvement.

A digital soil modeling project at Agroscope (funded by FOEN 2017-2020) builds on the outcomes of the recently completed national research programme “Sustainable Use of Soil as a Resource” (www.nfp68.ch/en). It addresses the shortcomings of missing spatially inclusive and comprehensive soil information in Switzerland. A LULUCF module aims at improving the estimates of soil carbon contents in Swiss non-forest soils.

A study on GHG (CO₂, CH₄, N₂O) emissions from an intensively used fen under grassland management in the Rhine valley (canton Sankt Gallen; Agroscope in collaboration with the University of Basel 2017–2020, financed by FOEN) will improve the robustness of country-specific emission factor estimates for grassland soils rich in organic matter in the medium term. A further objective of the study is to test if cover fills reduce peat oxidation and carbon emissions from managed organic soils.

6.7 Category 4D – Wetlands

6.7.1 Description

Category 4D – Wetlands is not a key category.

Carbon stocks in living biomass and carbon stocks in mineral and organic soils were considered.

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 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 pool of living biomass was estimated as 6.50 t C ha⁻¹ (Mathys and Thürig 2010).

6.7.2.2 Carbon in soils

Surface waters (CC41)

The soil carbon stock for surface waters (CC41) is zero. However, for CC41 situated in areas with organic soil (see chp. 6.2.2 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 bogs and fens protected by Federal Legislation (Swiss Confederation 1991a, 1994) as well as reed. More than 10% of the unproductive wetlands 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). Currently, 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 wetlands is similar like in mineral soils of unproductive grassland (CC37) ($68.23 \text{ t C ha}^{-1}$; 0–30 cm).

6.7.2.3 Changes in carbon stocks

Living biomass, Dead organic matter, Mineral soils

Applying a Tier 1 approach, carbon stocks in living biomass, in dead organic matter, and in mineral soils were assumed to be in equilibrium for Wetlands remaining wetlands.

Organic soils

The emission from organic soils under CC41 was assumed to be zero because the respective areas are not drained.

The emission from organic soils under CC42 was estimated to be $5.30 \text{ t C ha}^{-1} \text{ yr}^{-1}$ 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.

Land-use change

In the case of land-use change, the net carbon changes in biomass and soil 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). This assumption was reconsidered as recommended by the ERT (UNFCCC 2009: §82), and it was concluded that it is justified because the exact year of the land use change is not known (cf. chp. 6.3.2). For carbon stock changes in wetland soils the conversion time is 20 years.

6.7.2.4 Non-CO₂ 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 $0.43 \text{ kt CH}_4 \text{ yr}^{-1}$ 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"). AD correspond to the total area of organic soils for subdivision "unprod wetland" (CC42) in CRF Table4.D. The emission factor of $1.6 \text{ kg N}_2\text{O-N ha}^{-1}$ 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 4D1

Activity data

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 2019).

Organic soils

The uncertainty of the carbon stock change (emission factor) in organic soils is 72.2% both for 1990 and 2017. It was calculated on the basis of measurement data compiled by ART (2011b). The uncertainty of the activity data (area of organic soil) is 61.9% (see chp. 6.3.3).

6.7.3.2 Uncertainties 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 2019).

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 2017, is $0.145 \text{ t C ha}^{-1} \text{ yr}^{-1}$ 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 4D2. The absolute uncertainty per hectare, calculated with the implied emission factor of 2017, is $0.338 \text{ t C ha}^{-1} \text{ yr}^{-1}$ for 4D2.

Organic soils

The uncertainty of the carbon stock change (emission 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 61.9% (see chp. 6.3.3), resulting in a combined uncertainty of 95.1%. Thus, the absolute uncertainties of the total organic soil emissions in 2017 are 0.883 kt C for 4D2. By dividing this uncertainty with the total area of 4D2, the absolute uncertainty per hectare results in $0.183 \text{ t C ha}^{-1} \text{ yr}^{-1}$ for 4D2.

Overall uncertainty 4D2

The root sum squares of the above-mentioned three absolute uncertainties is $0.410 \text{ t C ha}^{-1} \text{ yr}^{-1}$ for 4D2. This absolute uncertainty was used to calculate the relative emission factor uncertainty for 4D2 by dividing with the mean net carbon stock change per hectare of 4D2. In 2017, the mean net carbon stock change was $-2.151 \text{ t C ha}^{-1}$ for 4D2 (calculated from CRF Table 4.D). The resulting relative uncertainty is 19.1% for 4D2 (see Table 6-5).

In the same way the uncertainty for the year 1990 was calculated: 22.1% (cf. Table 6-5).

Flooded lands (CH₄)

The emission factor uncertainty for CH₄ 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 CH₄ emission factor of 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 (N₂O; category 4(II))

For N₂O 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%). The respective activity data uncertainty is 34.1% (Meteotest 2019); it was calculated by combining the uncertainties of the area of organic soils (see chp. 6.3.3) for forest land (27.4%) and for wetlands (61.9%).

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) 1990–2016 were updated (see chp. 6.3.5).

6.7.6 Category-specific planned improvements

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). 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 1500 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 4D is subject to further evaluation.

A digital soil modeling project at Agroscope (funded by FOEN 2017-2020) builds on the outcomes of the recently completed national research programme “Sustainable Use of Soil as a Resource” (www.nfp68.ch/en). It addresses the shortcomings of missing spatially inclusive and comprehensive soil information in Switzerland. A LULUCF module aims at improving the estimates of soil carbon contents in Swiss non-forest soils.

6.8 Category 4E – Settlements

6.8.1 Description

Table 6-31 Key categories in category 4E. Combined KCA results, level for 2017 and trend for 1990–2017, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
4E2	Land converted to settlements	CO ₂	L2

Carbon stocks in living biomass and carbon stocks 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 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).

6.8.2.2 Carbon 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 stock in mineral soils for CC52, CC53, and CC54 is 53.40 ± 5 t C ha⁻¹ (0–30 cm, uncertainty 9%). This value corresponds to soil carbon stocks in mineral soils under cropland and was calculated based on Leifeld et al. (2003, 2005). The approach correlated measured soil organic carbon stocks (t ha⁻¹) for arable land and leys with soil texture after correction for soil depth and stone content. Area upscaling used the Swiss digital soil map (SFSO 2000a), and average stocks were calculated as weighted means using the area of arable land and leys.

For organic soils the carbon stock for CC52, CC53, and CC54 was assumed as 240 t C ha⁻¹ (0–30 cm).

6.8.2.3 Changes in carbon stocks

Living biomass, Dead organic matter, Mineral soils

Applying a Tier 1 approach, changes in carbon stocks in biomass, in dead organic matter, and in mineral soils were assumed to be in equilibrium for Settlements remaining settlements.

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).

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% 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:

$$\Delta C_{s,i,b51} = [0.2 * (0 - \text{stock}C_{s,i,b}) / CT] * A_{i,b51}$$

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 was applied.

In the case of land-use change from or to CC52, CC53, and CC54, the net carbon changes in biomass and soil of CC52, CC53, and CC54 were calculated as described in chp. 6.1.3.2.

6.8.2.4 N₂O emissions from settlements

N₂O emissions associated with inputs from N in Settlements (category 4(I)E) were included in the Agriculture sector (category 3Da7 Other "Domestic use of inorganic fertilisers"; see chp. 5.5).

The calculation of emissions for categories 4(III) and 4(IV) (direct N₂O emissions from nitrogen mineralisation in mineral soils and indirect N₂O 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 emission 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) 1990–2016 were updated (see chp. 6.3.5).

6.8.6 Category-specific planned improvements

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). 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 1500 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 4E is subject to further evaluation.

6.9 Category 4F – Other land

6.9.1 Description

Category 4F – Other land is not a key category.

As shown in Table 6-2 and in Table 6-6 Other land (CC61) covers unmanaged, non-vegetated areas such as glaciers, rocks and shores.

6.9.2 Methodological issues

By definition, Other land has no carbon stocks. Coherently, changes in carbon stock in 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 soil were calculated as described in chp. 6.1.3.

The calculation of emissions on land converted to other land for categories 4(III) and 4(IV) (direct N₂O emissions from nitrogen mineralisation in mineral soils and indirect N₂O 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 emission factor uncertainty in subcategory 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) 1990–2016 were updated (see chp. 6.3.5).

6.9.6 Category-specific planned improvements

No category-specific improvements are planned.

6.10 Categories 4(III) and 4(IV) – N₂O emissions

6.10.1 Description

Categories 4(III) and 4(IV) are not key categories.

This chapter presents the methods for calculating direct (category 4(III)) and indirect (category 4(IV)) N₂O 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 N₂O immobilisation is reported.

- In category 4(III), direct N₂O emissions from nitrogen mineralisation associated with loss of soil organic matter are reported.
- In category 4(IV)2, indirect emissions of N₂O due to nitrogen leaching and run-off after mineralisation of soil organic matter are reported.

The following N₂O emissions were included in the Agriculture sector:

- Direct N₂O emissions on Cropland remaining cropland (no category registered in CRF Table 4(III); see chp. 5.5) and on Grassland remaining grassland (category 4(III)C1; see chp. 5.5). In Switzerland, grassland is considered to be under agricultural management.
- Indirect N₂O 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. 5.3).

6.10.2 Methodological issues

Direct N₂O emissions

Direct N₂O 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, vol. 4, chp. 11):

$$\text{Emission(N}_2\text{O)} = - \text{deltaCs} * 1 / (\text{C:N}) * \text{EF1} * 44/28, \text{ if } \text{deltaCs} < 0 \quad [\text{kt N}_2\text{O}]$$

where:

- deltaCs: soil carbon 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 N₂O-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 N₂O 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).

Indirect N₂O emissions

The indirect N₂O 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):

$$\text{Emission(N}_2\text{O)} = -\text{deltaCs} * \text{Frac}_{\text{LEACH}} / (\text{C:N}) * \text{EF5} * 44/28, \text{ if deltaCs} < 0 \quad [\text{kt N}_2\text{O}]$$

where:

- $\text{Frac}_{\text{LEACH}}$: fraction of mineralised N lost by leaching or run-off, see Table 6-32.
- C:N ratio as above for direct N₂O emissions
- EF5: default emission factor = 0.0075 kg N₂O-N (kg N)⁻¹, IPCC 2006 (Volume 4, Table 11.3)

If deltaCs is zero or positive (carbon gain) there are no N₂O emissions provoked by the specific change of land-use or management.

For calculating deltaCs, all land-use changes and conversions between land-use subcategories were taken into account.

On productive forest land (CC12), small annual changes in carbon contents of mineral soils are reported that were calculated with the Yasso07 model (chp. 6.4.2.7). These changes were deliberately not considered for the calculation of N₂O emissions in categories 4(III) and 4(IV) as they are not associated with a land-use change or any change in management.

Table 6-32 Fractions of mineralised N lost by leaching or run-off ($\text{Frac}_{\text{LEACH}}$), see also chp. 5.5.2.4.2.

	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
$\text{Frac}_{\text{LEACH}}$	--	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
$\text{Frac}_{\text{LEACH}}$	--	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
$\text{Frac}_{\text{LEACH}}$	--	0.178	0.178	0.178	0.178	0.178	0.178	0.178	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 estimated as the mean of the upper and the lower limit of the uncertainty ranges listed in IPCC (2006), Vol 4, Tables 11.1 and 11.3 (Table 6-5):

- Uncertainty 4(III) (EF1): 135.0%
- Uncertainty 4(IV) (EF5): 161.5%

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 (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 CO₂ 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).

6.10.3.2 Time-series consistency

Time series for categories 4(III) and 4(IV) N₂O 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) 1990–2016 were updated (see chp. 6.3.5).
- 4(III), 4(IV): Activity data (loss of soil organic matter) were recalculated due to various recalculations of carbon stock changes in mineral soils (see chp. 6.5.5 and 6.6.5).

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 6-33 Key categories in category 4G. Combined KCA results, level for 2017 and trend for 1990–2017, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
4G	HWP Harvested wood products	CO ₂ biog.	L2, T1, T2

The data presented in this chapter are estimates of net emissions (outflow) and removals (inflow) from HWP due to annual changes in the HWP carbon pool.

The approach to calculate carbon stock changes in HWP can be generally characterized as a production approach as described in chp. 12, 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) and that are produced in Switzerland and that are used for material (i.e. not for energetic) purposes.

The Harvested wood products pool also includes products made from domestic harvest that were exported and are in use in other countries. However, 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 results are presented in FOEN (2019e).

6.11.2 Methodological issues

The same methodology was used for reporting under the UNFCCC and accounting under the Kyoto Protocol for HWPs in Switzerland 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 change, 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 HWPs 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 (FOEN 2019e).
- Emissions from HWP in solid waste disposals and from wood harvested for energy purposes were accounted on the basis of instantaneous oxidation (FOEN 2019e).
- Imported HWP are not included in the HWP pool.
- Exported HWP were included in the calculation (notation key "IE" in CRF 4(KP-I)C).
- The feedstock from domestic harvest was calculated according to equation 2.8.1 in IPCC (2014). Exported round wood was not included in the calculation of HWP.
- Based on the available datasets 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") and all carbon stock changes in HWPs were reported under Forest management.
- The change in carbon stocks of HWPs was estimated separately for each product category and differentiating HWPs from Deforestation and from Forest management (including HWP from Afforestations) by applying equation 2.8.4 in IPCC (2014). Applying instantaneous oxidation to HWPs originating from Deforestation, the same results were obtained for changes in carbon stocks of HWP reported under the UNFCCC (CRF Table 4.Gs1) and under the Kyoto Protocol (CRF 4(KP-I)C).

6.11.2.1 Activity data

The time series are shown in the CRF Table 4.Gs2. The activity data are described in detail in FOEN (2019e):

- Data for the product categories sawnwood and wood panels are retrieved from FAOSTAT for the years 1961–1990 (<http://www.fao.org/faostat/en/#data/FO>, Forestry Production and Trade) and from national statistics for the years after 1990 (Tab. 4.1 in FOEN 2019f).
- Data for the product category paper and paperboard were based on FAOSTAT (Forestry Production and Trade).

- In order to estimate the share of industrial roundwood originating from domestic forests, as feedstock for HWP production, data from national wood processing statistics and foreign trade statistics (see FOEN 2019e for details) were used.

In order to estimate carbon amounts in each HWP category and subcategory, default conversion factors were taken from IPCC (2014; Table 2.8.1).

6.11.2.2 Emission factors

Emission factors for specific product categories were calculated following eq. 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 (Tab. 2.8.2 in IPCC 2014).

6.11.2.3 Results

Emissions and removals per product category are listed in Table 6-34. Figure 6-13 shows the resulting CO₂ emissions and removals.

Table 6-34 CO₂ 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 CO₂ yr⁻¹ (positive values refer to emissions, negative values refer to removals). HWPs originating from Deforestation were calculated using instantaneous oxidation; there are no HWPs from Afforestation (see main text).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
	kt CO ₂									
HWP	-1'304.7	-822.8	-530.5	-475.5	-363.0	-503.4	-286.0	-255.0	-251.0	-403.6
changeC _{HWP-sawnwood}	-738.3	-466.5	-275.7	-184.7	-121.6	-297.8	-173.9	-123.4	-213.5	-272.2
changeC _{HWP-panels}	-465.7	-376.2	-400.6	-370.5	-294.4	-237.0	-193.9	-165.8	-181.2	-165.9
changeC _{HWP-paper and paperboard}	-100.7	19.9	145.8	79.7	53.0	31.3	81.8	34.2	143.7	34.5

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	kt CO ₂									
HWP	-709.1	-542.5	-407.5	-440.1	-605.7	-739.0	-542.2	-514.7	-382.4	-409.7
changeC _{HWP-sawnwood}	-408.5	-146.3	-78.8	-86.2	-255.2	-344.2	-334.1	-124.0	-228.3	-192.3
changeC _{HWP-panels}	-387.4	-306.1	-241.0	-272.1	-347.4	-417.6	-291.0	-254.1	-277.1	-301.2
changeC _{HWP-paper and paperboard}	86.7	-90.0	-87.7	-81.8	-3.2	22.9	82.9	-136.7	123.0	83.9

	2010	2011	2012	2013	2014	2015	2016	2017
	kt CO ₂							
HWP	-415.0	-458.6	-293.7	-89.5	-299.5	-228.2	-125.0	-166.1
changeC _{HWP-sawnwood}	-175.6	-77.2	34.6	130.3	23.5	15.1	24.5	-6.2
changeC _{HWP-panels}	-332.0	-297.4	-188.2	-123.8	-146.5	-143.5	-41.9	-42.9
changeC _{HWP-paper and paperboard}	92.6	-84.1	-140.2	-96.0	-176.5	-99.8	-107.6	-117.0

Fluctuations in the HWP pool are mainly caused by changes in the production of sawnwood and paper and paperboard (see Table 6-34). The production of sawnwood strongly correlates with the domestic harvesting rate. The contribution of paper and paperboard to changes in HWP fluctuates over the years. Because of the strong reduction in the production of sawnwood since 2011, the relative contribution of paper and paperboard to the HWP pool considerably increased.

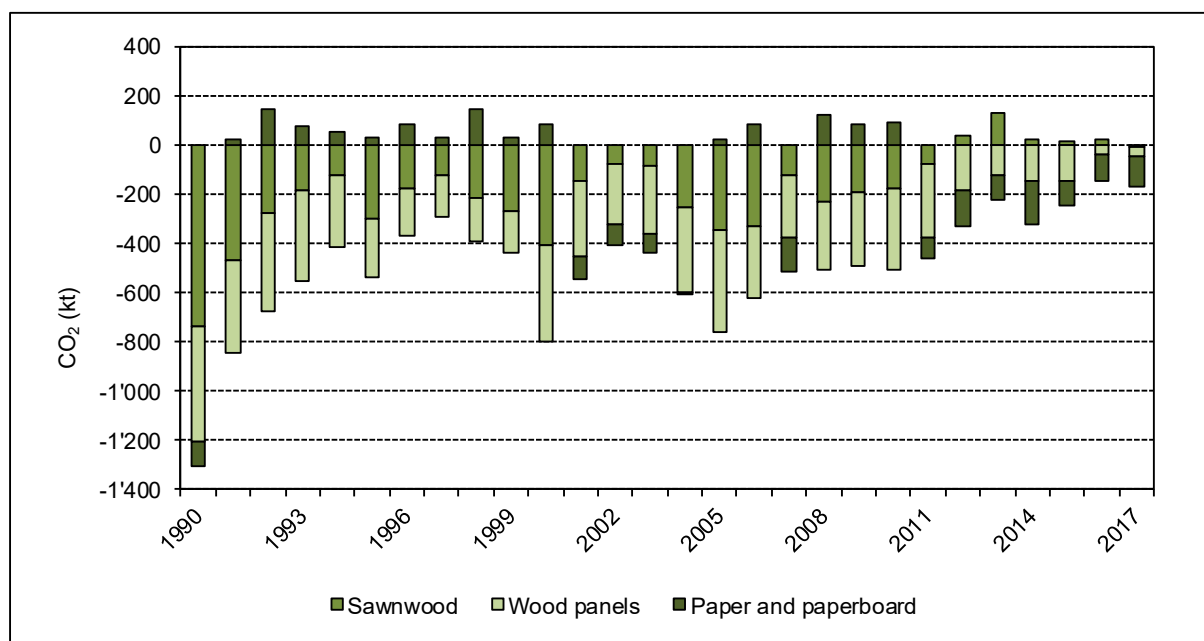


Figure 6-13 CO₂ emissions and removals from category 4G Harvested wood products originating from Forest management (KP) (in kt CO₂; positive values refer to emissions, negative values refer to removals).

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 4.5% (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% for activity data prior to 1990 and 2% for activity data since 1990 (national activity from survey on wood processing in sawmills, combined survey)
- Wood Panels production: 4% for activity data prior to 1990 and 2% for activity data since 1990 (national activity from survey in the wood industry)
- Paper and Paperboard production: 5% (activity data from FAOSTAT).

Conversion factors

The uncertainties of conversion factors used to calculate emission factors were based on the following sources:

- Wood density: 25% (default from IPCC 2006, Volume 4, Table 12.6)
- 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).

Overall uncertainty 4G

The resulting uncertainty of the emission factor (carbon stock change) for HWP amounts to 57% (as shown in Table 6-5):

$$U_{\text{HWP EF}} = \sqrt{25^2 + 10^2 + 50^2} = 57\%$$

The overall relative uncertainty of carbon losses and gains in HWP was thus calculated as:

$$U_{\text{HWP Sawnwood}} = \sqrt{5^2 + 5^2 + 25^2 + 10^2 + 50^2} = 57\%$$

$$U_{\text{HWP Panels}} = \sqrt{5^2 + 4^2 + 25^2 + 10^2 + 50^2} = 57\%$$

$$U_{\text{HWP Paper}} = \sqrt{5^2 + 5^2 + 25^2 + 10^2 + 50^2} = 57\%$$

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.

No category-specific QA/QC activities were carried out.

6.11.5 Category-specific recalculations

4G: In the FAO-database the following activity data were updated for 2015 and 2016: production of industrial roundwood, export of wood pulp and panels, production of panels (plywood) and sawnwood.

4G: Due to recalculations in AREA-data and NFI-data the split between HWP from Deforestation and from Forest management was also recalculated (minor changes).

6.11.6 Category-specific planned improvements

For the calculation of paper and paperboard there are still some methodological challenges, such as how to determine the amount of domestic pulp wood contained in recycled products (see UNFCCC 2018, ID#KL.7). Therefore, a study was planned to obtain additional national activity data on paper and paperboard to improve the calculation of the contribution of this pool. However, due to limited personal resources the latter is suspended.

7 Waste

Responsibilities for sector Waste	
Method updates	Rainer Kegel (FOEN)
Author	Rainer Kegel (FOEN)
EMIS database operation	Rainer Kegel (FOEN)
Annual updates (NIR text, tables, figures)	Beat Rihm (Meteotest), Dominik Eggli (Meteotest)
Quality control (annual updates)	Dominik Eggli (Meteotest); Michael Bock (FOEN), Adrian Schilt (FOEN), Rainer Kegel (FOEN)
Internal review	Adrian Schilt (FOEN), Rainer Kegel (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 reported in chp. 9)

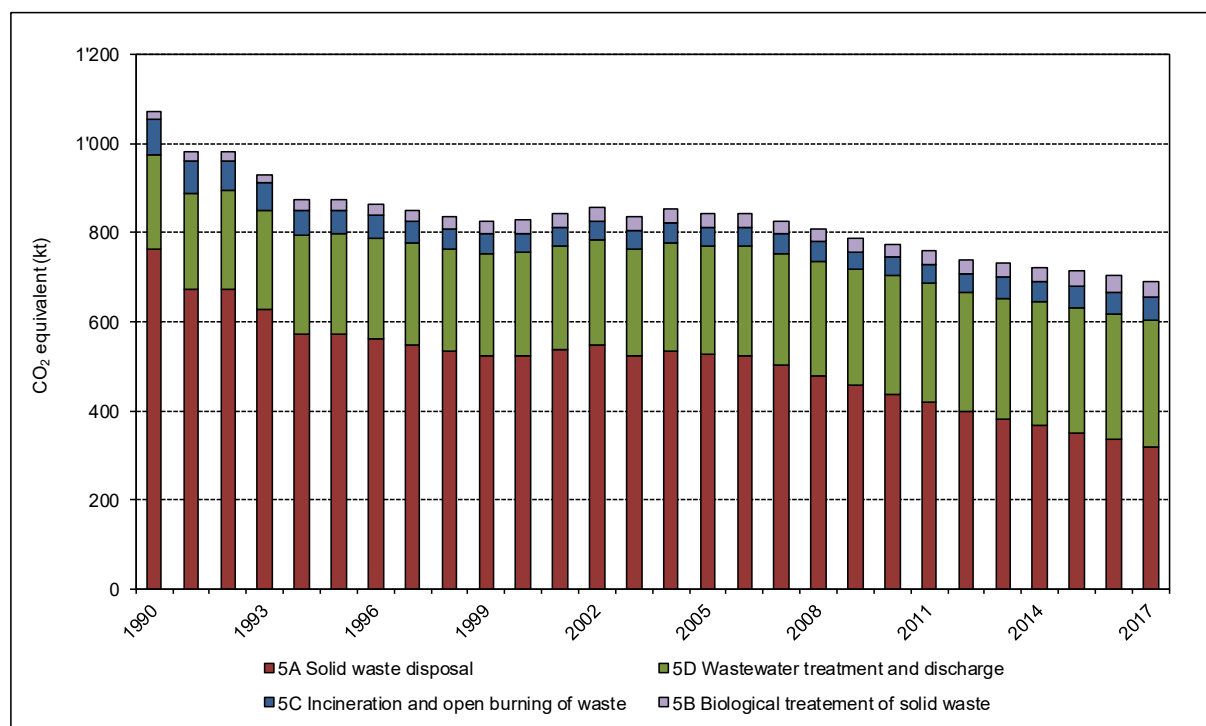


Figure 7-1 Switzerland's greenhouse gas emissions from sector 5 Waste. There are no direct greenhouse gas emissions from sector 5 E Other.

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
CO ₂ equivalent (kt)				
CO ₂	54	30	19	12
CH ₄	915	738	697	710
N ₂ O	103	106	114	123
Sum	1071	874	830	845

Gas	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
CO ₂ equivalent (kt)										
CO ₂	12	11	11	11	10	10	10	10	10	10
CH ₄	669	647	631	614	597	584	574	562	550	536
N ₂ O	129	130	133	136	131	138	139	144	143	145
Sum	810	788	775	760	738	732	723	716	703	691

CH₄ is the most important greenhouse gas in sector 5 Waste over the entire reporting period. Nevertheless, CH₄ emissions have decreased.

The relative trends of the gases are shown in Figure 7-2.

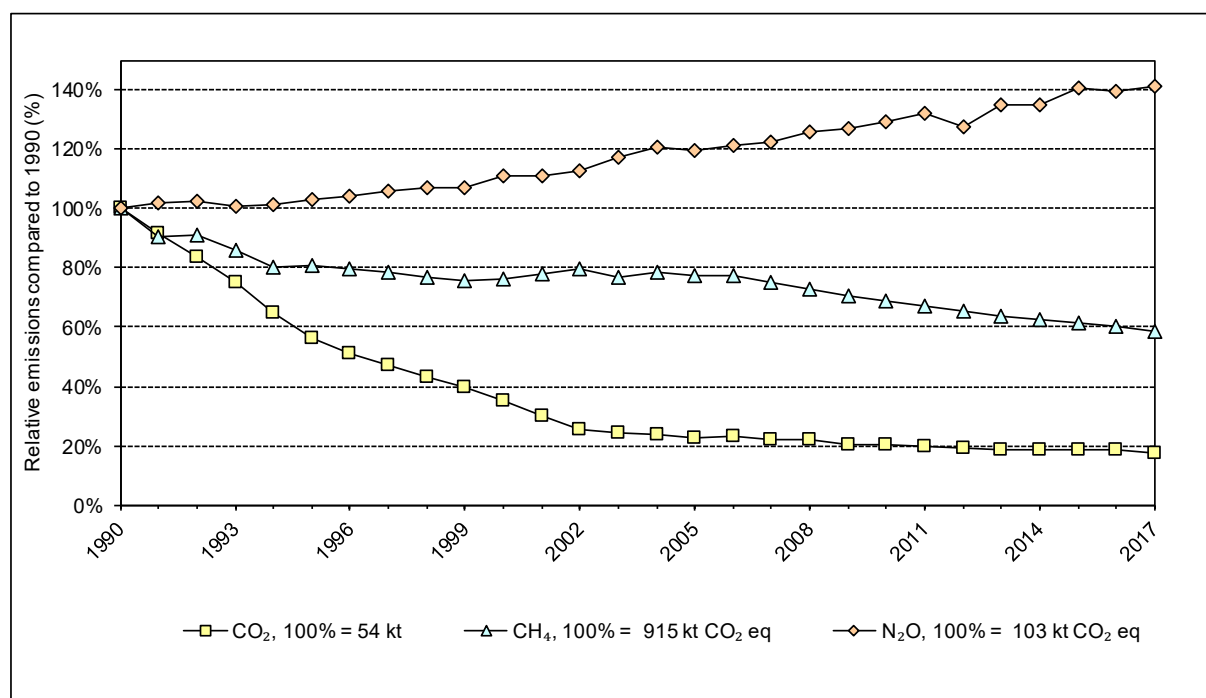


Figure 7-2 Relative trends of greenhouse gas emissions from sector 5 Waste. The base year 1990 represents 100%.

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 7-4). 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 7-4).

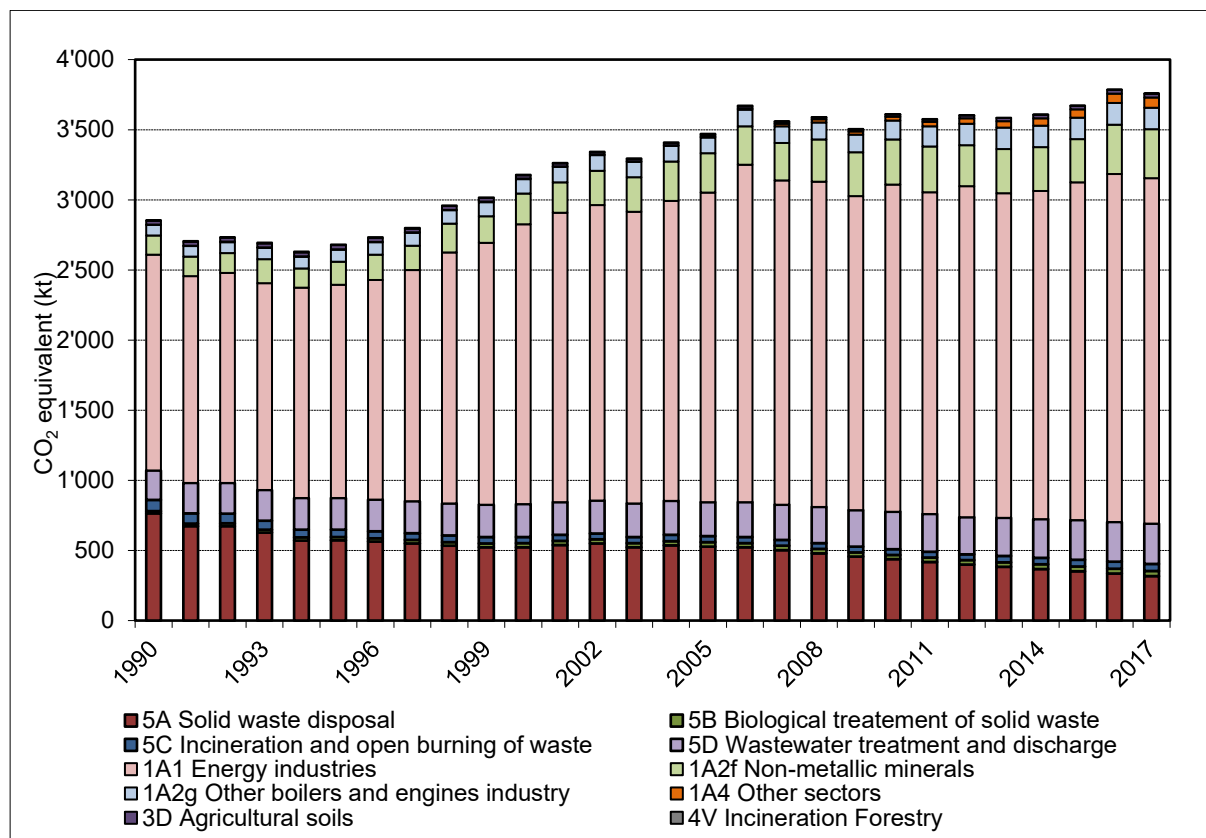


Figure 7-3 Total waste-related GHG emissions, reported in different sectors.

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 regarding waste avoidance and waste management (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 7-4 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 2006 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 (MSWIP) and special waste incineration plants (SWIP), where energy is recovered (1A1a). MSWIP 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 1A4ai, 1A2gviii and 1A1a), 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. In 2014, within sector 3 Agriculture only compost used as fertiliser was relevant for emissions (N₂O emissions as described in chp. 5.5.2.2, Table 5-22).
- 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 MSWIP and are therefore reported under sector 1 Energy. Emissions related to wastewater treatment are reported under 5D.

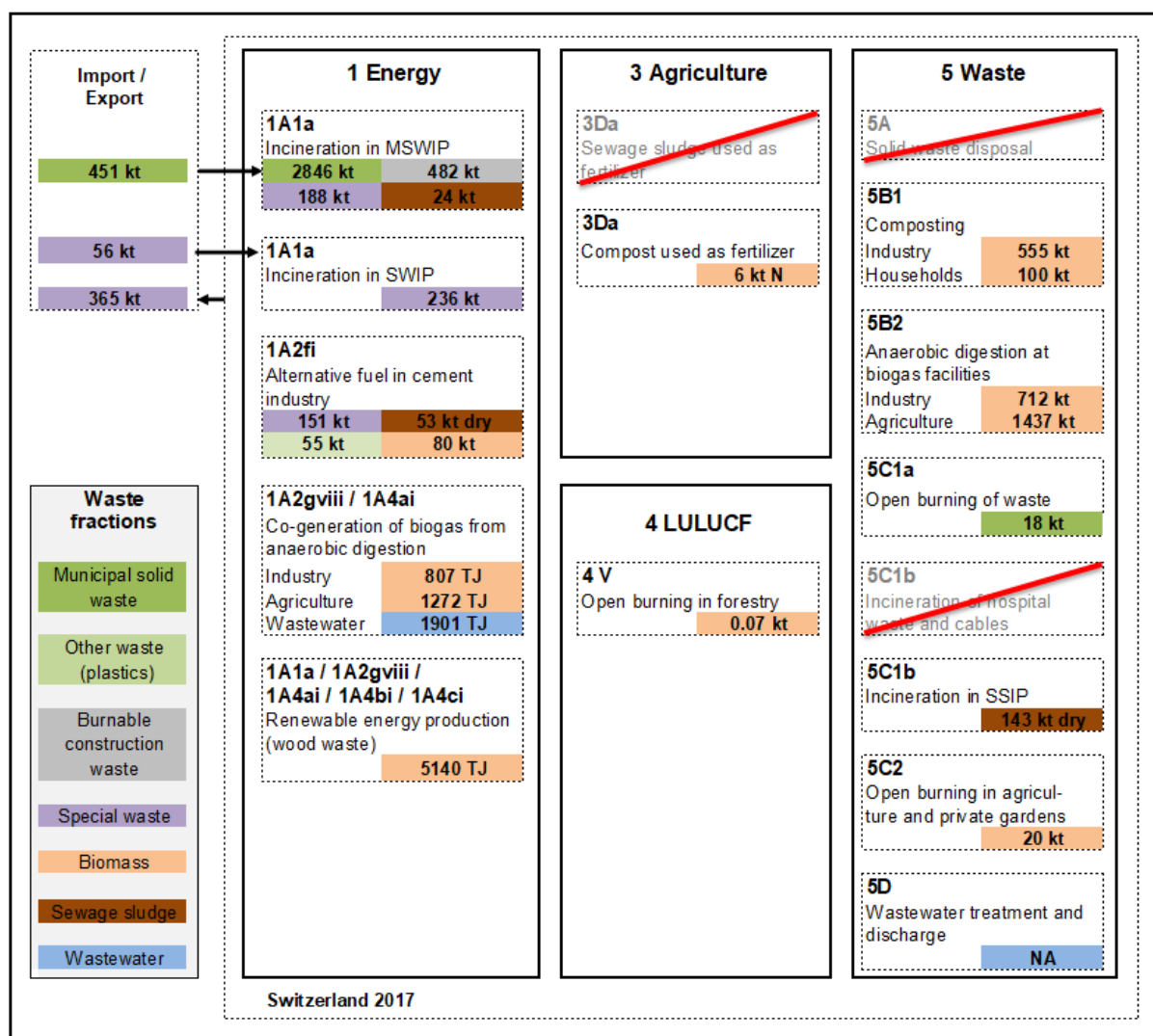


Figure 7-4 Overview on the type of treatment and amounts of waste treated in the respective sectors in Switzerland in 2017. Abbreviations: MSWIP: Municipal Solid Waste Incineration Plant, SWIP: Special Waste Incineration Plant, SSIP: Sewage Sludge Incineration Plant

Regarding the treatment and amounts of relevant waste types the following details can be provided (state in 2017, recycled amounts are not shown in Figure 7-4 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 2018i). The amount of waste incinerated includes imported MSW, 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 MSWIP. 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 2018i). Only the amount of incinerated special waste is relevant for emissions (EMIS 2019/1A1a Kehrichtverbrennungsanlagen and EMIS 2019/1A1a Sondermüllverbrennungsanlagen). Some special waste is also used as an alternative fuel in the cement production (EMIS 2019/1A2f i Zementwerke Feuerung).
- **Sewage sludge:** Since 2010 sewage sludge may not be used anymore as a fertiliser in agriculture due to the content of organic contaminants, heavy metals and other substances. Therefore, all sewage sludge is incinerated, either in MSWIP or in SSIP 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 2019/1A2fi 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 from the food industry or further fractions, depending on the process concerned. Biomass from agriculture, forestry and private gardens are burned without energy recovery (EMIS 2019/5C2 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 2019/1A2fi Zementwerke Feuerung). Compost is used as a fertiliser (see Table 5-22 “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 2017 and trend for 1990–2017, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
5A	Solid waste disposal	CH4	L1, L2, T1, T2

Source category 5A1 Managed waste disposal sites comprises all emissions from managed solid waste landfill sites. As incineration is mandatory for combustible waste since 2000, inputs into managed solid waste landfill sites have dropped to zero. Remaining emissions thus stem from landfilling before 2000. Emissions from the 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 biogenic active landfill sites were equipped to recover landfill gas in 2017 (SFOE 2018a). 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).

Table 7-3 Specification of source category 5A Solid waste disposal in Switzerland.

5A	Source	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)

7.2.2 Methodological issues

Methodology (5A)

Emissions are calculated by a Tier 2 method based on the decision tree in the 2006 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 2017g).

The values for the parameter degradable organic carbon (DOC) are provided for each waste fraction (Table 7-4). For all waste types the IPCC 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 (DOC) values for fractions of different waste compositions (weight fraction, wet basis).

Waste composition (weight fraction, wet basis)	IPCC default value		Country-specific parameters	
	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 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 (weight fraction, wet basis)	IPCC default value		Country-specific parameters	
	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 DOC dissimilated) = 0.5 (IPCC default value)
- Delay time (months) = 6 (IPCC default value)
- Fraction of methane (F) in developed landfill gas = 0.5 (IPCC default value)
- Conversion factor, C to CH₄ = 1.33 (IPCC default value)
- Oxidation factor (OX) = 0.1

The oxidation factor OX 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 MSW and IW):

- Methane correction factor (MCF) for unmanaged, shallow solid waste disposal sites (SWDS) = 0.4 (IPCC default value)
- Methane correction factor (MCF) for unmanaged, deep SWDS = 0.8 (IPCC default value)
- Methane correction factor (MCF) for managed SWDS = 1 (IPCC default value)
- The other two MCF (managed, semi-aerobic and uncategorised) are not relevant because such SWDS are not occurring in Switzerland, i.e. no waste has been distributed to such sites.

The waste composition of MSW deposited has changed during the last 60 years (see Table 7-6).

Table 7-6 Composition of MSW 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	23.8%	26.5%	21.4%	26.6%	31.5%
Garden	4.2%	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 (MSW), industrial waste (IW) and sewage sludge (SS) the amount of CH₄ generated in landfills is calculated. The amount of CH₄ 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 CH₄ 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 HWP 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 is 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 CO₂, CH₄, CO, NMVOC and SO₂ are country-specific based on measurements and expert estimates, as documented in EMIS 2019/1A1 & 5A Kehrichtdeponien. CO₂ emissions from non-biogenic waste are included, while CO₂ 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 2017.

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	NA	NA
Flaring	kg / t CH ₄ burned	2750	NA	NA	1.0	17	NA	NA
Open burning	kg / t waste burned	570	522	6.0	2.5	50	16	0.8

Activity data (5A)

There are three kinds of activity data for 5A1 Managed waste disposal sites: Waste quantities disposed on landfills, direct CH₄ emissions and CH₄ flared.

For the calculation of these three kinds of activity data the amounts of MSW, IW and SS deposited on SWDS are relevant.

Table 7-8 Activity data in 5A1: Waste disposed on managed waste disposal sites (documented in EMIS 2019/1A1a & 5A Kehrichtdeponien).

5A1 Managed waste disposal sites	Unit	1950	1960	1970	1980	1990	1995	2000	2005
Municipal solid waste (MSW)	kt	570.2	675.4	864.0	532.4	650.0	540.0	291.7	13.7
Construction waste (CW)	kt	9.9	10.5	36.0	84.8	150.0	60.0	53.9	1.4
Sewage sludge (SS)	kt (dry)	NO	NO	3.2	29.6	60.0	28.1	4.2	1.0
Open burned waste	kt	298.9	293.9	225.8	96.7	NO	NO	NO	NO
Total waste quantity	kt	879.0	979.8	1129.0	743.5	860.0	628.1	349.7	16.1

5A1 Managed waste disposal sites	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Municipal solid waste (MSW)	kt	1.2	NO	NO	NO	NO	NO	NO	NO	NO	NO
Construction waste (CW)	kt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Sewage sludge (SS)	kt (dry)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Open burned waste	kt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total waste quantity	kt	1.2	NO	NO	NO	NO	NO	NO	NO	NO	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 2019/1A1a & 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. Open burning of waste on SWDS has occurred in the past. By reason of legal requirements and regulations it is assumed that open burning did not take place since 1990 anymore (Consaba 2016) and is therefore NO in Table 7-8.

With these primary activity data total CH₄ emissions generated are calculated using the spreadsheet FOD model provided by IPCC (2006). For the calculation of direct CH₄ emissions, CH₄ flared and used in co-generation units is determined and subtracted from total CH₄ 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 Table 5.A.

The amount of CH₄ used in co-generation stems from the Swiss statistics of renewable energies (SFOE 2018a). The amount of landfill gas flared has been assessed in a separate investigation (Consaba 2016). The CH₄ flared has been estimated as follows:

- A list of all managed SWDS 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 CH₄ management were distinguished:
 - landfills with gas recovery in combined heat and power generation, boiler and torch;
 - landfills with gas recovery or thermal treatment (boiler, torch, non-catalytic oxidation, flameless oxidation);
 - landfill gas recovery without methane elimination (biofilter, aerobiosation);

- landfills without gas treatment (direct release).
- A survey was conducted in 14 managed SWDS and data on their operation mode has been collected.
- With these data the amounts flared in SWDS category a) and b) were estimated.
- The amount flared on all managed SWDS has been extrapolated considering the waste amounts deposited.
- A time series for the amount of methane torched relative to the total amount of CH₄ estimated with the Swiss FOD IPCC 2006 model (managed and unmanaged sites) has been calculated.

The amount flared is expressed as a percentage of CH₄ produced in all SWDS in Switzerland. The percentage flared varies between 5 and 15% since 1990.

Table 7-9 Activity data in 5A1: Direct CH₄ emissions, CH₄ flared and CH₄ used in combined heat and power (CHP) units (as documented in EMIS 2019/1A1a & 5A Kehrichtdeponien).

5A1 Managed waste disposal sites	Unit	1990	1995	2000	2005
CH ₄ direct emissions	kt	30.5	22.9	20.9	21.1
CH ₄ flared	kt	1.8	5.2	5.6	3.4
CH ₄ used in co-generation units (reported under 1A1a)	kt	4.9	12.1	11.3	4.1

5A1 Managed waste disposal sites	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
CH ₄ direct emissions	kt	19.2	18.3	17.5	16.7	16.0	15.3	14.7	14.0	13.4	12.7
CH ₄ flared	kt	2.6	2.4	2.4	2.1	1.8	1.6	1.4	1.4	1.4	1.4
CH ₄ used in co-generation units (reported under 1A1a)	kt	1.8	1.5	1.0	0.9	0.9	0.8	0.6	0.4	0.2	0.2

The CH₄ generated in landfill sites decreased since 1990 because waste quantities disposed of in landfills have been decreasing. Together with the relative increase of CH₄ recovery from 1990 until 2017 this is the reason for the pronounced trend of CH₄ emissions from the source category 5A.

7.2.3 Uncertainties and time-series consistency

Uncertainty in CH₄ and CO₂ emissions from 5A Solid waste disposal

For lack of a detailed uncertainty analysis with the new FOD model, a combined uncertainty of 30% is assumed for the CH₄ emissions (EMIS 2019/1A1a & 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

No category-specific recalculations were carried out.

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 upgraded and used as fuel.

In 5B Biological treatment of solid waste the emissions from the composting of digested matter as well as the CH₄ losses from biogas facilities and emerging from biogas upgrading are included. Emissions related to the use of biogas for combined heat and power generation as well as emissions from biogas upgrading are reported in sector 1 Energy source categories 1A2gviii Other and 1A4ai Commercial/Institutional.

Table 7-10 Specification of source category 5B Biological treatment of solid waste.

5B	Source	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 2006 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 2019/5B1 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 2019/5B1 Kompostierung. Emission factors are country-specific and encompass CH₄, N₂O and NMVOC based on measured or estimated values reported in the literature.

Activity data (5B1)

Activity data for source category 5B1 Composting are shown in Table 7-12 and documented in detail in EMIS 2019/5B1 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 further 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.

Activity data for backyard composting were reassessed in 2017 (Schleiss 2017). Basically, amounts of organic waste composted in backyards are based on expert assessments as well as on data from a small number of cities and villages. The experts took into account different parameters affecting the waste amounts composted in backyards over the time, i.e. urban, rural situation, communication and incentive programs, and separate door-to-door collection of organic wastes.

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 2006 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 to be a constant emission factor for each biogas facility. This is based on an evaluation of measurement data for methane losses that has shown that those losses are not dependent on the amount of substrate processed in a particular facility. Therefore, CH₄ 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 2019/1A1a & 5 B 2 Vergärung LW and EMIS 2019/1A1a & 5 B 2 Vergärung IG. However, as NMVOC and CO emissions from source category 5B are of biogenic origin, they are not considered for the calculation of indirect CO₂ emissions in chp. 9 Indirect CO₂ and N₂O emissions.

N₂O emissions from source category 5B2 are considered to be negligible according to the 2006 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 CH₄ for anaerobic digestion at industrial and agricultural biogas facilities is based on investigations performed in the framework of the GHG 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 CH₄ 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 CH₄ from biogas upgrading is based on official regulations regarding maximal CH₄ leakage, as well as studies focussing on CH₄ emissions from biogas upgrading. Accordingly, regulations by the Swiss Gas and Water Association (SGWA 2016a) set an emission limit value (ELV) for CH₄ 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 ELV 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 2018a). 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 2017.

5B Biological treatment of solide waste	Unit	CH ₄	N ₂ O	NO _x	CO	NM VOC	SO ₂
Composting (industrial)	g/t composted waste	1'000	50	NA	NA	300	NA
Composting (backyard)	g/t composted waste	1'000	50	NA	NA	300	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 solide waste	Unit	1990	1995	2000	2005
Composting (industrial)	kt (wet)	240	360	519	526
Composting (backyard)	kt (wet)	110	155	180	170
Digestion (industrial biogas facilities)	number	NO	4	11	14
Digestion (agricultural biogas facilities)	number	102	76	68	72
Biogas up-grade	GJ	NO	NO	19'866	40'637

5B Biological treatment of solide waste	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Composting (industrial)	kt (wet)	530	532	530	532	534	536	540	545	550	555
Composting (backyard)	kt (wet)	140	130	120	110	100	100	100	100	100	100
Digestion (industrial biogas facilities)	number	16	21	22	28	26	26	25	26	27	28
Digestion (agricultural biogas facilities)	number	75	75	72	80	89	97	98	99	98	106
Biogas up-grade	GJ	71'721	85'008	121'627	168'170	236'074	277'700	337'403	408'222	442'708	456'665

To improve transparency the CH₄ and N₂O emissions of source category 5B Biological treatment of solid waste are shown on a completely disaggregated level in Table 7-13.

Table 7-13 CH₄ and N₂O emissions of 5B Biological treatment of solid waste.

5B Biological treatment of solide waste	Gas	Unit	1990	1995	2000	2005
Composting (industrial)	CH ₄	t	240.2	360.3	519.3	526.2
	N ₂ O	t	12.0	18.0	26.0	26.3
Composting (backyard)	CH ₄	t	110.0	120	130	140
	N ₂ O	t	5.5	6.0	6.5	7.0
Digestion (industrial)	CH ₄	t	NO	4.9	13.6	17.2
Digestion (agricultural)	CH ₄	t	125.5	93.5	83.6	88.6
Biogas up-grade	CH ₄	t	NO	NO	15.7	28.0

5B Biological treatment of solide waste	Gas	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Composting (industrial)	CH ₄	t	530.4	531.8	529.7	531.7	533.6	535.6	540.5	545.3	550.2	555.1
	N ₂ O	t	26.5	26.6	26.5	26.6	26.7	26.8	27.0	27.3	27.5	27.8
Composting (backyard)	CH ₄	t	140.0	130.0	120.0	110.0	100.0	100.0	100.0	100.0	100.0	100.0
	N ₂ O	t	7.0	6.5	6.0	5.5	5.0	5.0	5.0	5.0	5.0	5.0
Digestion (industrial)	CH ₄	t	19.7	25.9	27.1	34.5	32.0	32.0	30.8	32.0	33.2	34.5
Digestion (agricultural)	CH ₄	t	92.3	92.3	88.6	98.4	109.5	119.4	120.6	121.8	120.6	130.5
Biogas up-grade	CH ₄	t	44.8	51.3	70.9	94.7	128.0	144.7	168.7	204.1	221.4	228.3

7.3.3 Uncertainties and time-series consistency

Uncertainty in CH₄ 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 2019/5B1 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 2019/1A1a & 5 B 2 Vergärung LW and EMIS 2019/1A1a & 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 2019:

- 5B2: Activity data for anaerobic digestion in the year 2016 has changed because an error in the calculation has been corrected.
- 5B2: Industrial wastewater treatment plants (5D2) have started upgrading of biogas (sewage gas) and injecting it into the natural gas grid since the year 2013. This has not been reported so far in 5D2 and therefore not been subtracted in the calculation for the losses for biogas upgrading from anaerobic digestion at industrial and agricultural biogas facilities. The inclusion of the losses of biogas upgrading in industrial wastewater treatment plants (5D2) leads to a decrease of CH₄ emissions from biogas upgrading in source category 5B2.
- 5B2: An error has been corrected in the calculation of the amount of biogas from digestion that is torched in industrial biogas facilities. Emissions from torches slightly increase for the years 1992-2016. This recalculation also influences the total amount of organic waste treated in biogas facilities and therefore the emissions from the intermediate storage of organic waste, from fermentation and from the storage of liquid and solid digestate.
- 5B2: An error has been corrected in the calculation of the amount of biogas from digestion that is torched in agricultural biogas facilities. Emissions from torches slightly increase for the years 2008-2016. This recalculation also influences the total amount of organic waste treated in biogas facilities and the emissions from fermentation and from the storage of liquid and solid digestate.

7.3.6 Category-specific planned improvements

- 5B: A research project in the framework of a joint research program is investigating the CH₄ emissions from agricultural biogas facilities. Results will be implemented in the greenhouse gas inventory after completion of the project as appropriate.

7.4 Source category 5C – Incineration and open burning of waste

7.4.1 Source category description

Source category 5C – Incineration and open burning of waste is not a key category.

There is a long tradition in Switzerland to incinerate waste. The heat generated during the incineration has to be recovered if technically and economically feasible. In accordance with the 2006 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 in crematoria.

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 burned 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 4 V (chp. 6.4.2.13).

Table 7-14 Overview of waste incineration sources reported under 5C.

5C	Waste incineration	Specification
5C1	Hospital waste incineration	Emissions from incinerating hospital waste in hospital incinerators
	Illegal waste incineration	Emissions from illegal incineration of municipal solid wastes at home. Emissions from waste incineration at construction sites (open burning)
	Insulation material from cables	Emissions from incinerating cable insulation materials
	Sewage sludge	Emissions from sewage sludge incineration plants
	Crematoria	Emissions from the burning of bodies in crematoria
5C2	Open burning of branches	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 2006 IPCC Guidelines (IPCC 2006, vol. 5, chp. 5.2). In general, the GHG emissions are calculated by multiplying the

waste quantity incinerated by emission factors. For crematoria, the GHG 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 (updated every two years until 2006). The emission factors are based on emission declarations from an incineration plant in 2002 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, illegal waste incineration and incineration of insulation material, 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 2006 IPCC Guidelines (IPCC 2006, vol. 5, chp. 5.2). Emission factors are taken from EMEP/CORINAIR (EMEP/EEA 2013).

Indirect CO₂ emissions from fossil CO and NMVOC emissions from illegal waste incineration, insulation material from cables and hospital waste incinerations are documented in chp. 9 Indirect CO₂ and N₂O emissions.

Emission factors (5C)

Table 7-15 presents an overview of the emission factors for 5C for the latest inventory year.

Table 7-15 Emission factors for 5C Waste incineration and open burning of waste in 2017.
Documentation/sources: EMIS 2019/5C1 and EMIS 2019/5C2 (details see Table 7-14), EMEP/EEA (2013).

5C Waste incineration and open burning of waste	CO₂ t/t	CH₄ kg/t	N₂O g/t	NO_x kg/t	CO kg/t	NMVOC kg/t	SO₂ kg/t
Hospital waste incineration	0.9	NA	60	1.5	1.4	0.3	1.3
Municipal waste incineration (illegal)	0.5	6.0	150	2.5	50	16	0.75
Industrial waste incineration	1.3	NA	NA	1.3	2.5	0.5	6.0
Sewage sludge incineration	NA	0.1	800	0.7	0.19	0.005	0.47
Open burning of natural residues in agriculture	NA	6.8	180	1.4	49	1.5	0.03
Open burning of natural residues in private households	NA	6.8	180	1.4	49	1.5	0.03
	CO₂ t/crem.	CH₄ kg/crem.	N₂O g/crem.	NO_x kg/crem.	CO kg/crem.	NMVOC kg/crem.	SO₂ kg/crem.
Cremation	NA	NA	NA	0.21	0.05	0.007	NA

Comments on CO₂ emission factors:

- For all waste incineration categories, only CO₂ emissions from non-biogenic waste are taken into account.
- Hospital waste incineration: The waste is mainly of fossil origin. The default value for the CO₂ emission factor is taken from SAEFL (2000). Since 2002, no emissions from hospital waste incineration occur, as all hospital waste incinerator plants have been closed and hospital waste is incinerated in municipal solid waste incineration plants (accounted for in 1A1a).
- Illegal waste incineration: The CO₂ emission factor is estimated by using the same assumption as in case of MSW incineration: The C-content is based on the study by

FOEN (2014I) and the fossil carbon fraction was determined by Rytec (2014). See also chp. 3.2.5.2 and detailed information in EMIS 2019/1A1a Kehrichtverbrennungsanlagen (pp. 5–7).

- Industrial waste (consists of cable insulation materials): The CO₂ emission factor is based on measurements of the flue gas treatment of a cable disassembling site where O₂ was measured in the flue gas. Assuming that the ratio of CO₂/O₂ is the same as in municipal solid waste incineration plants, a fraction of 7% of CO₂ 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 occurred.
- Sewage sludge plants: As sewage sludge is biogenic waste, the emission factor for CO₂ 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-CO₂) gases:

- Hospital waste incineration: All emission factors are taken from SAEFL (2000).
- Illegal waste incineration: The emission factor for N₂O is taken from the 2006 IPCC Guidelines (IPCC 2006, vol. 5), the emission factors for CH₄, SO₂, NO_x, NMVOC from SAEFL (2000) and USEPA (1995a).
- Industrial waste (cable insulation materials): All emission factors are adopted from SAEFL (2000).
- Sewage sludge plants: For 1990 emission factors are taken from SAEFL (2000). From 2002 onwards constant emission factors are used, which are deduced from measurements (LHA 2004) taken at the largest sewage sludge incineration plant incinerating one third of Switzerland's sewage sludge. Between 1990 and 2002 the emission factors are interpolated. Emission factors for NMVOC, CO, SO₂ and CH₄ decrease due to gradual technical improvements.
- 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 2019/5C1 Krematorien).
- The emission factors of burning of branches in agriculture and gardening are calculated based on EMEP/EEA (2013) except for CH₄ and N₂O for which emission factors are based on EMEP/CORINAIR (EMEP/EEA 2002), see also documentation in EMIS 2019/5C2 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 CO₂ emissions from fossil CO and NMVOC emissions are reported in chp. 9 Indirect CO₂ and N₂O emissions.

Activity data (5C)

The activity data for 5C Waste incineration are the quantities of waste incinerated, see Table 7-16. 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 Table 5.C are aggregated.

Table 7-16 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
Hospital waste incineration	kt	30.0	17.5	5.0	NO
Municipal waste incineration (illegal)	kt	32.3	26.2	24.9	21.7
Industrial waste incineration	kt	7.5	NO	NO	NO
Sewage sludge incineration	kt (dry)	57.0	50.2	64.3	94.9
Open burning of natural residues in agriculture	kt	16.5	15.2	14.0	12.8
Open burning of natural residues in private households	kt	6.1	4.9	3.6	2.4
Total	kt	149.3	114.0	111.8	131.7
Cremation	Numb.	37'513	40'968	44'821	48'169

5C Incineration and open burning of waste	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Hospital waste incineration	kt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Municipal waste incineration (illegal)	kt	22.4	20.7	21.0	20.3	20.3	19.9	19.3	19.3	19.0	18.3
Industrial waste incineration	kt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Sewage sludge incineration	kt (dry)	95.1	96.2	97.4	98.1	98.7	121.2	123.9	132.9	139.6	142.6
Open burning of natural residues in agriculture	kt	12.0	11.8	11.5	11.4	11.3	11.2	11.1	11.0	10.8	10.7
Open burning of natural residues in private households	kt	1.7	1.5	1.2	1.2	1.2	1.2	1.2	1.2	1.1	1.1
Total	kt	131.2	130.2	131.2	131.0	131.4	153.4	155.4	164.3	170.6	172.7
Cremation	Numb.	51'116	52'402	52'813	52'530	50'567	53'205	55'616	59'664	54'634	57'694

Hospital waste incineration: Does not occur anymore in specific hospital waste incineration plants since 2002. The amount of hospital waste burnt in 1990 stems from BUS (1988).

Illegal municipal waste incineration: 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 decreases to 0.25% in 2030 and then remains constant.

Industrial waste incineration (cable insulation): Does not occur anymore since 1995. The amount burnt in 1990 is estimated by the amount reported by a company that was supposed to burn approx. 1/3 of all insulation material in Switzerland.

Sewage sludge incineration: Activity data for sewage sludge incineration is calculated as follows: Total amount of sewage sludge (according to waste statistics) minus sewage sludge burnt in MSWIP minus sewage sludge used as alternative fuel in cement industry.

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 OAPC, Article 26b. In Switzerland, cantonal authorities are responsible for the implementation of the regulations of the OAPC. 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 in 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 also is 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 that has been approved by the authorities. Based on the numbers from the evaluated cantons an extrapolation to the amount burnt in Switzerland has been made. For the extrapolation the statistics on the usage of wood has been used (FOEN 2012i). For the determination of a time series of natural residues burnt, elder 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 (5 C 2 ii) are reported in LULUCF sector 4 V (chp. 6.4.2.13).

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 CO₂ and CH₄ of 40% and 60% of emission estimates, respectively, and for N₂O in low uncertainty of 40% of emission estimates (see Table 1-10 for quantification of “low” and “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 2019:

- 5C1: Activity data for sewage sludge incineration has been reestimated for the years 2010-2016 according to a recommendation in EAWAG 2018. Values for 2007-2009 have also changed because of the interpolation of the data between 2006 and 2010.

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 7-17 Key categories of 5D Wastewater treatment and discharge. Combined KCA results, level for 2017 and trend for 1990–2017, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
5D	Wastewater treatment and discharge	CH ₄	L1, L2
5D	Wastewater treatment and discharge	N ₂ O	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: 1. Mechanical treatment, 2. Biological treatment, and 3. Chemical treatment. The treated wastewater flows into a receiving system (lake, river or stream). Pre-treated industrial and commercial effluents are also handled for final treatment in municipal WWT plants (see below). Concerning wastewater streams, there is no difference between the terms “industrial” and “commercial” (see Figure 7-5). Switzerland’s wastewater management infrastructure – comprising about 850 WWT plants and 40’000–50’000 km of public sewers – is now practically complete (FOEN 2017I). The vast majority of WWT plants apply an anaerobic sludge treatment with sewage gas recovery, and use the sewage gas for heat production. About 290 WWT plants also apply combined heat and power (CHP) units. See also EMIS 2019/5D1 Wastewater Treatment Plants.

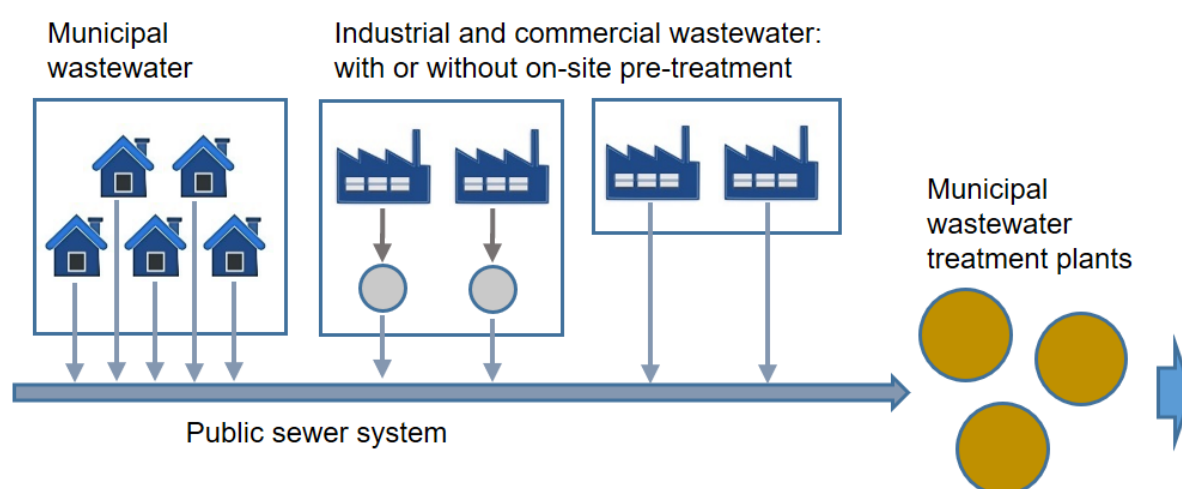


Figure 7-5 Graphical representation of municipal and industrial or commercial wastewater streams.

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 municipal WWT 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 WWT plants pre-treat wastewater before its discharge to the domestic sewage system, where the industrial wastewater is additionally treated together with domestic wastewater in municipal WWT plants (see Figure 7-5 and Figure 7-6). 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, SO₂), domestic and industrial wastewater streams are distinguished (i.e. different emission factors relative to population, see below). See also EMIS 2019/5D2 Pre-treatment of industrial wastewater.

Table 7-18 Specification of source category 5D Wastewater treatment and discharge.

5D	Source	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 ₂ O are implemented in 5D1)

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.

Wastewater treatment also leads to emissions reported in other categories, as illustrated in Figure 7-6. 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 2008. Therefore, this process is crossed out in Figure 7-6. 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).

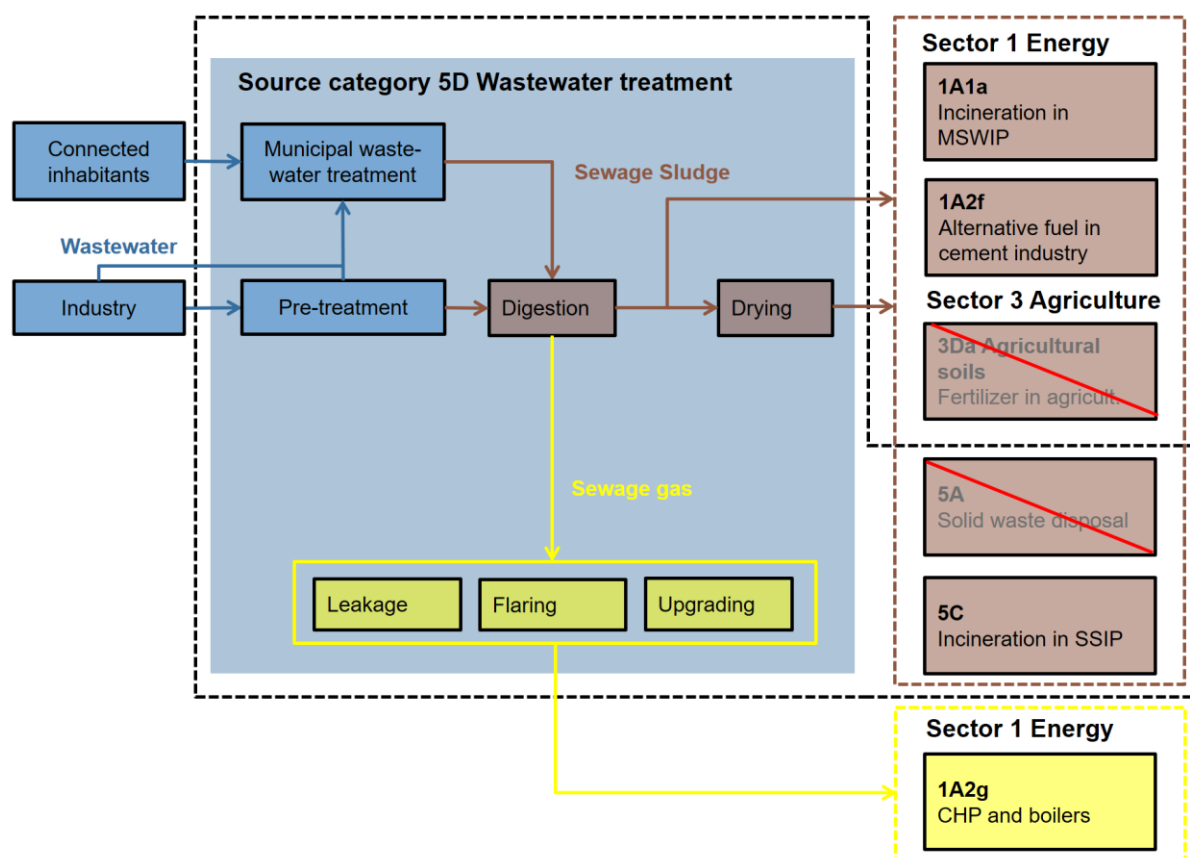


Figure 7-6 System boundaries of processes related to wastewater treatment. CHP = Combined heat and power generation. MSWIP = Municipal solid waste incineration plant. SSIP = Sewage sludge incineration plant.

7.5.2 Methodological issues

CH₄ emissions are calculated by a Tier 2 method based on the decision tree of the 2006 IPCC Guidelines (IPCC 2006, vol. 5, chp. 6, Fig. 6.2 and Fig. 6.3).

N₂O emissions are calculated using a country-specific method according to IPCC (2006).

Details regarding the calculation of CH₄ and N₂O emissions are provided in the following.

7.5.2.1 CH₄ emissions

Methodology (5D, CH₄)

CH₄ 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). As noted above industrial and commercial wastewater is treated together with domestic wastewater in municipal WWT plants. Accordingly, the contribution of industrial and commercial wastewater is taken into account in the calculation of CH₄ emissions from domestic wastewater by means of a correction factor for additional industrial and commercial biochemical oxygen demand (BOD) discharged into the domestic sewer system. Industries handling wastewater with high BOD usually use anaerobic digesters to produce sewage gas.

The emissions related to sewage gas production (and recovery) during industrial and commercial pre-treatment of wastewater are also taken into account in the calculation of emissions from municipal WWT plants, because the underlying Swiss renewable energy statistics in Switzerland (see below) does not differentiate between sewage gas production in domestic and industrial WWT plants.

Accordingly, total CH₄ emissions from domestic, industrial and commercial wastewater treatment and discharge are calculated as the sum of two terms:

$$CH_{4,total} = CH_{4,wastewater} + CH_{4,sewage\ gas}$$

(i) Wastewater

In accordance with the 2006 IPCC Guidelines (IPCC 2006) the contribution of wastewater sewerage to WWT 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 municipal WWT 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 WWT 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 WWT 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 WWT plants, often under aerobic conditions. The sewage sludge from these small scale treatment installations is either dealt with by centralized WWT plants or MWIP (municipal waste incineration plants). Simpler systems are e.g. septic tanks with at least three chambers. However, the production of CH₄ in an anaerobic environment is strongly temperature dependent and significant CH₄ 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 Gröno, 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 CH₄ emissions. CH₄ emissions from wastewater produced by inhabitants not connected to municipal WWT plants are thus considered insignificant and set to zero in the Swiss greenhouse gas inventory.

ii) Sewage gas

The CH₄ 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, CH₄)

(i) Wastewater

The wastewater of all connected inhabitants, i.e. virtually all wastewater generated in Switzerland, is seweraged to WWT plants using closed sewer systems. The emission factor according to the 2006 IPCC Guidelines (IPCC 2006, vol. 5, chp. 6, Equation 6.2) is represented by the product of the maximum CH₄ producing potential (B_0 , default value 0.60 kg CH₄/kg BOD) and the methane correction factor (MCF) for the wastewater treatment and discharge system. For the wastewater seweraged to centralized WWT plants, the 2006 IPCC Guidelines (IPCC 2006) propose that the MCF is zero (range 0.0–0.1) for well managed aerobic WWT plants. While WWT 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 CH₄ emissions may still occur. Therefore, the MCF is set to 0.05 (corresponding to the mid-value of the range of well managed aerobic WWT plants), which also brings total CH₄ emissions from WWT 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 CH₄ producing capacity of the wastewater not treated in WWT plants is zero, as the wastewater has a temperature most likely too low to produce significant amounts of CH₄. Accordingly, the emission factor for wastewater not treated in WWT plants is zero and the corresponding emissions are zero, too.

(ii) Sewage gas

To calculate the country-specific implied emission factor $EF_{sewage\ gas}$ for CH₄ 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 in Switzerland (SFOE 2018a). These statistics provide the amount of sewage gas used in furnaces and CHP 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.

(iii) Values of emission factors referred to the number of inhabitants

The CH₄ emission factors for 5D Wastewater treatment and discharge are summarized in Table 7-19.

Table 7-19 Country-specific CH₄ emission factors for source category 5D Wastewater treatment and discharge in 2017 referred to the number of inhabitants. Detailed information is given in EMIS 2019/5D1 5D2 Kläranlagen GHG (Wastewater Handling - Emissions of Nitrous Oxide (N₂O) and Methane (CH₄), Update to the 2006 IPCC Guidelines).

5D Wastewater treatment and discharge	Unit	2017
Population	in 1000	8'452
Emissions from WW sewerage to WWT plants	kg CH ₄ /person/a	0.80
Emissions from WW not sewerage to WWT plants	kg CH ₄ /person/a	NA
Emissions from losses during sludge treatment	kg CH ₄ /person/a	0.09

Activity data (5D, CH₄)

(i) Wastewater

In correspondence with the emission factor $EF_{wastewater}$ given above, the activity data is the fraction of population connected to municipal WWT plants (T_{plant}), as well as the total organically degradable material (TOW) in domestic, industrial and commercial wastewater. According to the 2006 IPCC Guidelines (IPCC 2006), TOW 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 7-20). For BOD the default value for Europe given by the 2006 IPCC Guidelines (IPCC 2006) is used for Switzerland (60 g/inhabitant/day). The parameter I corresponds to the correction factor for additional industrial and commercial BOD discharged into domestic sewers with default value 1.25. While the amount of sewage sludge removed from WWT plants is known, detailed information about its BOD content is not available. Therefore, the amount of BOD removed with sewage sludge is set to zero, in accordance with the default value given by the 2006 IPCC Guidelines (IPCC 2006).

Time series of the activity data are shown in Table 7-20.

(ii) Sewage gas

As elaborated above, a per capita CH₄ emission factor ($EF_{\text{sewage gas}}$) is calculated for CH₄ emissions from separate sewage sludge treatment, and the respective activity data is population (Table 7-20).

7.5.2.2 N₂O emissions**Methodology (5D, N₂O)**

Direct N₂O emissions from centralized WWT plants and N₂O emissions from wastewater effluent are calculated in accordance with the 2006 IPCC Guidelines (IPCC 2006).

(i) N₂O emissions from WWT plants

Direct N₂O emissions from WWT plants are determined with equation 6.9 of the 2006 IPCC Guidelines (IPCC 2006):

$$N_2O_{PLANTS} = EF_{PLANT} * P * T_{PLANT} * F_{IND-COM}$$

N_2O_{PLANTS} corresponds to the total N₂O emissions from WWT plants in kg N₂O/yr, P to the population, T_{PLANT} to the degree of utilization of modern, centralized WWT 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.

(ii) N₂O emissions from wastewater effluents

The following equation from the 2006 IPCC Guidelines (IPCC 2006) for the N₂O emissions from wastewater effluent is used:

$$N_2O_{EFFLUENT} = EF_{EFFLUENT} * N_{EFFLUENT} * 44/28$$

$N_2O_{Effluent}$ corresponds to the total N₂O emissions from effluents (kg N₂O/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 N₂O emissions from discharged wastewater (kg N-N₂O/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). 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 WWT plants in form of N_2O ($N_{2\text{O}_{\text{Plants}}}$, see calculation above).

Emission factors (5D, N_2O)

(i) N_2O emissions from WWT plants

The IPCC default emission factor is applied: $EF_{\text{PLANT}} = 3.2 \text{ g N}_2\text{O/inhabitant/yr}$ (IPCC 2006).

(ii) N_2O emissions from wastewater effluents

The IPCC default emission factor is applied: $EF_{\text{EFFLUENT}} = 0.005 \text{ kg N}_2\text{O/kg N}$ (IPCC 2006).

Activity data (5D, N_2O)

(i) N_2O emissions from WWT plants

The needed time-dependent and country-specific activity data are summarized in Table 7-20:

- Population (P)
- Degree of utilization of modern, centralized WWT plants (T_{PLANT})
- In addition, the following constant factor is used: Industrial and commercial co-discharged protein, within IPCC range: $F_{\text{IND-COM}} = 1.0$ (EAWAG 2018)

(ii) N_2O emissions from wastewater effluents

The time-dependent and country-specific activity data are also summarized in Table 7-20:

- Population (P)
- Annual per capita protein consumption (Protein) (SBV 2018)
- 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: $\text{FNPR} = 0.16 \text{ kg N/kg protein}$ (IPCC 2006).
- Factor accounting for non-consumed protein added to the wastewater, within IPCC range: $F_{\text{NON-CON}} = 1.0$ (EAWAG 2018). This value is appropriate for Switzerland as it is illegal to discharge solid and liquid garbage with the wastewater, see Article 10 in the Waters Protection Ordinance, Swiss Confederation 1998a.
- Industrial and commercial co-discharged protein, IPCC default value: $F_{\text{IND-COM}} = 1.25$ (IPCC 2006).

Table 7-20 Activity data for source category 5D Wastewater treatment and discharge (source EMIS 2019/5D1 Wastewater Treatment Plants and EMIS 2019/5D2 Pre-treatment of industrial wastewater).

5D Wastewater treatment and discharge	Unit	1990	1995	2000	2005
Population	persons in 1000	6'796	7'081	7'209	7'501
Fraction of population connected to wastewater treatment plants	%	90.0	93.7	95.4	96.8
Connected persons	persons in 1000	6'116	6'635	6'877	7'261
Protein consumption	kg/inhab./a	38	37	37	36
N removed with sludge (N _{sludge})	N in t/a	9'465	9'009	8'831	9'026
N directly emitted (N _{WWT})	N in t/a	12.5	13.5	14.0	14.8
Total org. degr. material (TOW)	t/a	186'041	193'842	197'346	205'340

5D Wastewater treatment and discharge	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Population	persons in 1000	7'711	7'801	7'878	7'912	7'997	8'089	8'189	8'282	8'373	8'452
Fraction of population connected to wastewater treatment plants	%	97.1	97.2	97.2	97.3	97.3	97.3	97.3	97.3	97.3	97.3
Connected persons	persons in 1000	7'487	7'583	7'657	7'698	7'781	7'871	7'968	8'058	8'147	8'224
Protein consumption	kg/inhab./a	38	38	38	39	37	37	37	37	36	36
N removed with sludge (N _{sludge})	N in t/a	9'022	8'965	8'909	8'948	9'044	9'148	9'261	9'366	9'470	9'561
N directly emitted (N _{WWT})	N in t/a	15.2	15.4	15.6	15.7	15.8	16.0	16.2	16.4	16.6	16.7
Total org. degr. material (TOW)	t/a	211'089	213'552	215'660	216'591	218'918	221'436	224'174	226'720	229'211	231'374

7.5.2.3 Other gases

The sewage gas production generates emissions of further gases from flaring: CO₂ (biogenic), NO_x, CO, NMVOC, and SO₂. The emissions are calculated by multiplying population (as activity data, see Table 7-20) with country-specific emission factors based on measurements and expert estimates, documented in EMIS 2019/5D1 Wastewater Treatment Plants and EMIS 2019/5D2 Pre-treatment of industrial wastewater. The emission factors used are summarized in Table 7-21.

Table 7-21 Emission factors of CO₂ (biogenic), CH₄, N₂O, NO_x, CO, NMVOC and SO₂ for 5D Wastewater treatment and discharge in 2017.

5D Wastewater treatment and discharge	CO ₂ biog.	N ₂ O	CH ₄	NO _x	CO	NMVOC	SO ₂
	kg/person	g/person					
5D1 Domestic wastewater	0.4	40	884	0.6	0.28	0.011	0.003
5D2 Industrial wastewater	0.1	IE	IE	0.2	0.08	0.003	0.001

7.5.3 Uncertainties and time-series consistency

Uncertainty in CH₄ and N₂O emissions from 5D

7.5.3.1 CH₄ emissions

The default values of the 2006 IPCC Guidelines (IPCC 2006) are adopted to estimate the uncertainty of CH₄ 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%.
- CH₄ emission factor: Uncertainties of the single factors U(B₀) = 30%, U(MCF) = 10% (well managed plants) lead to an aggregated uncertainty of U(EF) = 32%.

- Combined uncertainty $U(\text{Em CH}_4) = 48\%$.

7.5.3.2 N₂O emissions

By applying the default uncertainties of the 2006 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 an interval of 0.0005–0.25 (with default value 0.005). If this range is interpreted as the 95% uncertainty interval, a symmetrised uncertainty of 2500% would result, which is not considered appropriate. The 2006 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 N₂O 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. This value is used for the uncertainty analyses in chp. 1.7.

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).

The reviewers concluded that the calculations of N₂O emissions are carried out correctly as stated in the IPCC Guidelines and no methodological issues were detected. The emission factors used agree with the default values of the IPCC Guidelines and best practice. However the report recommended to adjust two factors ($F_{\text{IND-COM}}$ and $F_{\text{NON-CON}}$) and to calculate the total amount of sewage sludge via the per capita production. Concerning methane the review showed methodological differences from the IPCC Guidelines. They state that sewage gas usage in combination with energy recovery should be allocated to Sector 1 Energy and not Sector 5 Waste. All these recommendations have been implemented and lead to recalculations in submission 2019.

In chapter 8 of the report the reviewers also proposed additional methods which would describe the production and emission pathways of GHG more accurately. The aim is to develop methods based on the 2006 IPCC Guidelines that are refined for Switzerland. The methods are based on literature reviews, expert judgements and running monitoring campaigns performed by Eawag. The finalized proposals are pending until these campaigns have been concluded. An implementation of those findings and recommendations will then be considered (see chp. 7.5.6).

7.5.5 Category-specific recalculations

The following recalculations were implemented in submission 2019: Major recalculations which contribute significantly to the total differences emissions of sector 5D between latest and previous submission are presented also in chp. 10.1.2.5.

- 5D1: The N₂O emission factor for domestic wastewater treatment has been slightly adjusted for the year 2016 as the statistics for protein consumption has become available (for the previous submission, the protein consumption for the year 2016 was based on the value for the year 2015 scaled with population).
- 5D1: Emission factors for domestic wastewater treatment have changed for the years from 1990-2016 due to a review of this process performed in 2018 (EAWAG 2018). The parameters N_{ind-com} and N_{non-com} have been set to 1.0 which leads to changes in the EF for N₂O for the whole reporting period. N₂O and the other EF have changed from 2007-2016 because of a recalculation of the amount of sewage sludge treated during that time. Changes occur as well because the parameter T_{plant} (inhabitants being connected to the public sewer system) has changed for the years 1995, 1998, 2006, 2008 and following years. The calculations for sewage gas flared and losses have also been corrected according to the review recommendations for the years 2006-2016. The amount of biogas used in CHP installations has been changed in the underlying statistics by the SFOE for the years 2010 and 2013-2016 (however this process is reported in 1A2g viii). In total, these recalculations lead to a decrease of N₂O emissions of approximately 40 kt CO₂ eq per year for the whole time period.
- 5D1: Emissions from combined heat and power generation (CHP) and boilers in domestic wastewater treatment plants were reported in source category 5D1 and 1A2gviii as well. This led to a double counting of emissions. Emissions in 5D1 have been removed from source category 5D1 and are now solely reported in 1A2gviii. This leads to a decrease of emissions for the years 1990-2016 in 5D1.
- 5D2: Emissions from combined heat and power generation (CHP) and boilers in industrial wastewater treatment plants were reported in source category 5D2 and 1A2gviii as well. This led to a double counting of emissions. Emissions in 5D2 have been removed from source category 5D2 and are now solely reported in 1A2gviii. This leads to a decrease of emissions for the years 1990-2016 in 5D2.

7.5.6 Category-specific planned improvements

Currently, longterm and representative measurements of N₂O emissions from wastewater treatment plants in Switzerland are ongoing (EAWAG 2018). Results for estimating representative EF of N₂O for waste water treatment are expected in 2022.

At the same time representative measurements of CH₄ and NH₃ emissions from wastewater treatment plants in Switzerland are ongoing (Kupper et al. 2018b). Results for estimating representative EF of CH₄ for waste water treatment are expected in 2021.

After the successful finish of both projects it is planned to implement the findings in a future inventory and NIR.

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) and motor oil in the tanks and motors of the shredded vehicles. GHG emissions do not occur.

Table 7-22 Specification of source category 5E Other (car shredding)

5E	Source	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 CO₂ emissions from fossil CO and NMVOC emissions are described in chp. 9

Indirect CO₂ and N₂O emissions.

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 2019/5E Shredder Anlagen). For CO a constant emission factor is applied over the entire reporting period.

Table 7-23 CO and NMVOC emission factors for 5E Other (car shredding) in 2017.

5E Other waste	Unit	CH ₄	N ₂ O	NO _x	CO	NMVOC	SO ₂
Shredding	g/t scrap	NA	NA	NA	5	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 2019/5E Shredder Anlagen).

Table 7-24 Activity data 5E Other (car shredding).

5E Other waste	Unit	1990	1995	2000	2005
Shredding	kt	280	300	300	300

5E Other waste	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
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.

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

No category-specific recalculations were carried out.

7.6.6 Category-specific planned improvements

No category-specific improvements are planned.

8 Other

Responsibilities for sector Other (IPCC sector 6)	
Author	Michael Bock (FOEN)
EMIS data base operation	Rainer Kegel (FOEN)
Annual updates (NIR text, tables, figures)	Beat Rihm (Meteotest)
Quality control (annual updates)	Dominik Eggli (Meteotest); Michael Bock (FOEN), Adrian Schilt (FOEN)
Internal review	Adrian Schilt (FOEN), Rainer Kegel (FOEN)

8.1 Overview

8.1.1 Greenhouse gas emissions

Within the sector 6 Other emissions from two sources are considered:

- Fire damage estates
- Fire damage motor vehicles

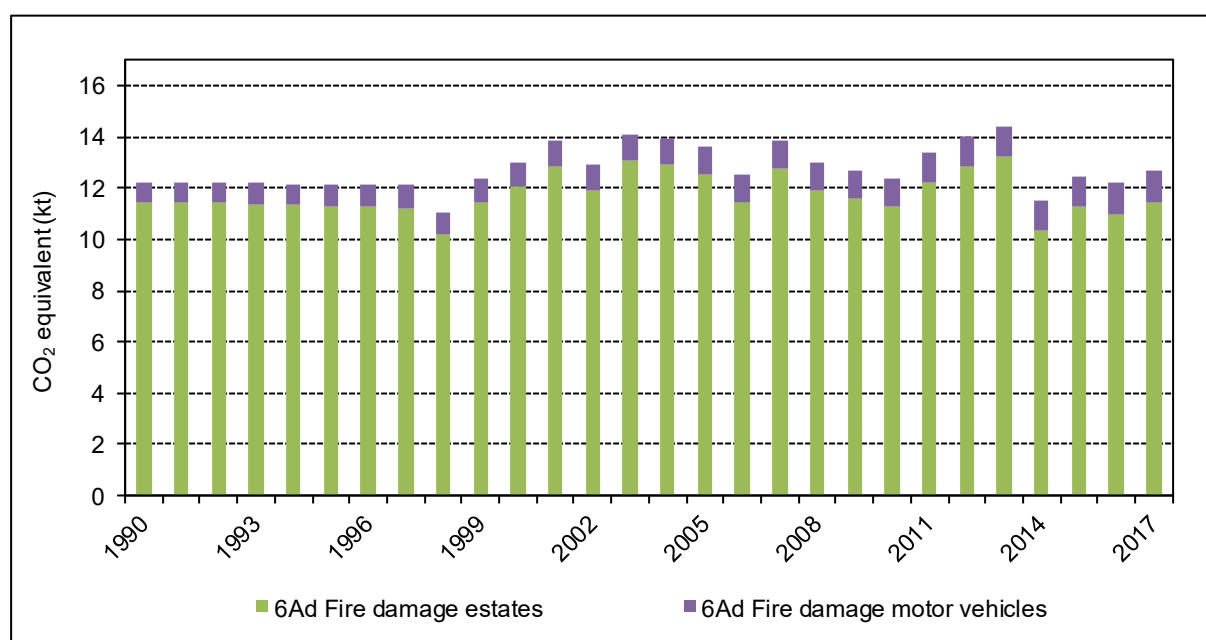


Figure 8-1 Switzerland's greenhouse gas emissions in the sector 6 Other.

Table 8-1 Trend of total GHG emissions from sector 6 Other in Switzerland.

Gas	1990	1995	2000	2005
	CO ₂ equivalent (kt)			
CO ₂	11.0	11.0	11.8	12.4
CH ₄	0.7	0.6	0.6	0.7
N ₂ O	0.6	0.5	0.5	0.6
Sum	12.2	12.1	13.0	13.6

Gas	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	CO ₂ equivalent (kt)									
CO ₂	11.8	11.5	11.3	12.2	12.8	13.1	10.5	11.3	11.1	11.5
CH ₄	0.6	0.6	0.6	0.6	0.7	0.7	0.6	0.6	0.6	0.6
N ₂ O	0.5	0.5	0.5	0.6	0.6	0.6	0.5	0.5	0.5	0.5
Sum	13.0	12.7	12.4	13.4	14.0	14.4	11.5	12.5	12.2	12.6

In sector 6 Other Fire damage estates account for most of the emissions, the rest stems from Fire damage motor vehicles. The total greenhouse gas emissions of this sector show variations around 12 kt CO₂ 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	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)

CO₂ emissions are calculated by a Tier 1 method based on the decision tree of the 2006 IPCC Guidelines (IPCC 2006, vol. 5, chp. 5, Fig. 5.1). Emission factors are country specific.

CH₄ emissions are calculated by a Tier 1 method based on the decision tree of the 2006 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 EPA 1992 ("OTH", fire damage motor vehicles).

N₂O emissions are calculated by a Tier 1 method based on the decision tree of the 2006 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). N₂O 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 CO₂, CO, NO_x and SO₂ are country-specific based on measurements and expert estimates originally gained for illegal waste incineration. It is assumed that for fire damage in estates emissions are similar (EMIS 2019/6Ad Brand- und Feuerschäden Immobilien).

The fraction between fossil and biogenic CO₂ emissions is assumed to remain constant since 2000 with 80% being fossil and 20% biogenic CO₂ emissions. Before 2000, it is assumed that the fraction of fossil CO₂ emissions from burnt goods has been increasing linearly from 20% in 1950 to 80% in 2000. Hence, the interpolated EF values for fossil CO₂ lay between 400 and 1500 t CO₂ / kt burnt good between 1950 and 2000, respectively. Vice versa, the EF values for biogenic CO₂ lay between 1500 and 400 t CO₂ / kt burnt good between 1950 and 2000, respectively.

Indirect CO₂ emissions from fossil CO and NMVOC emissions are documented in chp. 9 Indirect CO₂ and N₂O emissions.

b) Fire damage motor vehicles

Emission factors for CO₂, CO, NO_x and SO₂ are country-specific based on measurements and expert estimates originally gained for the combustion of cable insulation materials, documented in EMIS 2019/6Ad Brand- und Feuerschäden Motorfahrzeuge.

The emission factor for CH₄ from fire damage in motor vehicles is based on EPA (1992), while N₂O emissions have not been estimated for this source category.

Indirect CO₂ emissions from fossil CO and NMVOC emissions are documented in chp. 9 Indirect CO₂ and N₂O emissions.

Table 8-3 Emission factors for fire damages in 2017 (EMIS 2019/6Ad).

6A Other	Unit	CO ₂ biogenic	CO ₂ fossil	CH ₄	N ₂ O	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

Since a methodological change for the NIR 2017 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 approx. CHF 20'000. It is assumed that this corresponds to 780 kg of flammable material per case. It is further assumed that in average 50% of the material actually burns down during an incident because of the intervention of the fire brigade. 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 2019/6Ad 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 1996–2017. They are used to calculate the AD on a year-to-year basis starting from 1996. Between 1990 and 1996 the AD were interpolated linearly.

b) Fire damage motor vehicles

Since a methodological change for the NIR 2017 activity data are estimated yearly based on vehicle numbers published annually by the Swiss Federal Statistical Office SFSO (EMIS 2019/6Ad 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 remains constant during the reporting period. By applying this ratio to the actual vehicle number published annually by the SFSO, the total number of fire incidents with vehicles in Switzerland can be calculated for each year.

During a car fire incident, a car burns down only partially. It is assumed that approx. 100 kg of material burns down during a car fire. With these assumptions, the total number of material burnt can be calculated from the total number of car fire incidents in Switzerland.

Table 8-4 Activity data of burnt goods (documented in EMIS 2019/6Ad).

6A	Unit	1990	1995	2000	2005
6Ad Fire damage estates	kt	8.0	7.3	7.3	7.6
6Ad Fire damage motor vehicles	kt	0.48	0.52	0.58	0.64

6A	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
6Ad Fire damage estates	kt	7.2	7.0	6.8	7.4	7.8	8.0	6.3	6.8	6.6	6.9
6Ad Fire damage motor vehicles	kt	0.66	0.67	0.68	0.69	0.71	0.72	0.73	0.75	0.76	0.77

8.2.3 Uncertainties and time series consistency

Uncertainties of CO₂, CH₄ and N₂O 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

No category-specific recalculations were performed for the latest submission.

In response to issue O.1 of UNFCCC (2018), Table 5, Switzerland explains the recalculations performed between submission 2016 and 2017:

- 6Ad: Concerning fire-damaged estates, for the 2016 submission, the amount of material burned for the respective process was estimated using statistical fire insurance data for the years 1992–2001. The resulting value of 8 kt was used for the whole time series and not estimated on a year-to-year basis. For the 2017 submission Switzerland decided to update the time series with statistical data published annually by the insurance association, which have at that time been available for the years 1996–2015. As a result, the AD vary on a year-to-year basis starting from 1996. For 1990 the original 8 kt was still used. Between 1990 and 1996 it was interpolated linearly.
- 6Ad: Concerning fire-damaged motor vehicles, AD for motor vehicles in the 2016 submission were assessed for the years 1990–2002 and then left constant at the value for 2002 (i.e. 610 t) for 2003 onward. For the 2017 submission the time series has been updated using annually published vehicle data up to 2015 and AD increased to a value of 750 t.

8.2.6 Category-specific planned improvements

No category-specific improvements are planned.

9 Indirect CO₂ and N₂O emissions

Responsibilities for sector Indirect CO ₂ and N ₂ O emissions	
Method updates	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)	Felix Weber (INFRAS), Dominik Eggli (Meteotest)
Quality control (annual updates)	Dominik Eggli (Meteotest), Adrian Schilt (FOEN)
Internal review	Anouk-Aimée Bass (FOEN), Sabine Schenker (FOEN), Rainer Kegel (FOEN), Adrian Schilt (FOEN)

9.1 Overview

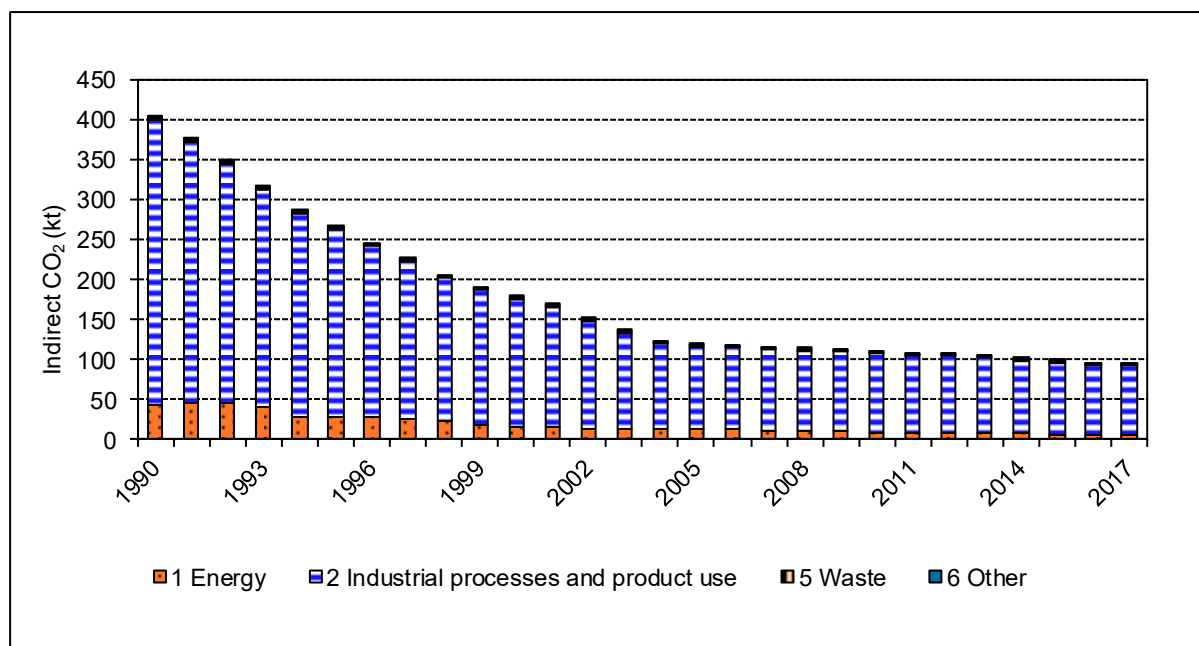
In this chapter, indirect CO₂ emissions that result from the atmospheric oxidation of NMVOC and CO as well as indirect N₂O emissions that are induced by the deposition of NO_x and NH₃ are documented. While indirect CO₂ emissions reported in this chapter are accounted for in the national total, indirect N₂O emissions are not.

Indirect emissions of CO₂ and N₂O are shown in CRF Table6, together with the emissions of the precursor gases CH₄, CO, NMVOC, NO_x and NH₃. While all emissions of precursor gases are shown in both CRF Table6 and in the respective sectors, the indirect emissions of CO₂ and N₂O 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 CO₂ emissions, only carbon of fossil origin is considered. Accordingly, while e.g. NMVOC and CO of biogenic origin are shown as precursor gases in CRF Table6, they are not included for the calculation of indirect CO₂ emissions. Consequently, the implied emission factors may vary from sector to sector and also from year to year. Indirect CO₂ emissions resulting from the atmospheric oxidation of CH₄ are generally not considered.

Chapter 9.2 explains in detail the methodological issues to derive indirect CO₂ and N₂O emissions based on the emissions of the precursor gases NMVOC and CO, as well as NO_x and NH₃ from the different sectors. As an overview, the resulting indirect CO₂ emissions are shown in Table 9-1, as well as in Figure 9-1 and Figure 9-2. The resulting indirect N₂O emissions are shown in Table 9-2, as well as in Figure 9-3 and Figure 9-4.

Indirect CO₂ emissions are considered for both the uncertainty analysis (see chp. 1.6) and the key category analysis (see chp. 1.5).

Indirect N₂O 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 CO₂ emissions.Table 9-1 Indirect fossil CO₂ emissions.

Indirect fossil CO ₂ emissions by source category	1990	1995	2000	2005
	(kt CO ₂)			
1 Energy	43.55	27.52	16.65	12.50
1B Fugitive emissions from fuels	43.55	27.52	16.65	12.50
2 Industrial processes and product use	355.98	235.16	159.24	103.50
2A Mineral industry	0.15	0.12	0.11	0.11
2B Chemical industry	1.30	0.35	0.02	0.01
2C Metal industry	3.36	2.41	2.21	1.26
2D Non-energy products from fuels and solvent use	224.26	132.65	85.73	44.91
2G Other product manufacture and use	124.09	97.61	69.27	55.91
2H Other	2.83	2.02	1.91	1.29
5 Waste	2.01	1.66	1.60	1.38
5C Waste incineration and open burning of waste	1.95	1.56	1.47	1.25
5E Other	0.06	0.10	0.13	0.13
6 Other	1.04	1.04	1.11	1.16
6Ad Fire damages	1.04	1.04	1.11	1.16
Total	402.58	265.38	178.60	118.55

Indirect fossil CO ₂ emissions by source category	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	(kt CO ₂)									
1 Energy	11.10	10.83	8.17	8.11	8.20	8.29	8.12	6.93	6.13	5.93
1B Fugitive emissions from fuels	11.10	10.83	8.17	8.11	8.20	8.29	8.12	6.93	6.13	5.93
2 Industrial processes and product use	100.56	99.40	98.98	97.50	96.48	94.12	90.90	89.31	86.92	87.47
2A Mineral industry	0.11	0.11	0.12	0.12	0.11	0.10	0.10	0.09	0.09	0.09
2B Chemical industry	0.02	0.01	0.04	0.01	0.01	0.01	0.01	0.01	0.00	0.00
2C Metal industry	1.35	0.85	0.93	1.05	0.81	0.80	0.77	0.67	0.63	0.65
2D Non-energy products from fuels and solvent use	43.44	43.14	42.93	41.83	40.38	40.04	37.01	35.55	34.15	34.70
2G Other product manufacture and use	53.82	53.29	52.70	51.98	53.08	51.15	51.06	51.05	51.03	50.98
2H Other	1.81	2.01	2.27	2.51	2.09	2.02	1.95	1.94	1.01	1.05
5 Waste	1.39	1.29	1.30	1.25	1.24	1.22	1.18	1.18	1.17	1.13
5C Waste incineration and open burning of waste	1.26	1.15	1.16	1.11	1.10	1.08	1.05	1.05	1.03	1.00
5E Other	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
6 Other	1.10	1.07	1.04	1.13	1.19	1.22	0.96	1.04	1.01	1.06
6Ad Fire damages	1.10	1.07	1.04	1.13	1.19	1.22	0.96	1.04	1.01	1.06
Total	114.15	112.59	109.49	107.99	107.11	104.85	101.17	98.47	95.23	95.59

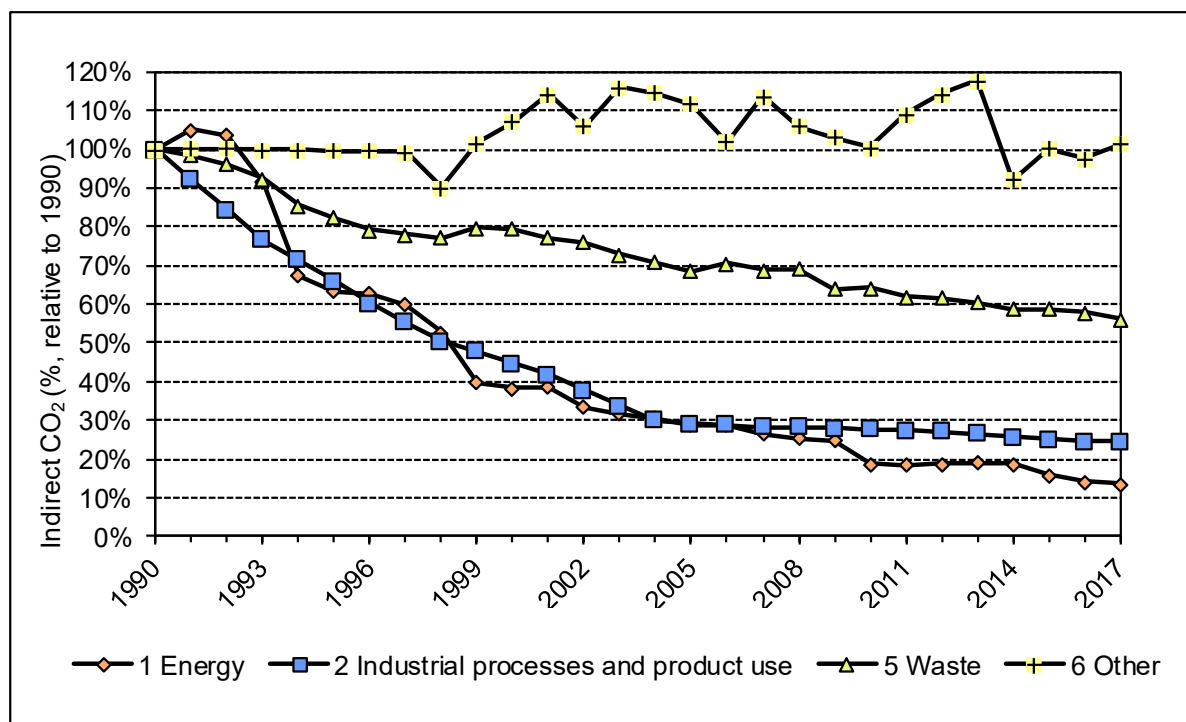


Figure 9-2 Relative trends of the indirect fossil CO₂ emissions by sector. The base year 1990 represents 100%.

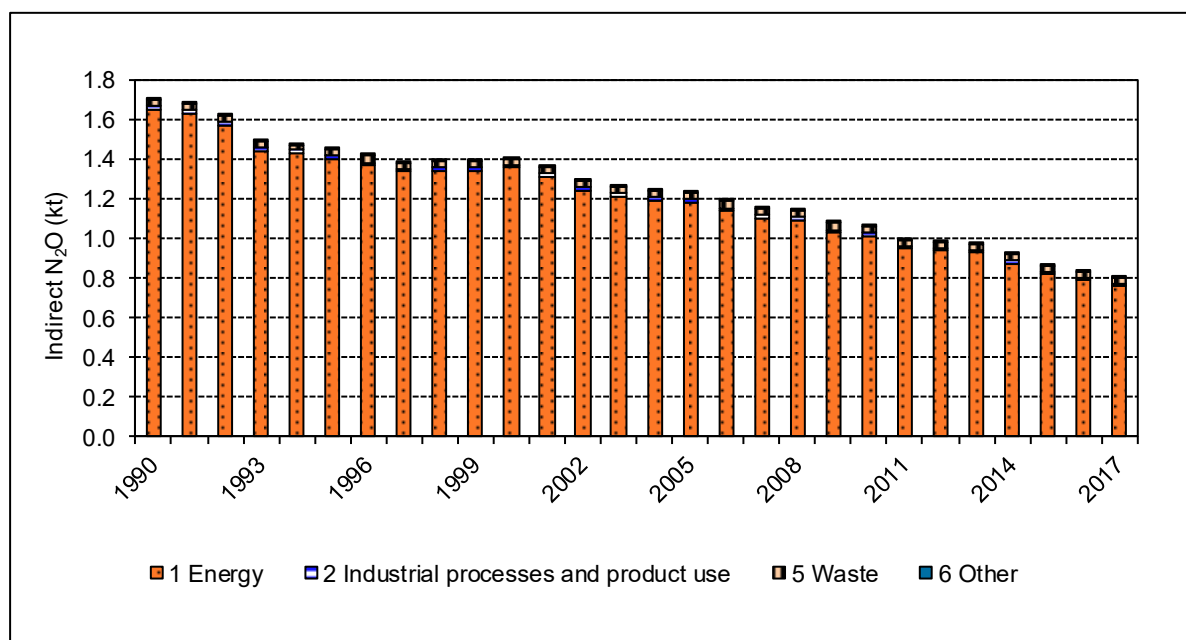
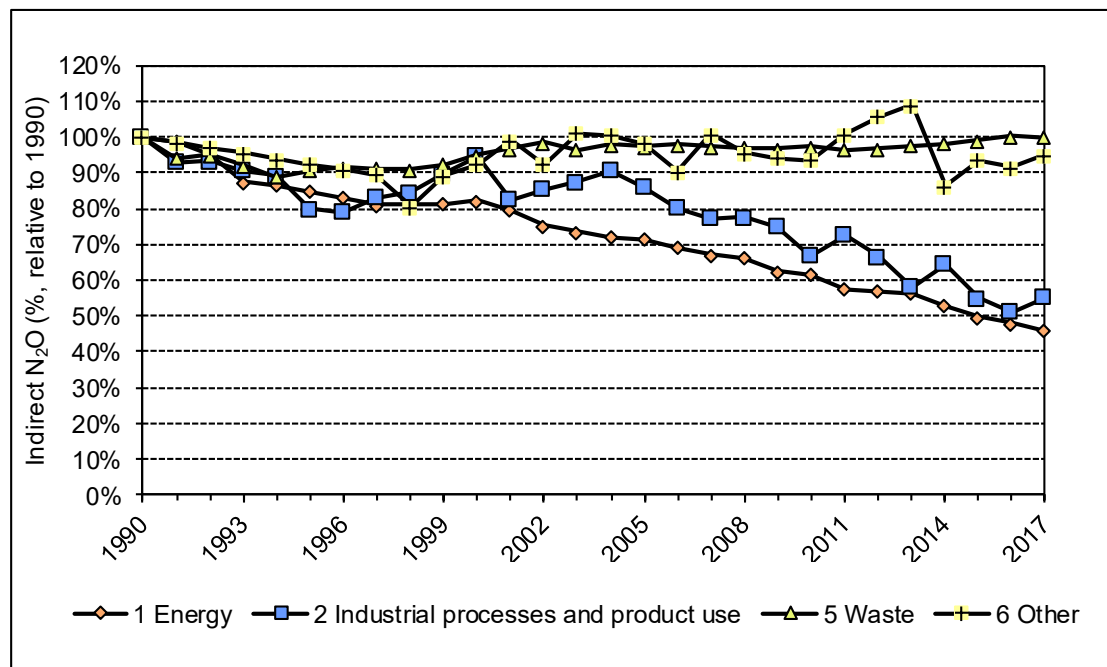


Figure 9-3 Switzerland's indirect N₂O emissions.

Table 9-2 Indirect N₂O emissions.

Indirect N ₂ O emissions by source category	1990	1995	2000	2005
	(kt N ₂ O)			
1 Energy	1.65	1.40	1.36	1.18
1A Fuel combustion activities	1.65	1.40	1.35	1.18
1B Fugitive emissions from fuels	0.00	0.00	0.00	0.00
2 Industrial processes and product use	0.02	0.01	0.02	0.02
2A Mineral industry	0.00	0.00	0.00	0.00
2B Chemical industry	0.00	0.00	0.00	0.00
2C Metal industry	0.00	0.00	0.00	0.00
2G Other product manufacture and use	0.01	0.01	0.01	0.01
2H Other	0.01	0.00	0.01	0.00
5 Waste	0.03	0.03	0.03	0.03
5A Solid waste disposal	0.02	0.01	0.01	0.01
5B Biological treatment of solid waste	0.01	0.01	0.01	0.01
5C Waste incineration and open burning of waste	0.00	0.00	0.00	0.00
5D Wastewater handling and discharge	0.00	0.00	0.00	0.00
6 Other	0.00	0.00	0.00	0.00
6Ad Fire damages	0.00	0.00	0.00	0.00
Total	1.70	1.45	1.40	1.23

Indirect N ₂ O emissions by source category	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	(kt N ₂ O)									
1 Energy	1.09	1.03	1.02	0.95	0.94	0.93	0.87	0.82	0.79	0.76
1A Fuel combustion activities	1.09	1.03	1.01	0.95	0.94	0.93	0.87	0.82	0.79	0.76
1B Fugitive emissions from fuels	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 Industrial processes and product use	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
2A Mineral industry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2B Chemical industry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2C Metal industry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2G Other product manufacture and use	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2H Other	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00
5 Waste	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
5A Solid waste disposal	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
5B Biological treatment of solid waste	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
5C Waste incineration and open burning of waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5D Wastewater handling and discharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6 Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6Ad Fire damages	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1.14	1.08	1.06	0.99	0.98	0.97	0.92	0.86	0.83	0.80

Figure 9-4 Relative trends of the indirect N₂O emissions by sector. The base year 1990 represents 100%.

9.2 Methodological issues

9.2.1 Methodological issues to derive indirect CO₂ emissions

Table 9-3 Key categories of indirect CO₂ emissions. Combined KCA results, level for 2017 and trend for 1990–2017, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
2	Indirect CO ₂ emissions	CO ₂	L2, T1, T2

Indirect CO₂ emissions from the atmospheric oxidation of NMVOC are calculated based on the stoichiometric conversion (carbon content fraction multiplied by the molecular weight of carbon dioxide divided by the molecular weight of carbon). Thereby, a constant carbon content of NMVOC of 60% is assumed, based on the 2006 IPCC Guidelines (IPCC 2006). Indirect CO₂ emissions from the atmospheric oxidation of CO are also calculated based on the stoichiometric conversion (molecular weight of carbon dioxide divided by the molecular weight of carbon monoxide). Thus, indirect CO₂ emissions (Em) result from the following equations:

$$Em_{CO_2, \text{ indirect from NMVOC}} = Em_{NMVOC, \text{ fossil}} * 0.6 * 44/12$$

$$Em_{CO_2, \text{ indirect from CO}} = Em_{CO, \text{ fossil}} * 44/28$$

Activity data for the calculation of indirect CO₂ emissions

Activity data to calculate indirect CO₂ emissions consists of NMVOC and CO emissions as reported in each individual sector and source category, carefully excluding NMVOC and CO emissions of biogenic origin and emissions already included as direct (CO₂) 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 2006 IPCC Guidelines (IPCC 2006) emission factors in source category 1A Energy are based on the assumption of complete oxidation (100%), CO₂ resulting from the atmospheric oxidation of CO and NMVOC emitted from this source category is already accounted for in the corresponding emission factors for direct CO₂ emissions. The respective emissions are thus implicitly reported as direct CO₂ emissions in 1A and no indirect CO₂ emissions from 1A Energy are reported (see chp. 3.2.4.4.1).

1B Fugitive emissions from fuels: CO₂ resulting from the atmospheric oxidation of NMVOC and CO emitted from source category 1B is reported as indirect CO₂ emissions unless it is already accounted for implicitly as direct CO₂ emissions in 1B (chp. 3.3). For 1B, Table 9-4 illustrates in which processes CO and NMVOC emissions occur, and whether the related CO₂ emissions are reported as indirect CO₂ emissions or implicitly as direct CO₂ emissions. In summary, all CO₂ resulting from the atmospheric oxidation of CO emitted from 1B is implicitly included in 1B as direct CO₂ and is therefore not reported as indirect CO₂.

CO₂ resulting from the atmospheric oxidation of NMVOC emitted from 1B is reported as indirect CO₂, except for CO₂ from source category 1B2c, where an oxidation factor of 100% is applied to calculate direct CO₂ emissions.

Table 9-4 Sources of indirect CO₂ emissions from source category 1B Fugitive emissions from fuels.

Source category name	CO emissions	NMVOC emissions
1B1a Coal mining and handling	-	-
1B2a Oil		
1B2a iii Oil – Transport	-	Indirect CO ₂ emissions reported in chp. 9
1B2a iv Oil – Refining/storage:	<i>Leakage:</i> -	<i>Leakage:</i> Indirect CO ₂ emissions reported in chp. 9
	<i>Crude oil:</i> -	<i>Crude oil:</i> -
1B2a v, Oil - Distribution of oil products:	<i>Gasoline storage tank:</i> -	<i>Gasoline storage tank:</i> Indirect CO ₂ emissions reported in chp. 9
	<i>Gasoline station:</i> -	<i>Gasoline station:</i> Indirect CO ₂ emissions reported in chp. 9
1B2b Natural gas		
1B2b ii, Natural gas - Production	-	Indirect CO ₂ emissions reported in chp. 9
1B2b iv, Natural gas – Transmission and storage	-	Indirect CO ₂ emissions reported in chp. 9
1B2b v, Natural gas - Distribution	<i>Distribution:</i> -	<i>Distribution:</i> -
	<i>Leakage gas pipeline:</i> -	<i>Leakage gas pipeline:</i> Indirect CO ₂ emissions reported in chp. 9
	<i>Other leakage:</i> -	<i>Other leakage:</i> Indirect CO ₂ emissions reported in chp. 9
1B2b vi, Other (losses due to major accidents)	-	Indirect CO ₂ emissions reported in chp. 9 (Emissions occur only in 2010 and 2011)
1B2c Venting and flaring	<i>Flaring:</i> CO ₂ emissions from CO are reported in 1B2c a as direct CO ₂ emissions (CO ₂ EF assumes an oxidation of 100%)	<i>Flaring:</i> CO ₂ emissions from NMVOC are reported in 1B2c a as direct CO ₂ emissions (CO ₂ EF assumes an oxidation of 100%)
	<i>H₂ Production:</i> -	<i>H₂ Production:</i> -

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 anodes in source category 2C3 Primary aluminium production, none of the CO₂ emissions resulting from the atmospheric oxidation of NMVOC and CO emitted from sector 2 are already considered under the direct CO₂ emissions of this sector. The CO₂ 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 CO₂ emissions from sector 2 IPPU. Also CO₂ 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 CO₂ emissions from sector 2 IPPU. 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 CO₂ emissions.

In addition, before indirect CO₂ emissions are calculated, biogenic NMVOC and CO need to be subtracted from the total NMVOC and CO emissions from sector 2. Biogenic NMVOC and CO 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 both direct CO₂ emissions from post-combustion of NMVOC and indirect CO₂ emissions from oxidation of NMVOC in the atmosphere occur. The amount of NMVOC that is destroyed in post-combustion facilities is assessed separately and the resulting CO₂ emissions are reported in the respective source categories 2D3a and 2G4. This amount of NMVOC is not part of the reported NMVOC emissions of source categories 2D3a and 2G4 which are used to calculate indirect CO₂ emissions that are reported in CRF Table6.

3 Agriculture and 4 LULUCF: NMVOC and CO emissions from the sectors 3 Agriculture and 4 LULUCF are of biogenic origin. Accordingly, no indirect CO₂ emissions are reported for these sectors.

5 Waste: NMVOC and CO emissions from sector 5 Waste contain fossil and biogenic shares. Only CO₂ resulting from the atmospheric oxidation of fossil NMVOC and CO is reported as indirect CO₂. Emissions of fossil NMVOC and CO stem from the following processes:

- Landfills with open burning: Partly fossil, 0 since 1990.
- Illegal waste incineration: Partly fossil, fossil share is assumed to be the same as for waste incinerated in MWIP, see chp. 7.4 Incineration and open burning of waste (5C1).
- Insulation material from cables: See chp. 7.4 Incineration and open burning of waste (5C1), 0 since 1995.
- Hospital waste incineration: See chp. 7.4 Incineration and open burning of waste (5C1), 0 since 2002.
- Shredding: See chp. 7.6 Other.

6 Other: NMVOC and CO emissions from sector 6 Other contain fossil and biogenic shares. Only CO₂ resulting from the atmospheric oxidation of fossil NMVOC and CO is reported as indirect CO₂. Emissions of fossil NMVOC and CO stem from the following processes:

- Fire damage estate: The share of fossil CO and NMVOC emission is assumed to be equal to the share of fossil CO₂ emissions, see chp. 8.2 (6Ad).
- Fire damage motor vehicles: The share of fossil CO and NMVOC emission is assumed to be 100%, see chp. 8.2 (6Ad).

9.2.2 Methodological issues to derive indirect N₂O emissions

Indirect N₂O emissions are estimated using a country-specific method according to a study of indirect N₂O emissions induced by nitrogen deposition in Switzerland (Bühlmann 2014, Bühlmann et al. 2015). In this study, ecosystem-specific emission factors for indirect N₂O 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 dataset 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 N₂O 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 N₂O-N per N-deposition (deposited in form of NO_x or NH₃, 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 N₂O emissions result compared to the emissions that would result by applying the 2006 IPCC Guidelines (IPCC 2006, see also Bühlmann et al. 2015).

To calculate indirect N₂O emissions induced by the deposition of NO_x and NH₃ 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 NO₂ equivalents) and NH₃ emissions using the stoichiometric conversion according to the following equation:

$$\text{Mass-N} = \text{Mass-NO}_{2,\text{eq}} * 14/46 + \text{Mass-NH}_3 * 14/17$$

Activity data for the calculation of indirect N₂O emissions

The activity data to calculate indirect N₂O emissions from a specific sector corresponds to the NO_x and NH₃ emissions reported in the respective source categories. However, the following exceptions need to be considered:

- Indirect N₂O emissions from sector 3 Agriculture are reported in the respective sector together with direct N₂O emissions (chp. 5.3.2.5.4 Volatilisation of NH₃ and NO_x from manure management systems, chp. 5.5.2.3 Indirect N₂O emissions from atmospheric deposition of N volatilised from managed soils (3Db1) and chp. 5.5.2.4 Indirect N₂O emissions from leaching and run-off from managed soils (3Db2)).
- For sector 6, the only indirect N₂O emissions to be considered are those resulting from NO_x emissions in source category 6Ad Fire damages. All other indirect N₂O emissions are included in sector 3 Agriculture together with direct N₂O emissions.

9.2.3 Uncertainties and time series consistency

Indirect CO₂ emissions are included in the uncertainty analysis, but indirect N₂O emissions are not included.

Uncertainties of indirect CO₂ emissions are based on respective uncertainties of NMVOC and CO emissions. Uncertainties of NMVOC emissions are estimated based on AD and EF uncertainties as documented in Switzerland's Informative Inventory Report 2019 (FOEN 2019d). The estimated uncertainties distinguish between fossil and biogenic shares. Uncertainties of CO emissions are estimated based on AD uncertainties documented in Switzerland's Informative Inventory Report 2019 (FOEN 2019d) and EF uncertainties are based on expert judgements and uncertainties provided by the EMEP/EEA Guidebook.

Combined uncertainties of indirect CO₂ emissions amount to 17% for indirect CO₂ emissions from sector 1 Energy, 110% for indirect CO₂ emissions from sector 2 IPPU, 44% for indirect CO₂ emissions from sector 5 Waste and 74% for indirect CO₂ emissions from sector 6 Other.

Consistency: Time series for indirect CO₂ and N₂O 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 NMVOC, CO, NO_x and NH₃ 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 NMVOC 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.
- See NO_x and NH₃ related recalculations reported in chp. 3 Energy, 4 Industrial processes and product use, 7 Waste and 8 Other.

9.2.6 Category-specific planned improvements

No category-specific improvements are planned.

10 Recalculations and improvements

Responsibilities for chapter Recalculations	
Overall responsibility	Regine Röthlisberger (FOEN)
Authors & annual updates (NIR text, tables, figures)	Regine Röthlisberger (FOEN), Michael Bock (FOEN), Andreas Schellenberger (FOEN)
EMIS database operation	Adrian Schilt (FOEN)
Quality control (annual updates)	Adrian Schilt (FOEN)
Internal review	Anouk-Aimée Bass (FOEN), Sabine Schenker (FOEN), Rainer Kegel (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 inventory submission of April 2018 was not subject to an in-depth review. Recommendations and encouragements from the in-depth review in 2017 (UNFCCC 2018) were mostly addressed in submission 2018 (see chp. 10.1.1, Table 10-1 in FOEN (2018)). The implementation of the recommendations not addressed in submission 2018 is listed in Table 10-1.

Table 10-1 Implementation of recommendations from the in-depth review in 2017 (UNFCCC 2018).

ID	classification	recommendations from ARR 2017	Answer including reference to chapter in NIR
KP-LULUCF			
KL.5	Forest management – CH ₄ and N ₂ O Adherence to reporting guidelines under Article 7, paragraph 1, of the Kyoto Protocol	Not resolved. Switzerland explained in the NIR (section 11.5.2.3) that it decided not to provide technical corrections of the FMRL on an annual basis, but to correct the FMRL periodically and therefore the next technical correction will be made for the 2019 inventory submission. The Party listed in the NIR (p.509) all the improvements which will be made to the technical correction of the FMRL.	KL.5 is addressed in chp. 11.5.2.3.

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 emissions in submission 2018 (previous) and submission 2019 (latest). Explanations are provided for source categories that underwent recalculations larger than 2% of the corresponding source category emissions and resulted in absolute changes larger than 5 kt CO₂ eq (approx. 0.01 per cent of the national total emissions). Additional recalculations and corrections of minor errors, which had a smaller impact than the above threshold, are listed in the relevant sectoral chapters. There were no recalculations larger than 0.5% of the national total emissions (approx. 250 kt CO₂ eq).

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 CO₂, Figure 10-2 for CH₄ and Figure 10-3 for N₂O. The largest recalculation in the energy sector resulted from the re-assessment of the CO₂ emission factor and the biogenic fraction of the most important waste-derived fuels used in the cement industry (see chp. 3.2.6.2.7), resulting in a decrease of up to 17 kt CO₂. All other recalculations had an impact that was smaller than 5 kt CO₂ eq (see Figure 10-1, Figure 10-2, Figure 10-3).

- 1A2f: The CO₂ emission factors for the most important waste derived fuels used in the cement industry – i.e. waste oil, solvents, residues from distillation and plastics and CSS (mix of special waste with saw dust) were reassessed in 2017 (Cemsuisse 2018). Emission factors between 2010 (the year of the previous assessment) and 2017 are now interpolated, while constant values are used before the first and after the last year with available data. Based on the new measurements, the biogenic fraction of waste derived fuels increased, resulting in a change of the fossil CO₂ emissions by up to -17 kt (see 1A2 in Figure 10-1 and chp. 3.2.6.5).
- 1B2a: The CH₄ emissions were revised based on reporting from refineries in the European Pollutant Release and Transfer Register (E-PRTR), leading to a change in CH₄ emissions by up to -4 kt CO₂ eq (see 1B in Figure 10-2 and chp. 3.3.3.5).
- 1A3b: The N₂O emissions were recalculated. New N₂O emission factors for starting engines, a correction of a mistake in the database and the determination that N₂O emissions from vehicles operating on natural gas are not occurring led to a change in N₂O emissions by up to -4 kt CO₂ eq (see 1A3 in Figure 10-3 and chp. 3.2.9.5)

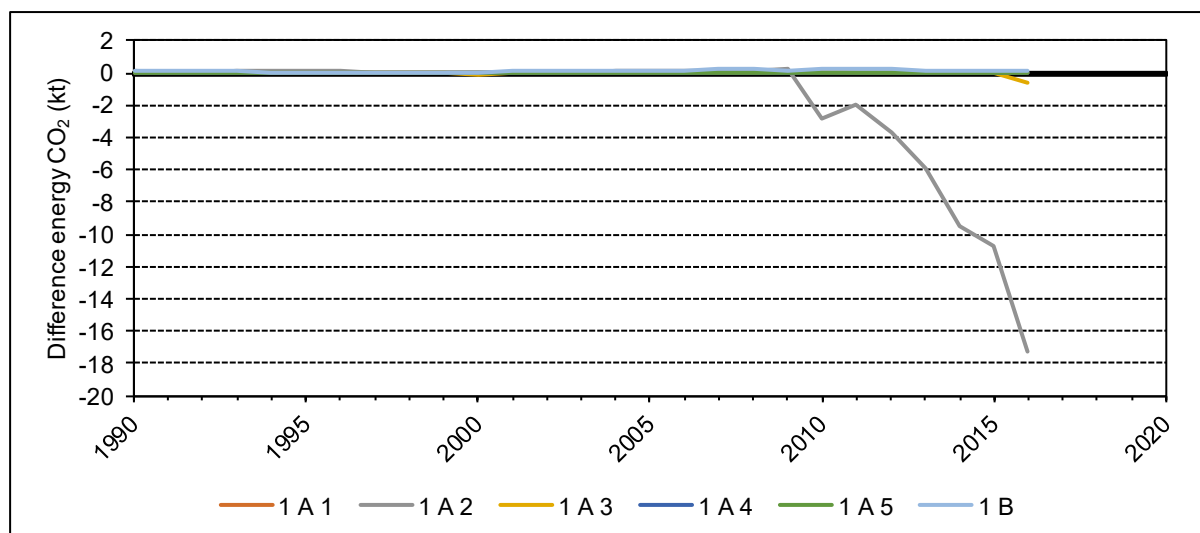


Figure 10-1 Differences in CO₂ emissions (in kt CO₂) between the latest and the previous submission for various source categories in the energy sector. Positive values refer to higher emissions and negative values to lower emissions in the latest compared to the previous submission.

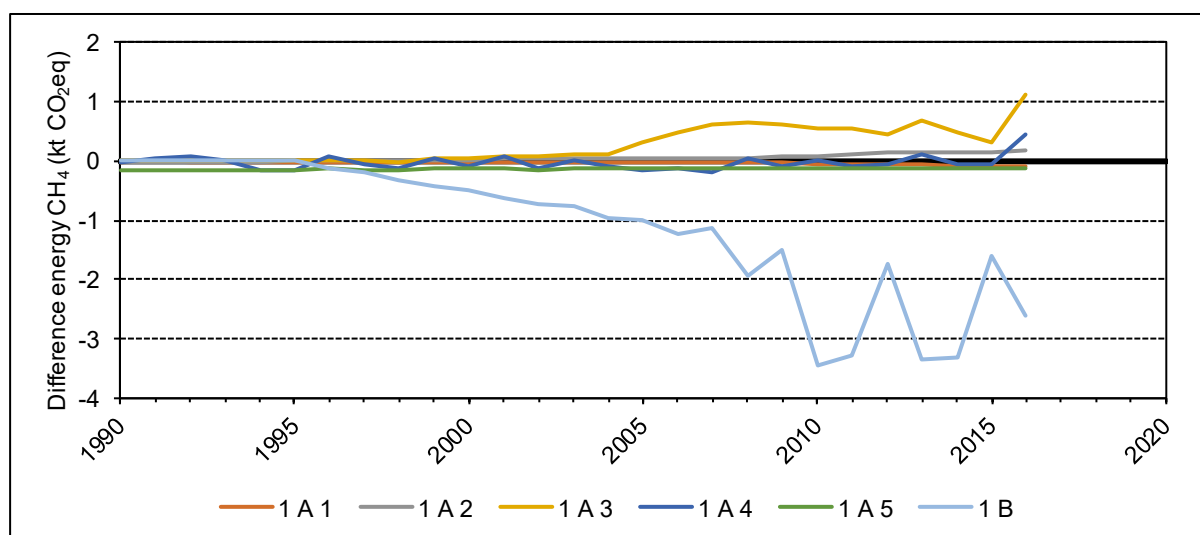


Figure 10-2 Differences in CH₄ emissions (in kt CO₂ eq) between the latest and the previous submission for various source categories in the energy sector. Positive values refer to higher emissions and negative values to lower emissions in the latest compared to the previous submission.

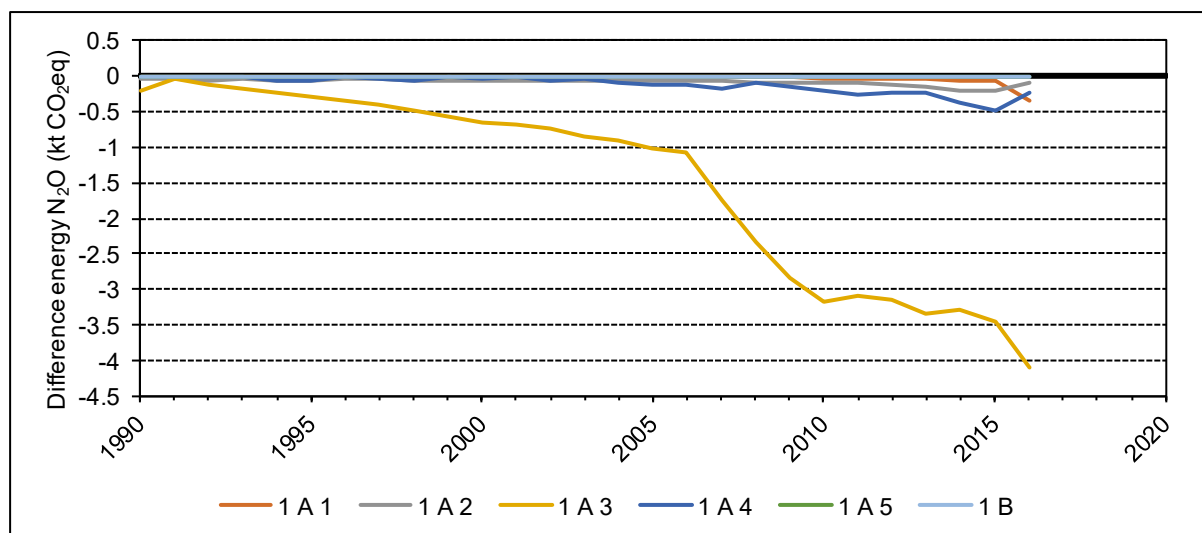


Figure 10-3 Differences in N₂O emissions (in kt CO₂ eq) between the latest and the previous submission for various source categories in the energy sector. Positive values refer to higher emissions and negative values to lower emissions in the latest compared to the previous submission.

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 CO₂, CH₄, and N₂O, and in Figure 10-5 for HFCs, PFCs, SF₆, and NF₃. The largest recalculation resulted from a re-assessment of HFCs and PFCs emissions in source category 2G (see chp. 4.8.5), resulting in emission changes ranging from -58 kt CO₂ eq to +26 kt CO₂ eq for HFCs and up to -37 kt CO₂ eq for PFC (see Figure 10-5). Furthermore, a new study regarding N₂O use in aerosol cans in households and restaurants led to revisions of N₂O emissions in source category 2G3b, resulting in changes ranging from -7 kt CO₂ eq to +2 kt CO₂ eq (see N₂O in Figure 10-4). All other recalculations had an impact that was smaller than 5 kt CO₂ eq (see Figure 10-4 and Figure 10-5).

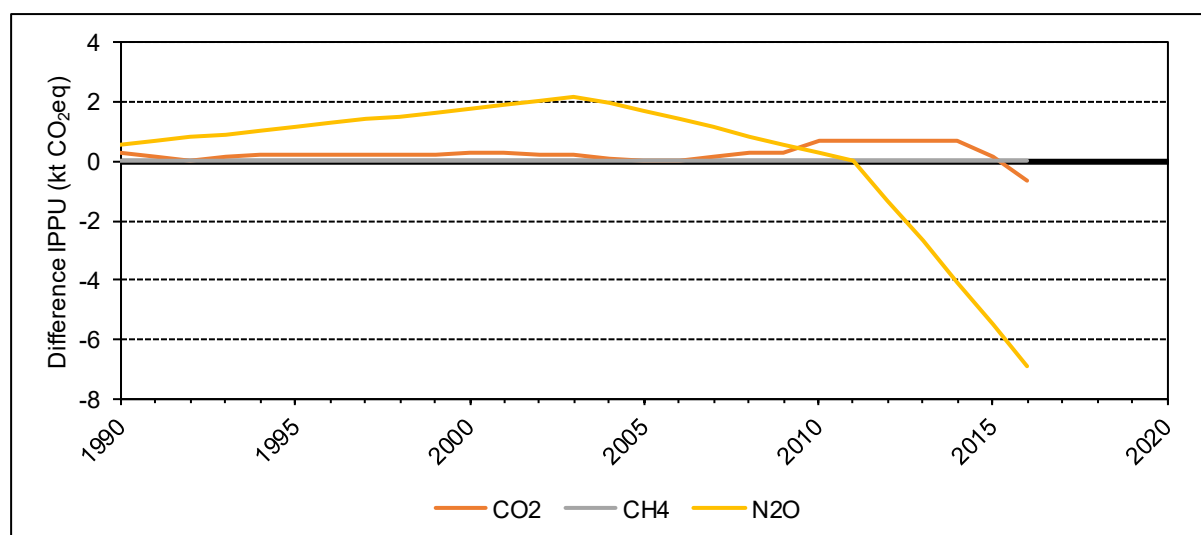


Figure 10-4 Differences in CO₂, CH₄, and N₂O emissions (in kt CO₂ eq) between the latest and the previous submission for sector IPPU. Positive values refer to higher emissions and negative values to lower emissions in the latest compared to the previous submission.

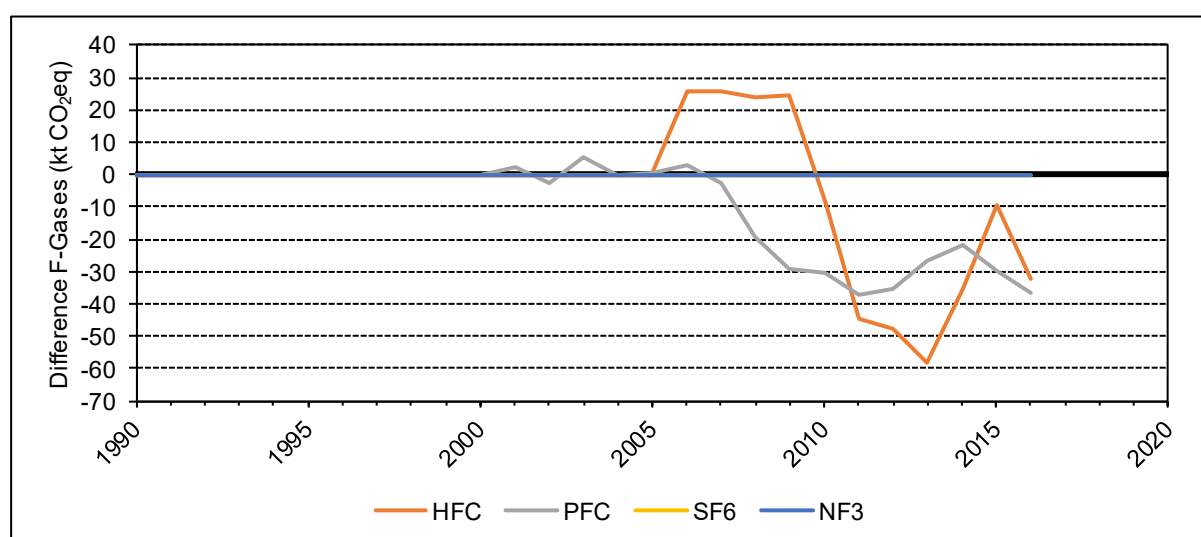


Figure 10-5 Differences in HFC, PFC, SF₆ and NF₃ emissions (in kt CO₂ eq) between the latest and the previous submission for the sector IPPU. Positive values refer to higher emissions and negative values to lower emissions in the latest compared to the previous submission.

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 CO₂, CH₄, and N₂O, and for the most important recalculations aggregated for all greenhouse gases in Figure 10-7. The largest recalculations resulted from changes to the nitrogen model AGRAMMON (particularly revised EF for N₂O emissions from liquid manure management; see chp. 5.3.5), and from adjustments in the amount of direct and indirect N₂O emissions from N mineralised in association with loss of soil C due to new data on N mineralisation in cropland and grassland (new Tier3 methodology in the LULUCF sector; see chp. 5.5.5).

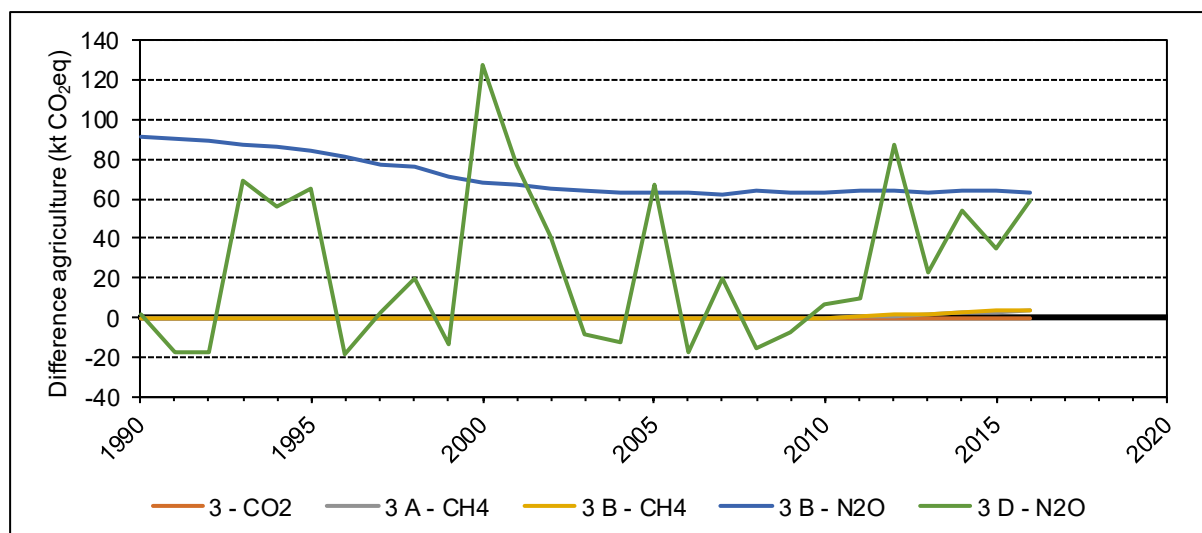


Figure 10-6 Differences in CO₂, CH₄, and N₂O emissions (in kt CO₂ eq) between the latest and the previous submission for sector Agriculture. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

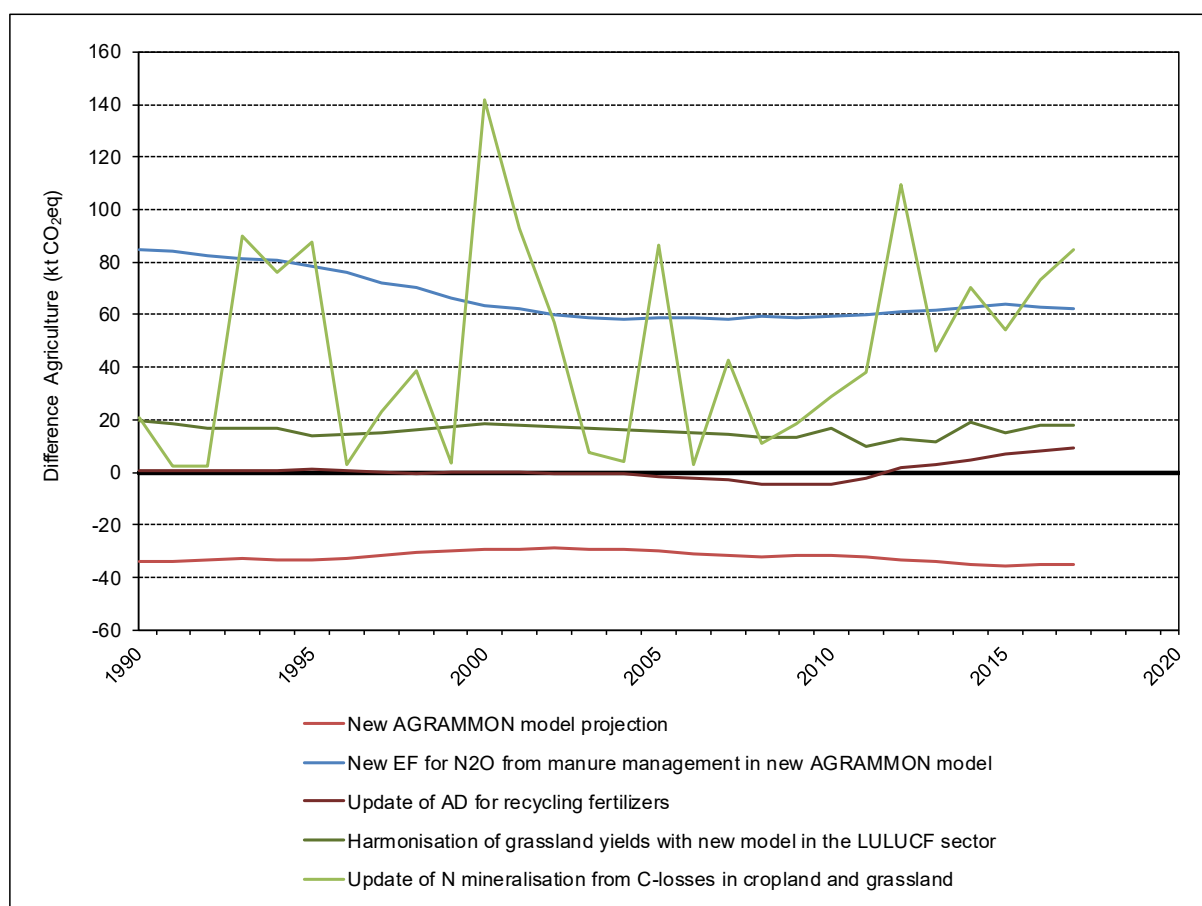


Figure 10-7 Differences in overall GHG emissions (in kt CO₂ eq) between the latest and the previous submission for sector Agriculture due to the most important recalculations. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission. Note that due to the successive implementation of the different recalculations the amounts are not always exact but must be understood as approximations.

- CH₄ emissions from sheep, swine, goats and poultry and "other" (livestock NCAC) were recalculated for the years 2014-2016 due to revised EF. Provisional estimates for net energy intake from the Swiss Farmers Union were updated (Giuliani 2018). The impact on overall emissions in kt CO₂ equivalents is approximately +1.3, +2.1 and +6.6 for the years 2014, 2015 and 2016.
- All estimates based on AGRAMMON data were recalculated for the whole time series due to the implementation of a new model version. The most important changes were the switch to a full nitrogen flow model (including N₂) and the revision of nitrogen excretion rates of some cattle and swine subcategories. More details on AGRAMMON recalculations can be found in chapter 3.6 of Kupper et al. (2018). The impact on overall emissions (including 3B and 3D) in kt CO₂ equivalents is approximately: 1990: -34.1; 2016: -36.0; mean 1990-2016: -32.2.
- Direct N₂O emissions from manure management in liquid systems were recalculated for all inventory years due to the revision of the respective emission factor in the course of the revision of the AGRAMMON model. The impact on overall emissions in kt CO₂ equivalents is approximately: 1990: +85.0; 2016: +62.6; mean 1990-2016: +66.9.
- Direct and indirect N₂O emissions from agricultural soils were revised for the whole time series due to new AD for recycling fertilisers (compost, digestates). The impact on overall emissions in kt CO₂ equivalents is approximately: 1990: +0.4; 2016: +8.1; mean 1990-2016: +0.1.
- N₂O emissions from N in crop residues returned to soils were recalculated for the whole time series due to harmonisation of grassland yields (AD) with the updated methodology in the LULUCF sector. The recalculation affected both direct and indirect N₂O emissions from agricultural soils. The impact on overall emissions in kt CO₂ equivalents is approximately: 1990: +19.6; 2016: +18.0; mean 1990-2016: +15.8.
- Direct and indirect N₂O emissions from N mineralised in association with loss of soil C were recalculated for the whole time series due to new data on N mineralisation in cropland and grassland (new Tier3 methodology in the LULUCF sector). The impact on overall emissions in kt CO₂ equivalents is approximately: 1990: +20.5; 2016: + 73.4; mean 1990-2016: +45.6.

10.1.2.4 Land Use, Land-Use change and Forestry

Recalculations with an overall impact of >100 kt CO₂ equivalents are assessed quantitatively. The remaining recalculations are described qualitatively in the respective chp. 6.X.5.

Overall changes in emissions by sources and removals by sinks in the LULUCF sector due to all recalculations realised in this submission are shown in Figure 10-8. The seesaw pattern of the deviation of CO₂ eq emissions and removals between the latest and the previous submission (range from -2'054.2 kt CO₂ eq in 1991 to 810.3 kt CO₂ eq in 2000) is controlled by major recalculations in subcategories 4A, 4B, and 4C (Figure 10-9).

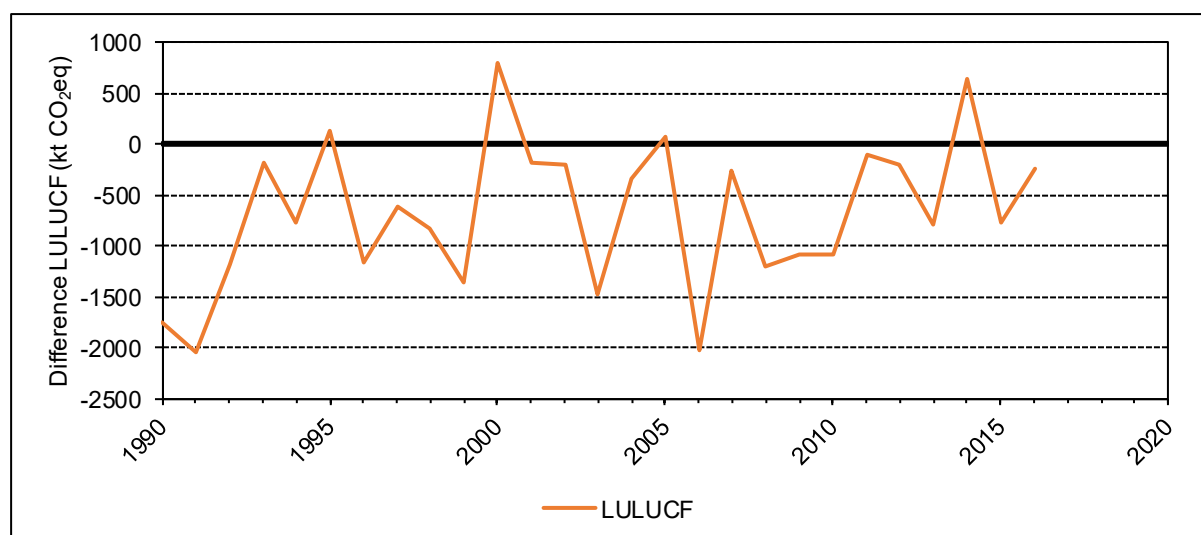


Figure 10-8 Differences in GHG emissions and removals (in kt CO₂ eq) between the latest and the previous submission for the LULUCF sector. Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

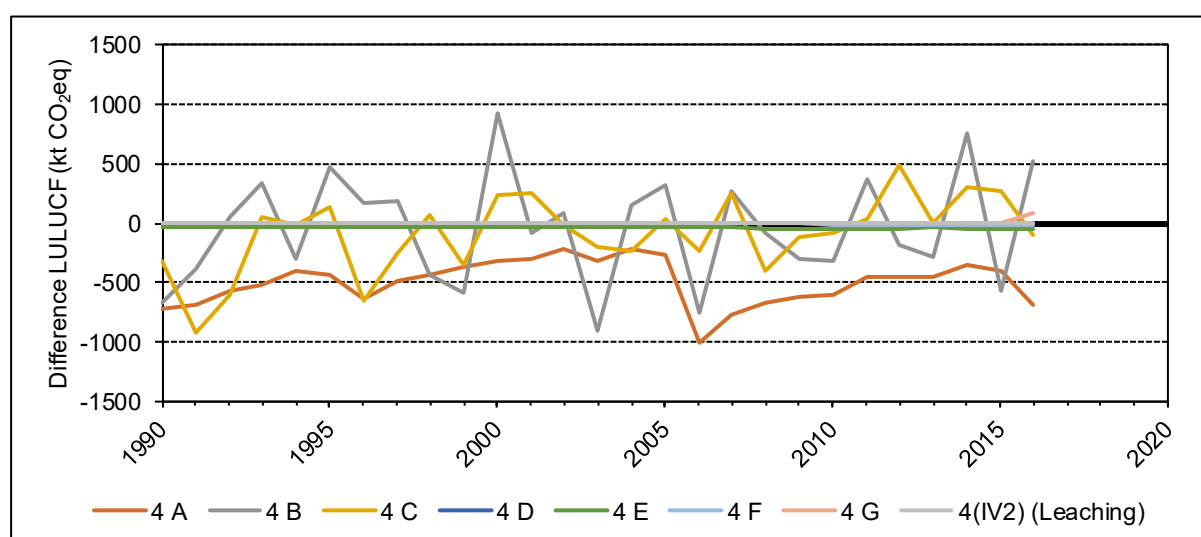


Figure 10-9 Differences in GHG emissions and removals (in kt CO₂ eq) between the latest and the previous submission for the subcategories 4A-4G and 4(IV2) (Leaching) in the LULUCF sector. Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

In category 4A Forest land two major recalculations were responsible for the differences shown in Figure 10-9.

- 4A: Based on new NFI 4 (2013-2017) data, the time series of carbon stocks, gains and losses in living biomass of productive forests (CC12) were recalculated from 2006 onwards (Thürig et al. 2018; cf. chp. 6.4.2.5 and chp. 6.4.2.1). Further, the time series of losses in living biomass of productive forests (CC12) was recalculated from 2006 onwards since values of cut and mortality from the NFI are weighted with forest statistics data (weighting is done for each NFI-intersurvey period; see chp. 6.4.2.5; Table 6-17). The impact on emissions and removals in kt CO₂ eq in category 4A1 is shown in Figure 10-10 separated for gains in living biomass and losses in living biomass. The net

changes in living biomass (gains minus losses) between the latest and the previous submission ranges from -477.2 kt CO₂ eq in 2016 to -204.0 kt CO₂ eq in 2012.

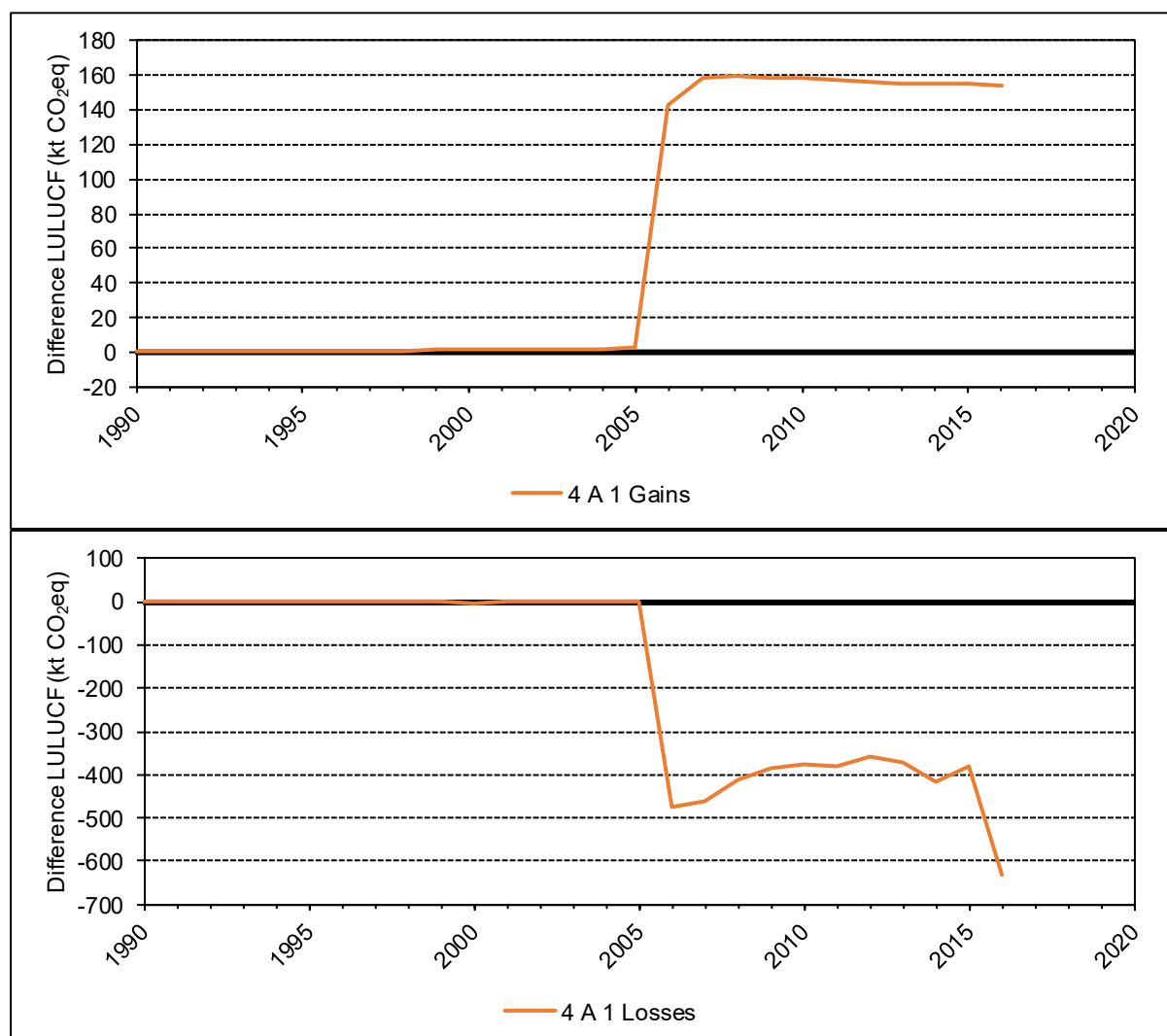


Figure 10-10 Differences in emissions and removals (in kt CO₂ eq) between the latest and the previous submission for subcategory 4A1 Gains in living biomass on Forest land remaining Forest land (CO₂) (upper panel) and subcategory 4A1 Losses in living biomass on Forest land remaining Forest land (CO₂) (lower panel). 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.

- 4A: Estimates of carbon stock changes in dead wood, litter, and mineral soil in productive forests (CC12) were recalculated for the whole time series to reflect methodological improvements in the implementation of the model Yasso07 for simulating C stocks and C stock changes in dead wood, litter, and mineral soil (cf. chp. 6.4.5). The impact on emissions and removals in kt CO₂ eq in category 4A1 is shown in Figure 10-11 for net carbon stock change in dead wood (upper panel) and net carbon stock change in litter (lower panel). The impact on net carbon stock changes in mineral soils is quantitatively negligible and not displayed. The deviation of CO₂ eq emissions and removals between the latest and the previous submission for dead wood ranges from -340.7 kt CO₂ eq in 1990 to -21.5 kt CO₂ eq in 2010, whereas the deviation for litter ranges from -587.4 kt CO₂ eq in 2006 to -3.8 kt CO₂ eq in 2014.

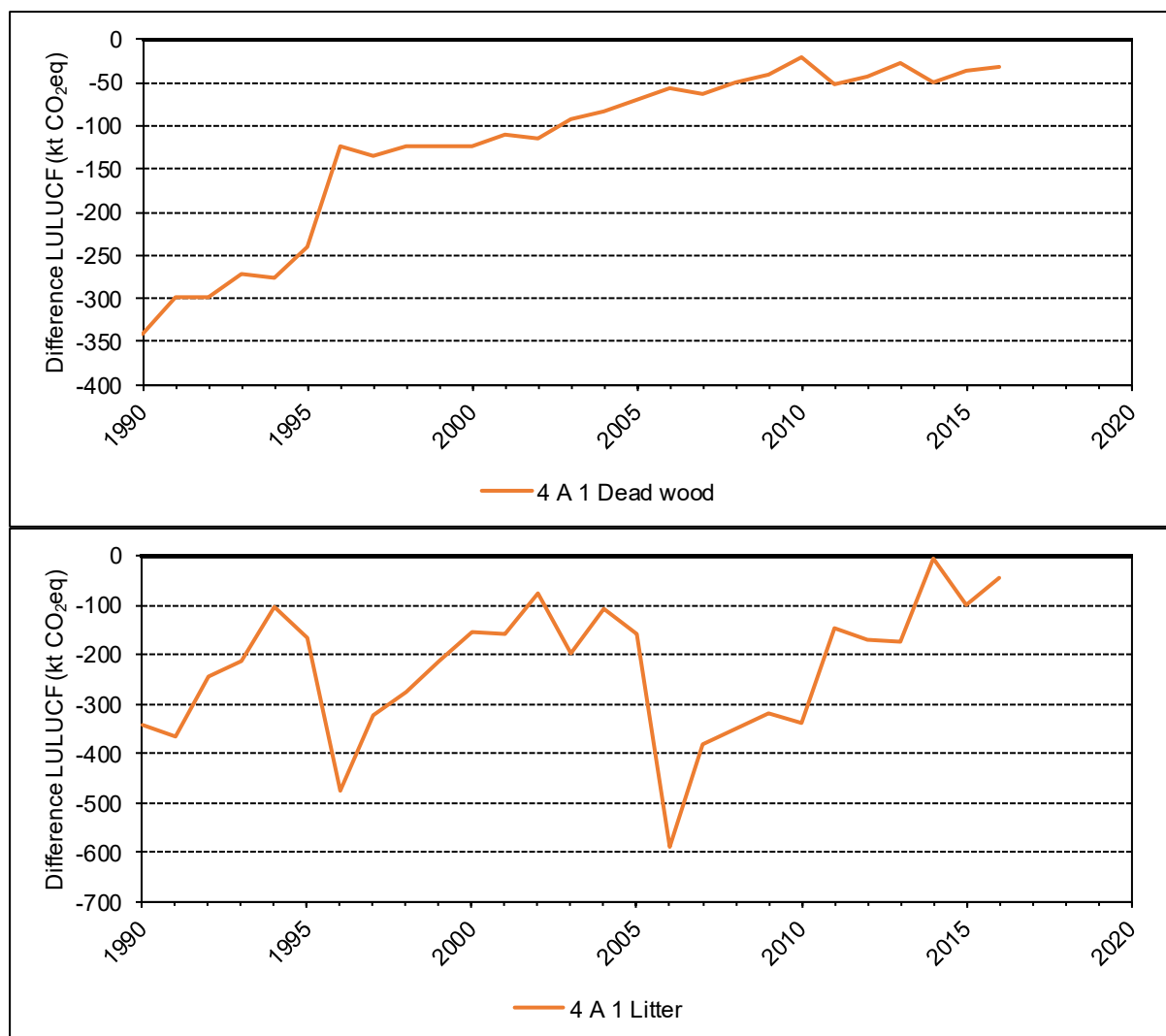


Figure 10-11 Differences in emissions and removals (in kt CO₂ eq) between the latest and the previous submission for subcategory 4A1 Net carbon stock change in dead wood on Forest land remaining Forest land (CO₂) (upper panel) and subcategory 4A1 Net carbon stock change in litter on Forest land remaining Forest land (CO₂) (lower panel). 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 4B Cropland two major recalculations changed overall CO₂ eq emissions and removals and induced a pronounced seesaw pattern of the deviation between the latest and the previous submission (Figure 10-9).

- 4B: Carbon stocks and carbon stock changes in living biomass of Cropland were recalculated for the period 1990-2016 based on harvest data from the Swiss Farmers Union (SBV 2018 and former editions) in the course of the new Tier 3 approach for agricultural soils. Data were reported as moving averages over five years (cf. chp. 6.5.2.1). The impact on emissions and removals in kt CO₂ eq in category 4B1 is shown in Figure 10-12 separated for gains in living biomass and losses in living biomass. The combined deviation of CO₂ eq emissions and removals between the latest and the previous submission ranges from -598.7 kt CO₂ eq in 1990 to 816.0 kt CO₂ eq in 2014.

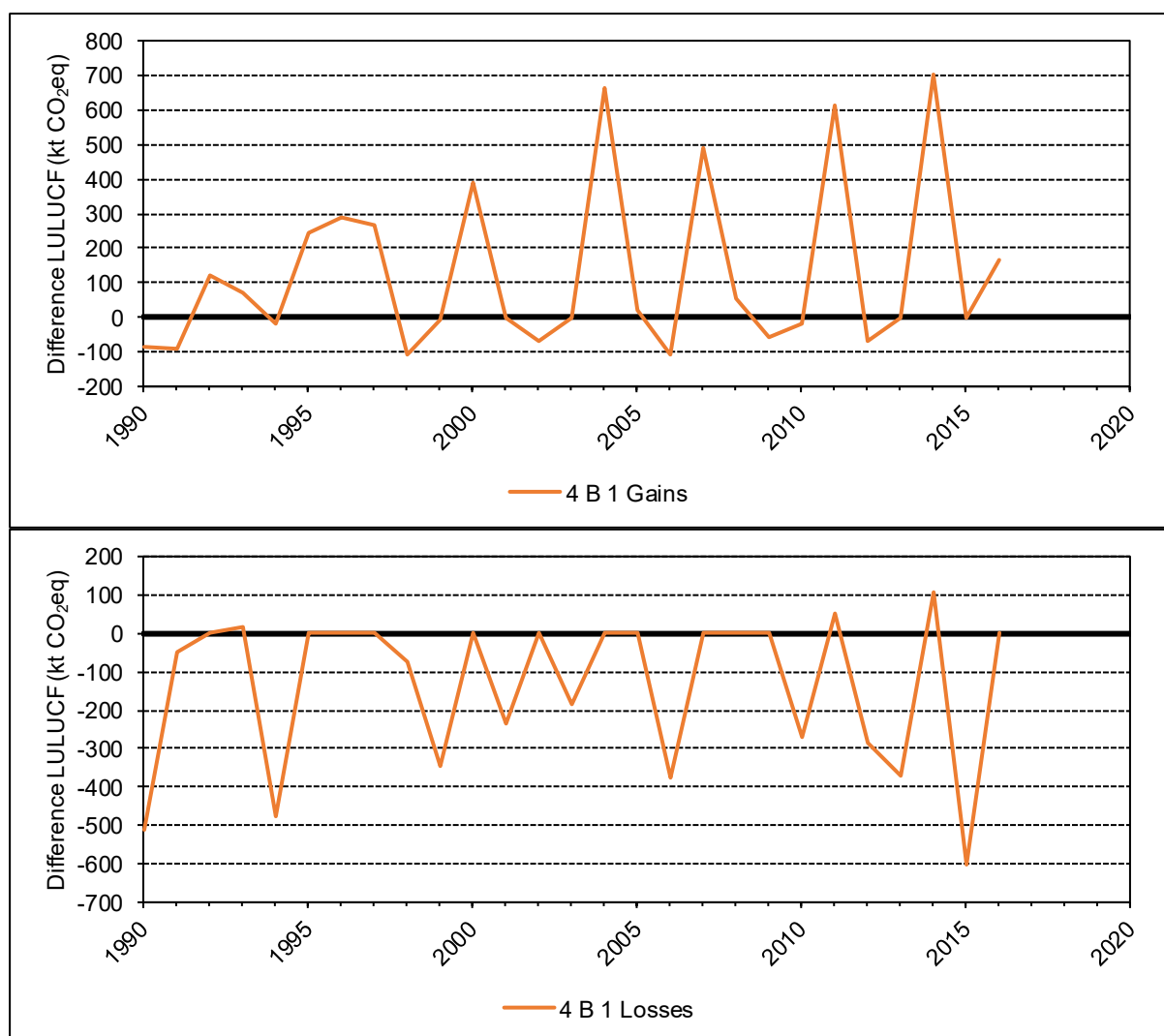


Figure 10-12 Differences in emissions and removals (in kt CO₂ eq) between the latest and the previous submission for subcategory 4B1 Gains in living biomass on Cropland remaining Cropland (CO₂) (upper panel) and subcategory 4B1 Losses in living biomass on Cropland remaining Cropland (CO₂) (lower panel). 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.

- 4B: Carbon stocks and carbon stock changes in mineral soils of Cropland were recalculated for the period 1990-2016 using a Tier 3 approach (application of the RothC model by Wüst-Galley et al. 2019, cf. chp. 6.5.2.3). The impact on emissions and removals in kt CO₂ eq in category 4B1 is shown in Figure 10-13. The deviation between the latest and the previous submission ranges from -725.1 kt CO₂ eq in 2003 to 537.7 kt CO₂ eq in 2000; mean 1990-2016: -38 kt CO₂ eq.

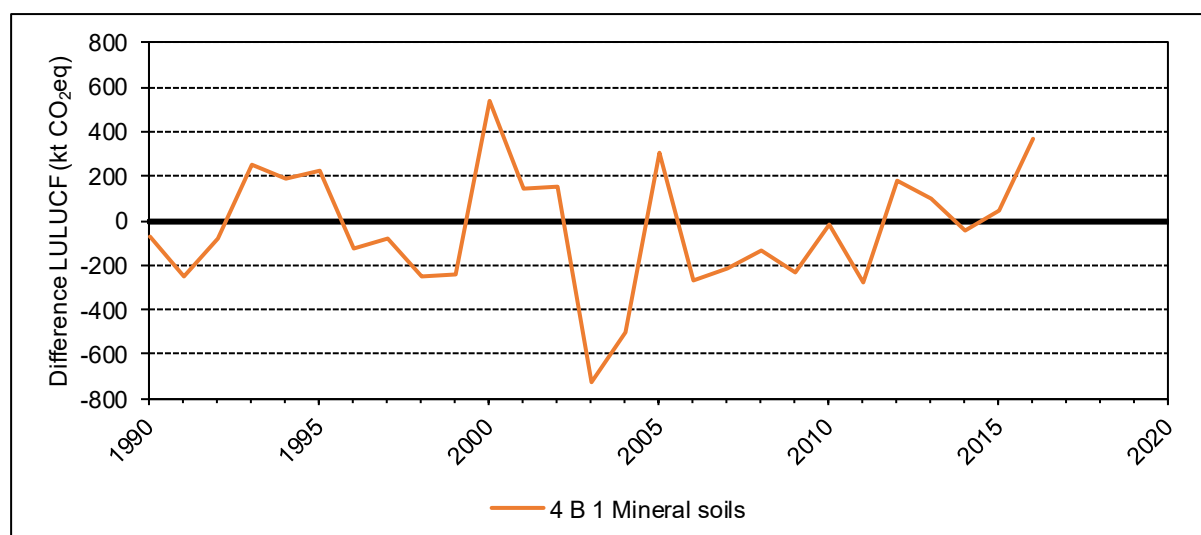


Figure 10-13 Differences in emissions and removals (in kt CO₂ eq) between the latest and the previous submission for subcategory 4B1 Net carbon stock change in mineral soils on Cropland remaining Cropland (CO₂). Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

In category 4C Grassland one major recalculation controlled the changes in CO₂ eq emissions and removals between the latest and the previous submission (Figure 10-9).

- 4C: Carbon stocks and carbon stock changes in mineral soils of permanent grassland (CC31) were recalculated for the period 1990-2016 using a Tier 3 approach (application of the RothC model by Wüst-Galley et al. 2019, see chp. 6.6.2.3). The impact on emissions and removals in kt CO₂ eq in category 4C1 (all other soil carbon stocks of subcategories CC32-CC37 remained unchanged) is shown in Figure 10-14. The deviation between the latest and the previous submission ranges from -954.5 kt CO₂ eq in 1991 to 465.6 kt CO₂ eq in 2012; mean 1990-2016: -125 kt CO₂ eq.

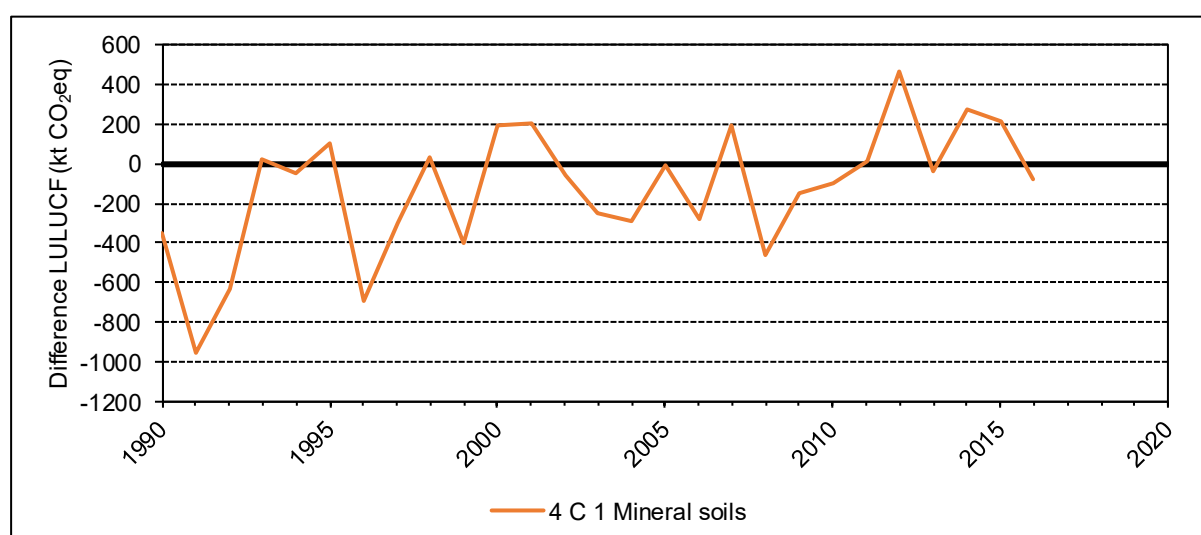


Figure 10-14 Differences in emissions (in kt CO₂ eq) between the latest and the previous submission for the subcategory 4C1 Net carbon stock change in mineral soils on Grassland remaining Grassland (CO₂). Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

10.1.2.5 Waste

The total changes in emissions in the Waste sector due to all recalculations are shown in Figure 10-15 for CO₂, CH₄, and N₂O. The largest recalculations resulted from changes in the N₂O emissions from 5D1 waste water treatment (see chp. 7.5.5), resulting in N₂O emission changes of -40 to -50 kt CO₂ eq.

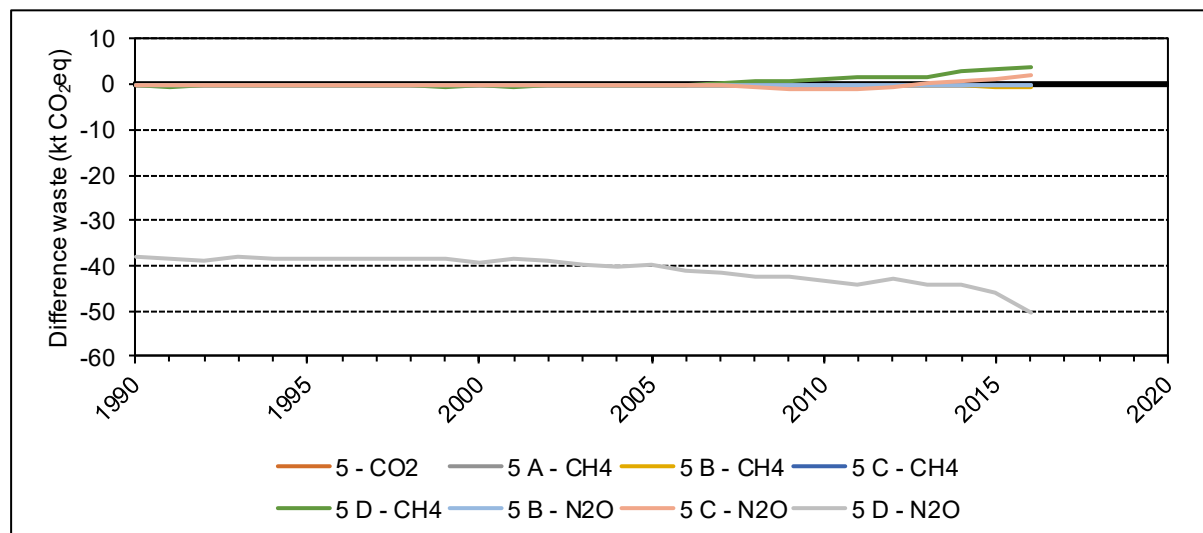


Figure 10-15 Differences in CO₂, CH₄, N₂O emissions (in kt CO₂ eq) between the latest and the previous submission for sector Waste. Positive values refer to higher emissions and negative values to lower emissions in the latest compared to the previous submission.

10.1.2.6 Other

No recalculations were carried out in sector Other.

10.1.2.7 Indirect CO₂ Emissions

The total changes in indirect CO₂ emissions due to all recalculations are shown in Figure 10-16. The recalculations are dominated by changes in emissions of precursor gases in source categories 2D3a and 2G4 (see chp. 4.5.5 and 4.8.5), with emission changes of up to -8 kt CO₂ eq (2D3a) and -2 kt CO₂ eq (2G4).

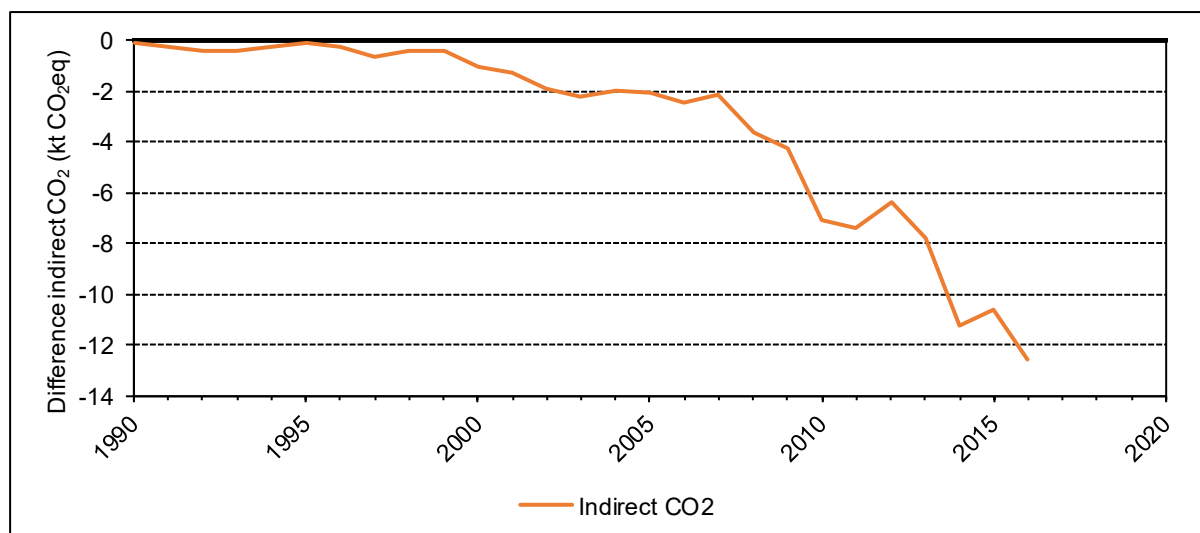


Figure 10-16 Differences in indirect CO₂ emissions (in kt CO₂ eq) between the latest and the previous submission. Positive values refer to higher emissions and negative values to lower emissions in the latest compared to the previous submission.

10.1.2.8 KP- LULUCF Inventory

All category-specific recalculations for 4A (chp. 6.4.5) and 4G (chp.6.11.5) including the update of the activity data 1990–2016 (see chp. 6.3.5) are relevant for the KP-LULUCF inventory. For Forest management, recalculations in carbon stock changes are similar to 4A as explained in chp. 10.1.2.4).

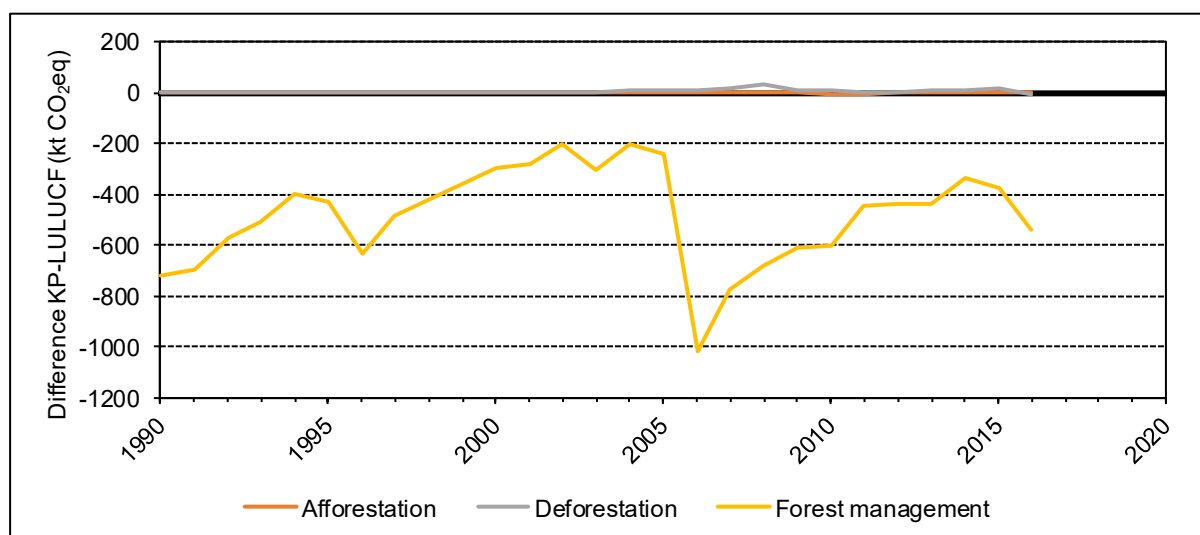


Figure 10-17 Differences in emissions (in kt CO₂ eq) between the latest and the previous submission for Afforestation, Deforestation (Kyoto Protocol Art. 3.3), and Forest Management (Kyoto Protocol Art. 3.4). Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

10.2 Implications for emission levels

Table 10-2 and Table 10-3 show the aggregated effect of all recalculations on the emission estimates for the base year 1990 and for the year 2016.

Table 10-2 Implications of recalculations for emission levels in 1990. Emissions (excluding indirect CO₂) are shown for the previous submission (FOEN 2018) and the latest submission. The difference refers to absolute values (Latest - Previous).

Emissions for 1990	CO ₂			CH ₄			N ₂ O			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	40'900	40'899	0.2	634	634	-0.2	292.3	293	-0.3				41'826	41'826	-0.2
2 IPPU	3'149	3'149	0.3	1.8	1.8	0.0	172	171	0.6	254	254	0.00	3'576	3'576	0.9
3 Agriculture	48.9	48.9	0.0	4'453	4'453	0.0	2'263	2'170	93.2				6'766	6'672	93.2
4 LULUCF	-2'571	-818	-1'752	29.6	29.4	0.2	56.6	58.7	-2.1				-2'484	-730	-1'754
5 Waste	53.7	53.7	0.0	915	915	-0.4	103	141	-37.9				1'071	1'109	-38.2
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	41'592	43'343	-1'752	6'034	6'035	-0.3	2'887	2'834	53.6	254	254	0.00	50'767	52'466	-1'698
	96.0%	100.0%	-4.0%	100.0%	100.0%	0.0%	101.9%	100.0%	1.9%	100.0%	100.0%	0.0%	96.8%	100.0%	-3.2%
Total excluding LULUCF	44'162	44'162	0.5	6'005	6'005	-0.6	2'831	2'775	55.7	254	254	0.00	53'252	53'196	55.6
	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%	102.0%	100.0%	2.0%	100.0%	100.0%	0.0%	100.1%	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	117	117	0.0	137	137	0.0	0.0	0.0	0.0

Table 10-3 Implications of recalculations for emission levels in 2016. Emissions (excluding indirect CO₂) are shown for the previous submission (FOEN 2018) and the latest submission. The difference refers to the absolute values (Latest - Previous).

Emissions for 2016	CO ₂			CH ₄			N ₂ O			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	36'962	36'980	-17.7	279	280	-1.1	220	225	-4.8				37'461	37'484	-23.6
2 IPPU	2'156	2'157	-0.7	2.7	2.7	0.0	38.1	45.1	-6.9	1'717	1'786	-69.3	3'914	3'991	-76.9
3 Agriculture	47.3	47.3	0.0	4'085	4'078	7.6	1'960	1'838	122.2				6'093	5'963	129.7
4 LULUCF	-2'180	-1'937	-243	16.0	15.9	0.0	47.7	47.8	-0.1				-2'116	-1'873	-243
5 Waste	9.9	9.9	0.0	550	547	3.3	143	192	-48.6				703	748	-45.3
6 Other	11.1	11.1	0.0	0.6	0.6	0.0	0.5	0.5	0.0				12.2	12.2	0.0
Total including LULUCF	37'007	37'268	-261	4'933	4'923	10	2'410	2'348	61.7	1'717	1'786	-69.3	46'066	46'326	-259
	99.3%	100.0%	-0.7%	100.2%	100.0%	0.2%	102.6%	100.0%	2.6%	96.1%	100.0%	-3.9%	99.4%	100.0%	-0.6%
Total excluding LULUCF	39'187	39'205	-18.4	4'917	4'907	10	2'362	2'301	61.8	1'717	1'786	-69.3	48'183	48'199	-16
	100.0%	100.0%	0.0%	100.2%	100.0%	0.2%	102.7%	100.0%	2.7%	96.1%	100.0%	-3.9%	100.0%	100.0%	0.0%

Emissions for 2016	HFC			PFC			SF ₆			NF ₃		
	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference
	CO ₂ equivalent (kt)											
2 IPPU	1'491	1'523	-32.5	18.2	55.0	-36.8	207.1	207.1	0.0	0.51	0.51	0.0

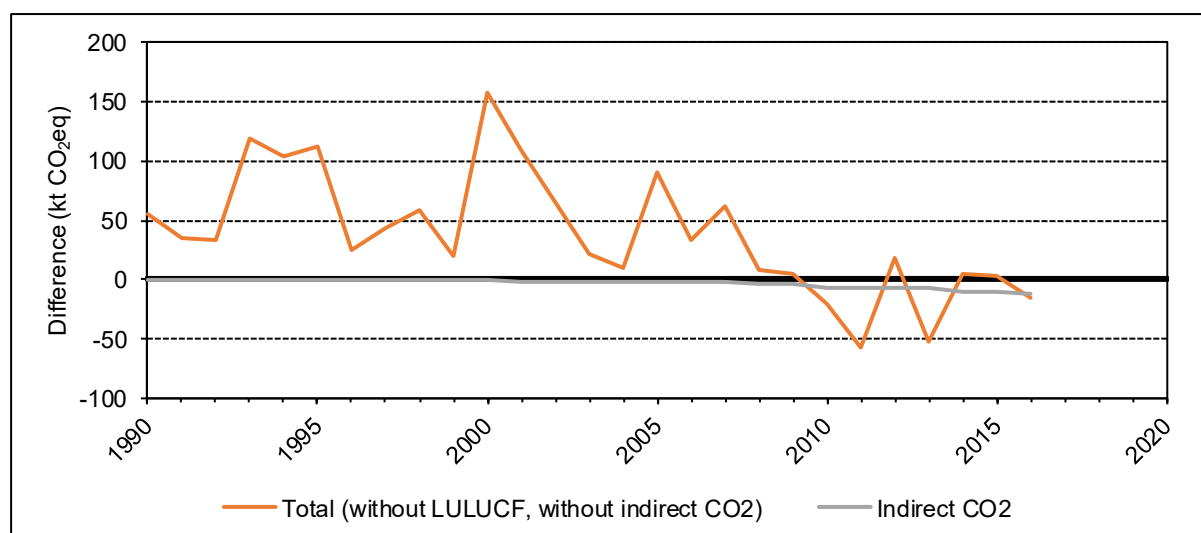


Figure 10-18 Implications of recalculations for the national total emissions (excluding LULUCF). The implications of recalculations for indirect CO₂ (in kt CO₂ eq) are shown separately (see also Figure 10-16). Positive values refer to higher emissions and negative values to lower emissions in the latest 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 -60 kt to +160 kt CO₂ eq. The largest contributions to the total effect stem from

- 2G Other product manufacture and use (HFCs and PFCs) ranging from +30 to -80 kt CO₂ eq over the period from 2005 to 2016.
- 3B Manure management and 3D Agricultural soils (N₂O) ranging from +50 to +200 kt CO₂ eq over the entire time period from 1990-2016.
- 5D Wastewater treatment and discharge (N₂O) ranging from -40 to -50 kt CO₂ eq over the entire time period from 1990-2016.

The aggregated effect of all the recalculations on national total emissions from LULUCF are shown in Figure 10-8. The effect of the recalculations ranges from -2000 kt to +800 kt CO₂ eq. As can be seen from the comparison of Figure 10-18 and Figure 10-8, recalculations in the LULUCF sector dominate the total effect. The most important recalculation is the implementation of the soil carbon model, resulting in large carbon stock changes in soils in source categories 4B Cropland and 4C Grassland.

To further visualize the aggregated effect of all the recalculations, the following figures compare total emissions as reported in the previous and the latest submission in absolute terms (instead of showing differences as in the figures above): Total emissions (without LULUCF, without indirect CO₂) in Figure 10-19, total indirect CO₂ emissions in Figure 10-20, total emissions from LULUCF in Figure 10-21, and total emissions from KP-LULUCF in Figure 10-22.

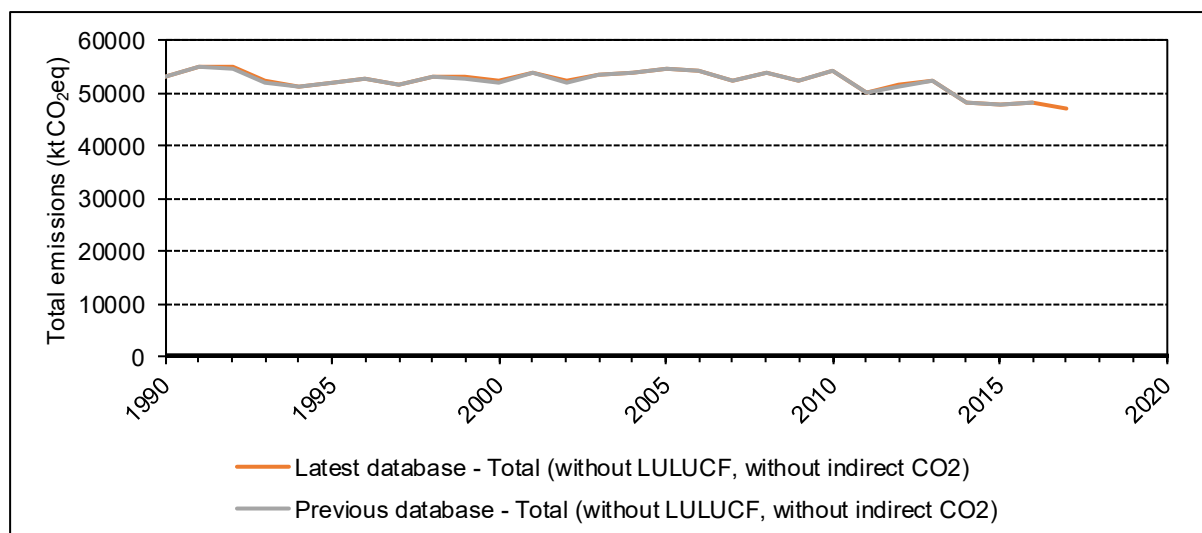


Figure 10-19 Comparison of total emissions (without LULUCF, without indirect CO₂) as reported in the previous and the latest submission.

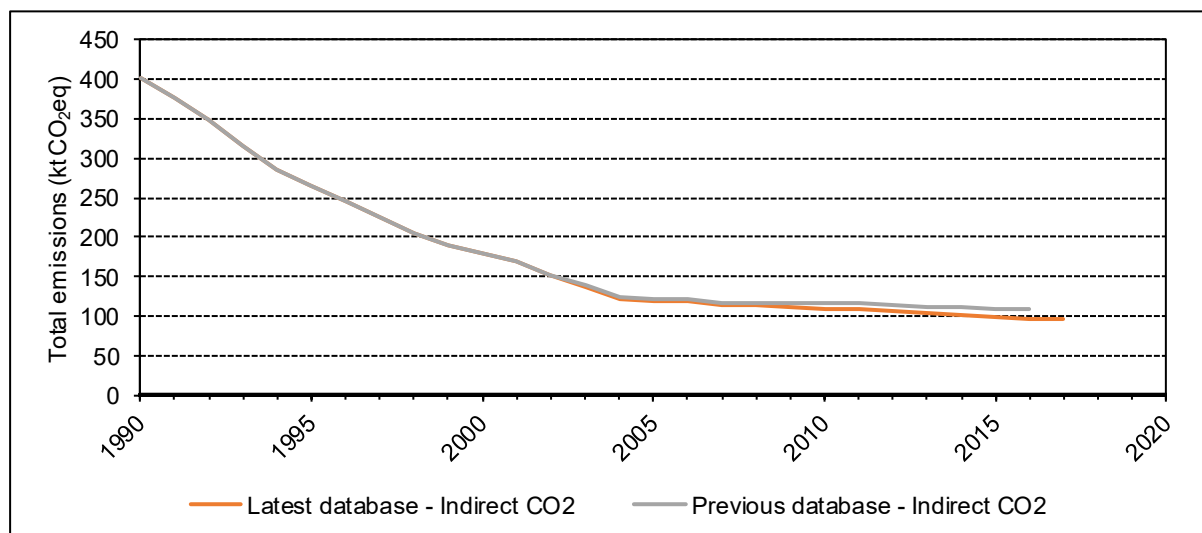


Figure 10-20 Comparison of total indirect CO₂ emissions as reported in the previous and the latest submission.

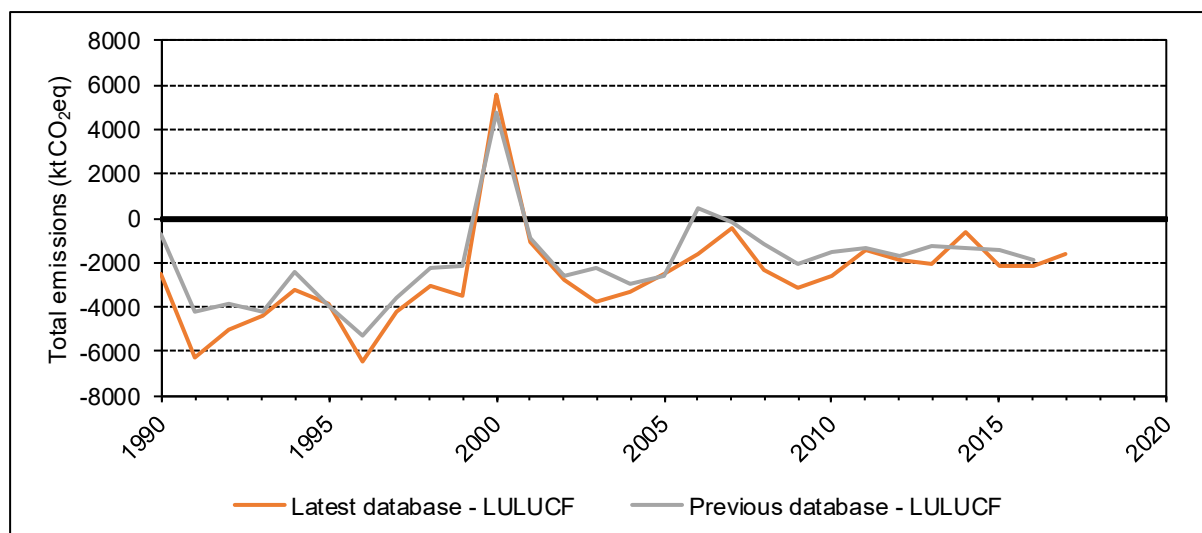


Figure 10-21 Comparison of total emissions from LULUCF as reported in the previous and the latest submission.

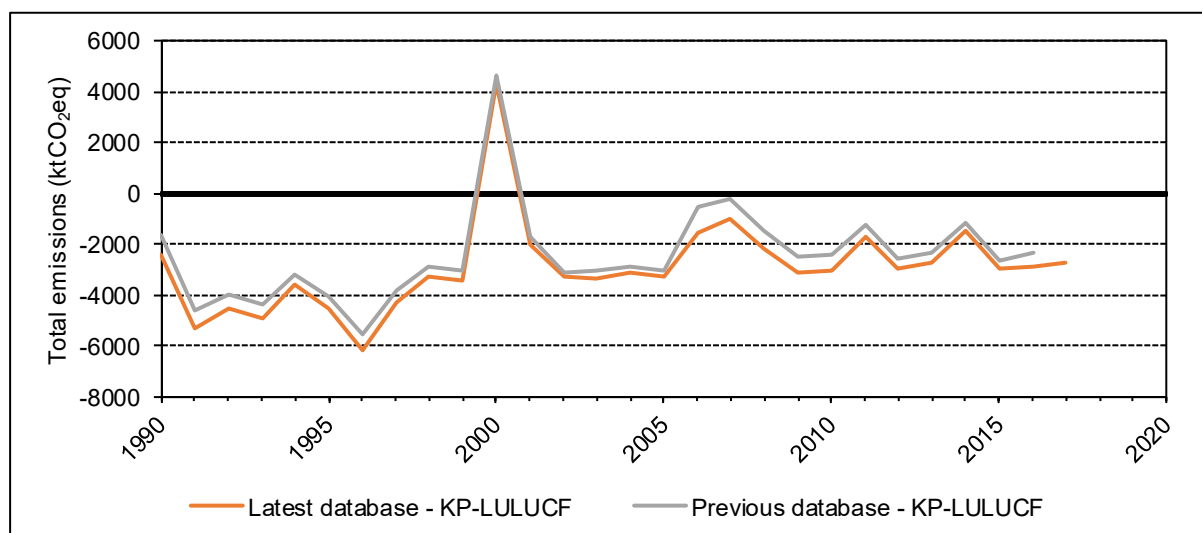


Figure 10-22 Comparison of total emissions from KP-LULUCF as reported in the previous and the latest submission.

10.3 Implications for emissions trends, including time series consistency

Due to recalculations, the emission trend 1990–2016 has slightly changed (see Table 10-4). However, as recalculations are applied to the entire time series (as appropriate), time series consistency is maintained.

Table 10-4 Estimated emission trends 1990–2016, calculated based on national total emissions excluding indirect CO₂ as shown in the previous and the latest submission (for additional details see Table 10-2 and Table 10-3).

Trend	1990		2016		change 1990/2016	
	Latest	Previous	Latest	Previous	Latest	Previous
	CO ₂ equivalent (kt)				%	
Total including LULUCF	50'767	52'466	46'066	46'326	-9.3%	-11.7%
Total excluding LULUCF	53'252	53'196	48'183	48'199	-9.5%	-9.4%

10.4 Planned improvements, including in response to the review process

- 1B2b Fugitive emissions from natural gas: In collaboration with the Swiss Gas and Water Industry Association (SGWA), fugitive emissions from the gas network will be re-assessed and updated in the greenhouse gas inventory as appropriate.
- 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 CO₂ compensation programmes (share of products with HFC, recycling of HFC, early replacement of HFC).
- 3B Manure management: An expert peer review of manure management is planned for summer 2020. Results will be implemented in future greenhouse gas inventories as appropriate.
- 3D Starting in 2019, FOEN funds the development and evaluation of a process-oriented model for N₂O emissions in agricultural soils subject to common Swiss management practices.
- 4: The suitability of newly available satellite data for land area representation in Switzerland is being evaluated.
- 4A: The implementation of the soil model Yasso07 to improve the accuracy in the estimates of temporal changes and turnover rates in the soil carbon, litter, and dead wood pools will be further developed.
- 4A: Projects in a new national research programme ("SOM control") aimed at identifying the drivers of soil organic matter storage in Swiss forest soils. In a follow-up project financed by FOEN, the implications for carbon stabilization in mineral forest soils are investigated and the application to further development of the Yasso model is examined (anticipated for GHG inventory submission 2021).
- 4B, 4C: In this submission, the model results for mineral agricultural soils were implemented for the first time. For future submissions, the calculations of the initial

carbon stocks and other improvements will be considered, as there are indications that the soil depth of some mountain soils has been underestimated.

- 4B, 4C: Starting in 2019, FOEN funds the development and evaluation of a process-oriented model for N₂O emissions in agricultural soils subject to common Swiss management practices.
- 4B, 4C, 4D: A digital soil modeling project at Agroscope (funded by FOEN 2017-2020) addresses the shortcomings of missing spatially inclusive and comprehensive soil information in Switzerland. A LULUCF module aims at improving the estimates of soil carbon contents in Swiss non-forest soils.
- 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 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 suitability of the obtained data for reporting in categories 4B, 4C, 4D, and 4E, respectively, is subject to evaluation. 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.
- 4C: A study on GHG (CO₂, CH₄, N₂O) emissions from an intensively used fen under grassland management in the Rhine valley (Agroscope in collaboration with the University of Basel, 2017–2020, financed by FOEN) will improve the robustness of country-specific emission factor estimates for grassland soils rich in organic matter in the medium term. A further objective of the study is to estimate potential emission reductions from coverage of managed organic soils with mineral soil material.
- 4G: For the calculation of paper and paperboard there are still some methodological challenges, such as how to determine the amount of domestic pulp wood contained in recycled products (see UNFCCC 2018, ID#KL.7). Therefore, a study was planned to obtain additional national activity data on paper and paperboard to improve the calculation of the contribution of this pool. However, due to limited personal resources the latter is suspended.
- 5B Biological treatment of solid waste: A research project in the framework of a joint research program is investigating the CH₄ emissions from agricultural biogas facilities. Results will be implemented in the greenhouse gas inventory after completion of the project as appropriate.
- 5D Wastewater treatment and discharge: Two research projects, aiming at deriving country-specific emission factors for CH₄ and N₂O from waste water treatment plants, are on-going. Results will be implemented in the greenhouse gas inventory after completion of the projects as appropriate.

PART 2

11 KP-LULUCF

Responsibilities for sector Kyoto Protocol - Land use and land use change (KP-LULUCF)	
Overall responsibility	Nele Rogiers (FOEN)
Authors & sector experts	Nele Rogiers (FOEN), Markus Didion (WSL), Esther Thürig (WSL)
Annual updates (NIR text, tables, figures)	Nele Rogiers (FOEN), Dominik Eggli (Meteotest)
Quality control (annual updates)	Markus Didion (WSL), Paolo Camin (FOEN), Andreas Schellenberger (FOEN)
Internal review	Markus Didion (WSL)

Switzerland has chosen to account over the entire second 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 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 greenhouse gas sources reported for the mandatory activities under Article 3, paragraph 3 and for Forest management under 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 CO₂ 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. Annual removals from Afforestation and Deforestation fluctuate (Figure 11-2), which 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 low and fluctuations in the annual net changes in Forest management can primarily be explained by changes in the losses from the living biomass, dead wood and litter pools (Table 11-1). The reason for the high CO₂ eq net emissions in 2000 and the small CO₂ eq net removals in the following year 2001 for Forest management is the winter storm “Lothar” by the end of 1999, which caused great damages in the forest stands and increased losses of living biomass due to salvage logging. Harvesting rates were exceptionally high in 1990 after storm Vivian (February 1990) and in 2000 after the storm Lothar (December 1999). Harvesting rates in Swiss forests tended to increase since 1991. Because harvesting rates started to decline in 2008 (Table 6-17) due to the international and domestic economic framework conditions, removals from Forest management increased between 2008 and 2012. Since 2013, harvesting rates are relatively constant but still showing remarkable year-to-year variability. The relatively small sink in 2014 is due to the comparably high harvesting rates (highest in period 2012–2017) and the rather high 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 paper and paperboard (see chp. 6.11 and Table 6-34). The production of sawnwood shows a good correlation with the domestic harvesting rate. The contribution of paper and paperboard to changes in HWP fluctuates

over the years. The relative contribution of paper and paperboard to the HWP pool considerably increased in the last 5 years.

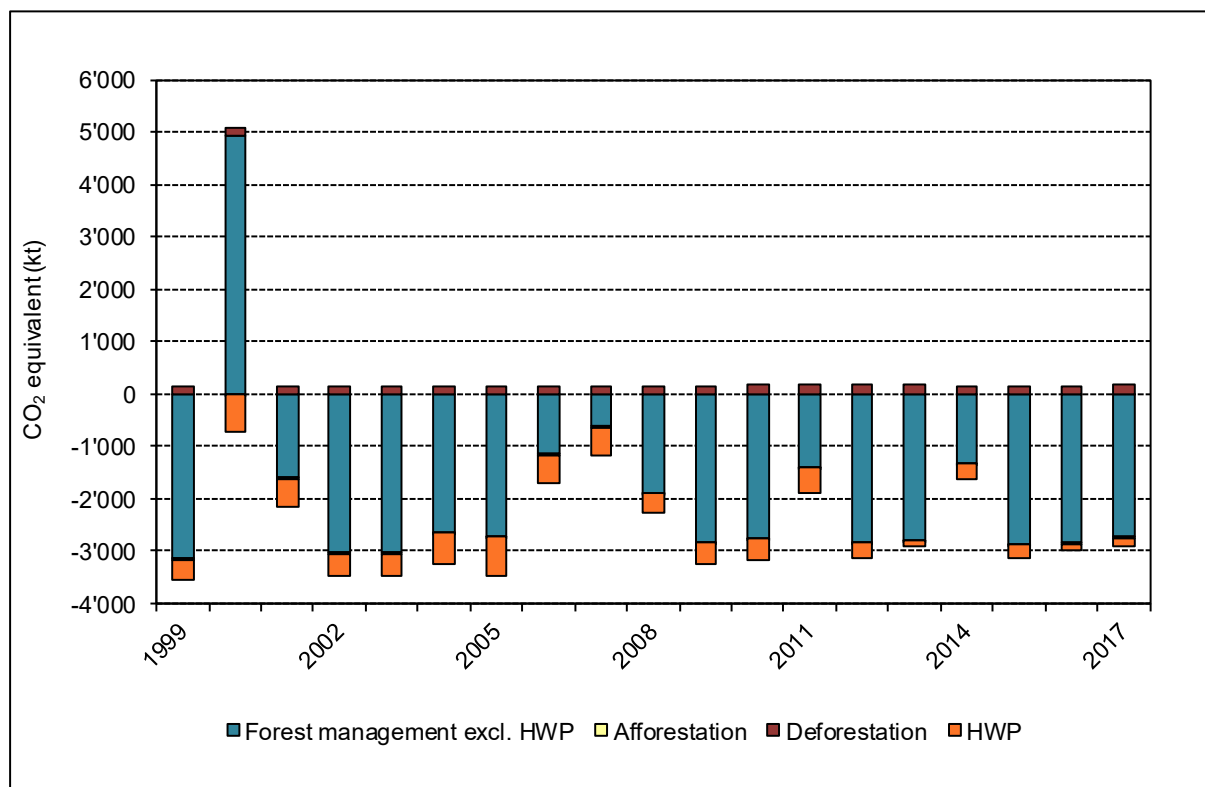


Figure 11-1 GHG emissions (positive sign) and removals (negative sign). Shown are data for Afforestation (too small to be distinguishable) and Deforestation under Article 3, paragraph 3, Forest management excluding HWP and HWP under Article 3, paragraph 4.

Table 11-1 Net CO₂ 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. Abreaveations are explained in chp. 6.1.3.2 except for loss_{drainage} and LUC (N₂O), loss_{LUC} (N₂O), loss_{drainage} (N₂O): N₂O 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; loss_{biomburn}: CH₄ and N₂O emissions from biomass burning. Figures correspond with CRF 4(KP) and CRF 4(KP-I)B.1.

Greenhouse gas source and sink activities	1990	1995	2000	2005
	kt CO ₂ equivalent			
A. Article 3.3 activities	88.29	110.45	126.08	131.79
A.1. Afforestation and Reforestation incl. N ₂ O; 4(KP)	-3.06	-15.01	-19.52	-23.23
Afforestation <= 20 yr	-3.07	-15.04	-19.55	-23.26
Afforestation > 20 yr	NO	NO	NO	NO
loss _{drainage} and LUC (N ₂ O)	0.005	0.02	0.03	0.03
A.2. Deforestation incl. N ₂ O; 4(KP)	91.35	125.46	145.60	155.03
Deforestation excl. N ₂ O	91.24	124.73	144.18	152.89
loss _{LUC} (N ₂ O)	0.12	0.74	1.42	2.13
B. Article 3.4 activities	-2'464.60	-4'614.09	4'224.64	-3'439.90
B.1. Forest management; 4(KP)	-2'464.60	-4'614.09	4'224.64	-3'439.90
gainC _{l_ag}	-9'759.92	-9'698.27	-9'729.14	-9'763.56
gainC _{l_bg}	-2'749.43	-2'751.16	-2'763.48	-2'776.54
lossC _{l_ag}	8'870.63	6'792.36	13'983.84	8'467.03
lossC _{l_bg}	2'682.95	2'006.43	3'902.35	2'461.81
changeC _h	21.38	-244.85	-87.82	-698.44
changeC _d	-251.80	-225.22	-370.99	-387.18
changeC _{s_m}	-3.71	-4.24	-7.72	-9.68
changeC _{s_o}	1.08	1.09	1.09	1.10
changeC _{HWP}	-1'304.70	-503.45	-709.14	-738.99
Forest management excl. CH ₄ and N ₂ O; 4(KP-I)B.1	-2'493.54	-4'627.32	4'218.99	-3'444.46
loss _{biomburn} (CH ₄ and N ₂ O)	28.80	13.08	5.51	4.41
loss _{drainage} (N ₂ O)	0.15	0.15	0.15	0.15
B.2. Cropland management	NA	NA	NA	NA
B.3. Grazing land management	NA	NA	NA	NA
B.4. Revegetation	NA	NA	NA	NA

Greenhouse gas source and sink activities	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	kt CO ₂ equivalent									
A. Article 3.3 activities	115.15	128.76	139.40	142.04	143.51	143.40	134.09	121.56	127.98	146.23
A.1. Afforestation and Reforestation incl. N ₂ O; 4(KP)	-25.20	-25.87	-24.14	-21.92	-21.09	-20.07	-17.89	-19.42	-19.18	-18.85
Afforestation <= 20 yr	-25.23	-25.90	-23.47	-21.17	-18.89	-17.27	-16.16	-15.57	-15.00	-14.65
Afforestation > 20 yr	NO	NO	-0.70	-0.77	-2.21	-2.82	-1.74	-3.87	-4.19	-4.21
loss _{drainage} and LUC (N ₂ O)	0.03	0.03	0.03	0.03	0.02	0.02	0.01	0.01	0.02	0.01
A.2. Deforestation incl. N ₂ O; 4(KP)	140.35	154.63	163.55	163.96	164.59	163.47	151.98	140.98	147.16	165.09
Deforestation excl. N ₂ O	137.80	151.94	160.82	161.19	161.78	160.63	149.12	138.13	144.31	162.21
loss _{LUC} (N ₂ O)	2.55	2.69	2.73	2.77	2.81	2.84	2.86	2.85	2.85	2.88
B. Article 3.4 activities	-2'257.42	-3'230.73	-3'155.17	-1'849.62	-3'109.88	-2'877.37	-1'611.08	-3'096.04	-2'975.10	-2'902.22
B.1. Forest management; 4(KP)	-2'257.42	-3'230.73	-3'155.17	-1'849.62	-3'109.88	-2'877.37	-1'611.08	-3'096.04	-2'975.10	-2'902.22
gainC _{l_ag}	-10'173.91	-10'186.88	-10'194.14	-10'201.87	-10'209.60	-10'218.80	-10'230.78	-10'235.93	-10'252.80	-10'300.92
gainC _{l_bg}	-2'910.20	-2'914.77	-2'917.66	-2'920.55	-2'923.44	-2'926.81	-2'930.93	-2'933.01	-2'938.58	-2'955.35
lossC _{l_ag}	9'243.69	8'623.66	9'101.62	9'024.79	8'295.51	8'548.85	8'766.20	8'156.48	8'020.70	8'419.08
lossC _{l_bg}	2'720.88	2'559.66	2'718.31	2'696.57	2'488.93	2'572.66	2'640.11	2'459.27	2'426.97	2'537.88
changeC _h	-288.70	-428.14	-900.05	317.46	-110.37	-373.15	598.88	-29.67	100.26	-164.52
changeC _d	-463.39	-470.77	-543.13	-304.05	-351.05	-384.29	-148.54	-279.04	-205.05	-267.41
changeC _{s_m}	-8.43	-8.93	-9.53	-10.69	-10.44	-10.67	-11.18	-10.61	-10.67	-10.73
changeC _{s_o}	1.11	1.11	1.12	1.12	1.12	1.13	1.14	1.14	1.14	1.15
changeC _{HWP}	-382.39	-409.67	-415.00	-458.64	-293.72	-89.47	-299.51	-228.17	-124.99	-166.07
Forest management excl. CH ₄ and N ₂ O; 4(KP-I)B.1	-2'261.35	-3'234.71	-3'158.45	-1'855.86	-3'113.05	-2'880.54	-1'614.61	-3'099.54	-2'983.02	-2'906.90
loss _{biomburn} (CH ₄ and N ₂ O)	3.77	3.82	3.12	6.09	3.02	3.01	3.38	3.34	7.76	4.53
loss _{drainage} (N ₂ O)	0.15	0.15	0.15	0.15	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

CRF accounting ("Information table on accounting for activities under Articles 3.3 and 3.4 of the Kyoto Protocol") gives an overview of the CO₂ eq emissions and removals from Afforestation and Deforestation under Article 3, paragraph 3 and Forest management under Article 3, paragraph 4.

In 2017, Forest management in Switzerland caused removals of -2902.22 kt CO₂ eq. The debit incurred from activities under Article 3.3 is 146.23 kt CO₂ eq.

11.1 General information

The inventory datasets on which the calculations are based are described in chp. 6.2, 6.3 (Swiss Land Use Statistics AREA) and 6.4.2.1 (National Forest Inventory NFI).

Methodological issues and assumptions concerning the calculation of activity data and emission 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 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 in this submission). 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 NIR1.

Some source 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 section E). Those are:

- 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 CO₂ 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). These definitions 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 m²) is fulfilled, and the conversion is a direct human-induced activity (FOEN 2006h).

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 2017; see also chp. 6.3.1) 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 m²) to areas not fulfilling the definition of forest as a consequence of direct human influence (FOEN 2006h).

Temporary removals of (cluster of) trees (e.g. for the construction of high-voltage power lines, cable-car and powerlines, 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. In the NFI methodology (Brändli 2010: 91) "forest aisles" under power lines are explicitly classified as forests. These forest aisles underlie however a specific management, i.e. maximum tree height is limited to a certain height. The NFI dataset thus covers such areas with a specific forest management practice.

After approximately 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). CRF 4(KP-I)A.2 shows that 80% of all these Kyoto Deforestations were still deforested after 28 years, whereas 20% were temporary removals of tree cover, which should be classified as "management interventions" rather than as real land-use changes. 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 emission factors 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.

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. 4'129.052 kha (see chp. 6.3.5; Table 6-8).

All activity data for reporting the activities under the Kyoto Protocol are retrieved from the Swiss Land Use Statistics (SFSO 2017; see also chp. 6.3.1). The Swiss Land Use Statistics AREA (SFSO 2006a) uses a georeferenced sample grid with a grid size of 100 m by 100 m. To each grid point a specific combination category (see Table 6-2) is assigned.

11.2.2 Methodology used to develop the land transition matrix

The methodology used to develop the land transition matrix 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: "Total for Activity

A.1" in CRF 4(KP-I)A.1 equals the cumulated afforested 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. 6.4.2.8). 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 4'129'052 ha (Table 6-8).

Table 11-2 Activity data for activities under Article 3, paragraphs 3 and 4, selected years. Data for Afforestation and Deforestation and values representing the area under Forest management were derived from the Swiss Land Use Statistics (AREA) (SFSO 2006a, 2018). See also CRF NIR-2.

	Unit	1990	1995	2000	2005
Afforestation area	kha	0.26	0.12	0.06	0.05
Cumulated area of Afforestation since 1990	kha	0.26	1.28	1.66	1.94
Deforestation area	kha	0.31	0.35	0.38	0.37
Cumulated area of Deforestation since 1990	kha	0.31	1.92	3.74	5.63
Forest management area	kha	1'210.66	1'221.65	1'229.17	1'236.06

	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Afforestation area	kha	0.06	0.05	0.05	0.05	0.05	0.07	0.07	0.06	0.05	0.05
Cumulated area of Afforestation since 1990	kha	2.10	2.16	2.20	2.25	2.30	2.37	2.44	2.50	2.55	2.60
Deforestation area	kha	0.32	0.35	0.38	0.38	0.37	0.37	0.33	0.30	0.31	0.37
Cumulated area of Deforestation since 1990	kha	6.68	7.03	7.41	7.78	8.16	8.52	8.86	9.16	9.47	9.83
Forest management area	kha	1'241.66	1'243.93	1'245.43	1'246.87	1'248.31	1'250.06	1'252.24	1'254.36	1'256.28	1'263.83

Afforestation

Activity data for Afforestations are derived from the Swiss Land Use Statistics (AREA; SFSO 2006a, 2018; see also chp. 6.3.1). A detailed description of the identification of Afforestations fulfilling the Kyoto definition is provided in FOEN (2010h).

Deforestation

Data for Deforestations are derived from the Swiss Land Use Statistics (AREA; SFSO 2006a, 2018; see also chp. 6.3.1). A detailed description of the identification of Deforestations under the Kyoto Protocol from the AREA dataset is given in FOEN (2010d) and Sigmaphan (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 AREA survey (see chp. 6.3.1) was conducted. Also, in the NFI methodology (Brändli 2010: 91) "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 limitation" was considered when classifying Deforestations, at the end still 20% 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; Sigmaphan 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 m².
- 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 direct human-induced: Conversion due to natural hazards and dynamics.

The four criteria were applied to the the land-use change data of the AREA survey (see chp. 6.2.2) for calculating annual values of the respective area (e.g. the cumulative area 0.980 kha in 2016, 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 dataset 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 emission 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, 2018; 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).

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). The main reason is natural forest regeneration in the Alpine area due to the abandonment of land. Evidence for this process is provided, for example, by Rigling and Schaffer (2015), Brändli (2014), SWI (2009), and Gehrig-Fasel et al. (2007).

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

Emission 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 soil carbon of Afforestations (CC11), productive forests (CC12) and unproductive forests (CC13) are displayed in Table 6-4, Table 6-18, and Table 6-21. All working steps and data required to reproduce the calculation of emission factors in the reporting tables are summarized in FOEN (2019c).

Separation of above- and below-ground living biomass

Carbon stock of total living biomass can be separated into above- and below-ground components using the ratios listed in Table 11-3. 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 methodology 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), changes in carbon stock of mineral soils and of organic soils are accounted for by reducing the carbon stock by 20% (see chp. 6.8.2.3). A conversion time (CT) of 20 years was applied for all pools except for the loss of living biomass, litter and 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 specific combination category (see Table 6-2).

	Living Biomass	Litter	Dead Wood	Mineral Soil	Organic Soil
Afforestation CC11 ≤ 20 yr	gain-loss $\text{gain}C_{l,i,CC11} - \text{loss}C_{l,i,CC11}$	stock-difference, CT=20 $(\text{stock}C_{h,i,CC11} - \text{stock}C_{h,i,b})/CT = 0$	stock-difference, CT=20 $(\text{stock}C_{d,i,CC11} - \text{stock}C_{d,i,b})/CT = 0$	stock-difference, CT=20 $(\text{stock}C_{s_m,i,CC11} - \text{stock}C_{s_m,i,b})/CT$	gain-loss $\text{change}C_{s_o,i,CC11}$
Afforestation CC11 > 20 yr	gain-loss $\text{gain}C_{l,i,CC12} - \text{loss}C_{l,i,CC12}$	gain-loss $\text{change}C_{h,i,CC12}$	gain-loss $\text{change}C_{d,i,CC12}$	gain-loss $\text{change}C_{s_m,i,CC12}$	gain-loss $\text{change}C_{s_o,i,CC12}$
Deforestation	stock-difference, CT=1 $(\text{stock}C_{l,i,a} - \text{stock}C_{l,i,CC12})/CT$	stock-difference, CT=1 $(\text{stock}C_{h,i,a} - \text{stock}C_{h,i,CC12})/CT$	stock-difference, CT=1 $(\text{stock}C_{d,i,a} - \text{stock}C_{d,i,CC12})/CT$	stock-difference, CT=20 C1X to CC51: $0.2 * (\text{stock}C_{s_m,i,CC51} - \text{stock}C_{s_m,i,CC1X})/CT =$ $0.2 * (0 - \text{stock}C_{s_m,i,CC1X})/CT$ C1X to other: $(\text{stock}C_{s_m,i,a} - \text{stock}C_{s_m,i,CC1X})/CT$	stock-difference, CT=20 C1X to CC51: $0.2 * (\text{stock}C_{s_o,i,CC51} - \text{stock}C_{s_o,i,CC1X})/CT =$ $0.2 * (0 - \text{stock}C_{s_o,i,CC1X})/CT$ C1X to other: $\text{gain-loss; change}C_{s_o,i,CCXX}$
Forest management CC12 remaining	gain-loss $\text{gain}C_{l,i,CC12} - \text{loss}C_{l,i,CC12}$	gain-loss $\text{change}C_{h,i,CC12}$	gain-loss $\text{change}C_{d,i,CC12}$	gain-loss $\text{change}C_{s_m,i,CC12}$	gain-loss $\text{change}C_{s_o,i,CC12}$
Forest management CC13 remaining	gain-loss $\text{gain}C_{l,i,CC13} - \text{loss}C_{l,i,CC13} = 0$	gain-loss $\text{change}C_{h,i,CC13} = 0$	gain-loss $\text{change}C_{d,i,CC13} = 0$	gain-loss $\text{change}C_{s_m,i,CC13} = 0$	gain-loss $\text{change}C_{s_o,i,CC13}$
Forest management CC12 to CC13	stock-difference, CT=20 $(\text{stock}C_{l,i,CC13} - \text{stock}C_{l,i,CC12})/CT$	stock-difference, CT=20 $(\text{stock}C_{h,i,CC13} - \text{stock}C_{h,i,CC12})/CT = 0$	stock-difference, CT=20 $(\text{stock}C_{d,i,CC13} - \text{stock}C_{d,i,CC12})/CT = (0 - \text{stock}C_{d,i,CC12})/20$	stock-difference, CT=20 $(\text{stock}C_{s_m,i,CC13} - \text{stock}C_{s_m,i,CC12})/CT = 0$	gain-loss $\text{change}C_{s_o,i,CC13}$
Forest management CC13 to CC12	gain-loss $\text{gain}C_{l,i,CC12} - \text{loss}C_{l,i,CC12}$	stock-difference, CT=20 $(\text{stock}C_{h,i,CC12} - \text{stock}C_{h,i,CC13})/CT = 0$	stock-difference, CT=20 $(\text{stock}C_{d,i,CC12} - \text{stock}C_{d,i,CC13})/CT = \text{stock}C_{d,i,CC12}/20$	stock-difference, CT=20 $(\text{stock}C_{s_m,i,CC12} - \text{stock}C_{s_m,i,CC13})/CT = 0$	gain-loss $\text{change}C_{s_o,i,CC12}$

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

- Gain and loss in living biomass of Afforestations (gross growth and cut and mortality) was 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 dead wood were assumed to be zero (IPCC 2006, 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.
- For organic soils, emissions due to drainage were calculated as described in chp. 6.4.2.10 and chp. 11.3.1.2.

Afforestation >20 years: units of land harvested since the beginning of the commitment period

After 20 years, afforested areas are subject to common forest management practices and the first thinnings and treatments are conducted. These afforested 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 changes of productive forests (CC12; see methodological description under Forest management) since nearly all of the afforestations (99.9%; see Table 6-9) develop into productive forests.

Deforestation

The differences in carbon stock of 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 mineral and organic soil carbon stocks due to disturbance caused by Deforestation and conversion to CC51 (buildings and constructions) were accounted for by reducing the carbon stock by 20% of the original 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).

Forest management

Living biomass

- Gain in living biomass (gross growth) of productive forests was used for “CC12 remaining” (Table 6-18). Gain of unproductive forests was used for “CC13 remaining” and is assumed to be zero (see chp. 6.4.2.8; Table 6-4).
- Losses in living biomass reflects yearly cut and mortality in productive forests “CC12 remaining” (Table 6-18). Unproductive forests are not systematically harvested (see description in chp. 6.4.2.8; Table 6-4). Thus losses of unproductive forests “CC13 remaining” are assumed to be zero. Moreover, since yearly harvesting amounts from forest statistics (FOEN 2017d) 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 of living biomass is 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 sink in carbon stock of living biomass in this type of Forest management.

Litter, dead wood and soil

- For productive forests “CC12 remaining”, yearly values for changes in carbon stocks of litter, dead wood and soil were used (Table 6-21). The estimates were obtained from simulations with Yasso07 (see chp. 6.4.2.7). For unproductive forests “CC13 remaining”, yearly changes in litter and dead wood and soil carbon stock were assumed to be zero (chp. 6.4.2.8).
- For the conversions between different forest combination categories (“CC13 to CC12” and “CC12 to CC13”) the difference in carbon stock of dead wood, litter and soil carbon was taken into account. For dead wood, the conversion “CC12 to CC13” leads to a net loss in carbon stock, in the case of a conversion “CC13 to CC12”, a net gain is reported (Table 6-4). Calculated carbon stock changes in litter and mineral soil were zero.
- For organic soils, emissions due to drainage were calculated as described in chp. 6.4.2.10.

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 combination categories “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 the land-use category 4A2 for a conversion time of 20 years. For further details and a quantitative comparison (area budget) see 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) assuming a specific carbon pool to be in balance, the carbon pool is indicated as not reported (NR). This is the case for litter and dead wood under Afforestation. Also for all 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. 6.4.2.9), 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 of 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 after afforestation: Under the Kyoto Protocol, changes in the litter pool after Afforestations were not reported. 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 after afforestation: no changes in the dead wood pool after afforestations were reported. 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, litter and soil were reported.

Changes in carbon pools not reported – Unproductive forests

A description of unproductive forests and the reasoning why the living biomass, litter, dead wood and soil pools were reported to be in equilibrium and thus not a source is given in detail in chp. 6.4.2.8.

Based on the fact that unproductive forest land only covers 8-9% of the area under Forest management (CRF 4(KP.I)B) and based on the description of these stands in chp. 6.4.2.8, emissions or removals of any of the pools of unproductive forests cannot account for more than 25-30% of the activity Forest management. According to Fig 1.2 note 4 in IPCC (2006), Volume 4, 25% is the threshold that would require a higher Tier. Because of limited financial resources (IPCC 2006 Volume 1, chp. 4.1.2, Fig. 4.1), Switzerland decided to use the Tier 1 approach and reported no changes in the carbon pools of living biomass, litter, dead wood and mineral soil of unproductive forest areas.

Greenhouse gas 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. CO₂ emissions due to drainage are calculated as described in chp. 6.4.2.10. N₂O emissions from drainage of organic soils were calculated as described in chp. 6.4.2.11.

Greenhouse gas sources reported as “included elsewhere (IE)”

- Emissions from biomass burning on Afforestations and unproductive forests were reported under Forest management, subdivision 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. 6.4.2.12).
- Biomass burning on areas under Forest management: CO₂ 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 CH₄ and N₂O were reported. The calculation of these emissions is described in chp. 6.4.2.12.

Greenhouse gas 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 “Ordinance on Chemical Risk Reduction” (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 thinings 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 HWPs 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 CO₂ 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 CO₂ 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; Gschwanter 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)

Recommendations and encouragements from the in-depth review in 2017 (UNFCCC 2018) were mostly addressed in submission 2018 (see chp. 10.1.1, Table 10-1 and Table 10-2 in FOEN (2018)). Methodological improvements for Forest land in the LULUCF and the KP-LULUCF sectors are listed in chp. 6.4.5, 6.11.5, and 10.1.2.4. 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 are shown in Table 6-10.

A detailed description of the determination of the emission 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 emission 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: 88.6% for Afforestations (associated UNFCCC category: 4A2), 50.2% for Deforestations (associated UNFCCC category: mainly 4E2) and 88.6% 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 (Table 6-10) and emission factors (Table 6-) 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	88.6	88.6
Deforestation	mainly 4E2 Land converted to settlements	4.6	50.0	50.2
Forest management	4A1 Forest land remaining forest land	1.1	88.6	88.6

11.3.1.6 Information on other methodological issues

N₂O 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 continuous 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.

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.

11.3.2.2 Comparison of the forest areas reported in the reporting tables

A direct comparison of the areas reported in the reporting tables under the Convention Forest land remaining forest land (CRF Table4.A) and under Forest management under the Kyoto Protocol (CRF 4(KP-I)B.1) is not possible due to the different structure of these 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 LUC: 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 (2018) the reported activity data for the inventory year 2016 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 Convention and the Kyoto Protocol is identical. For the next submission, the area comparison will be updated.

Table 11-6 Area budget (in kha) of KP-LULUCF and LULUCF under the UNFCCC in the year 2016 for forest land (Meteotest 2018).

activity	Table, Cells	area UNFCCC 2016 kha	area KP 2016 kha	Check Difference kha	remarks
All Forest Land					
Forest Management	4(KP-I)B.1, D11		1'253.423		a)
Afforestations <= 20 years	4(KP-I)A.1, C29		1.170		b)
Afforestations > 20 years	4(KP-I)A.1, C13		1.397		c)
Total area KP			1'255.989		
Non-Kyoto loss of forest cover			-0.980		d)
Forest Land UNFCCC	4.A, C10	1'255.010			e)
Total		1'255.010	1'255.010	0.000	
Afforestation, CC11					
UNFCCC	4.A, C32+C36+C40 +C44+C48	1.170			f)
KP (<= 20 years)	4(KP-I)A.1, C29		1.170	0.000	g)

Remarks:

a) KP Forest management consists of CC12 and CC13 areas fulfilling the criteria of the KP.

b) KP Afforestations are afforested areas since 1990 cumulated over 20 years at most.

c) KP Afforestations "older than 20 years" (>20 years) comprise the area that has been afforested since more than 20 years. In the UNFCCC reporting tables these areas belong to 4A1 (CC12 or CC13).

d) The non-Kyoto loss of forest cover is the part of the total area of forest loss (reported under the UNFCCC) not fulfilling the definition of Deforestations according to the Kyoto Protocol (see chp. 11.2.3). For the comparison this area must be subtracted from the KP forest area. It is an annual value (not cumulated) calculated on the basis of the AREA survey data (chp. 6.2.2).

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. 6.2.2).

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 congruent.

11.3.2.3 Impact of forest management on changes in carbon stocks in soil and in litter

Accounting for forest management impacts on carbon storage in litter and soil in Swiss productive forests with Yasso07

To estimate carbon stocks and carbon stock changes in the reported litter and soil pools, Switzerland uses the carbon cycling model Yasso07 (Didion et al. 2012, Didion and Thürig 2018; chp. 6.4.2.7). 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 detailed screening of the available scientific literature on the impact of forest management on carbon stock changes in litter and soils is provided in Didion (2014). The majority of studies indicated no significant effect of forest management on soil carbon stocks with the exception of clearcutting (e.g. Jandl et al. 2007). Since silvicultural practices in Switzerland are regulated by law and exclude intensive management options such as clearcuts, fertilisation or liming (Swiss Confederation 1991, 1992), no or only minor forest management impacts on soil carbon stocks can be expected. 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 losses of litter carbon can be rapidly replaced (Nave et al. 2010).

11.4 Article 3.3.

Net CO₂ eq removals from Afforestation and CO₂ 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 clear-cutting, 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. CO₂ emissions on organic soils under Afforestation are due to former drainage (see chp. 11.3.1.2). Figure 11-2 shows net CO₂ eq removals and emissions from Afforestation and CO₂ eq emissions from Deforestation for the years 1999–2017. Associated data for selected years are listed in Table 11-1.

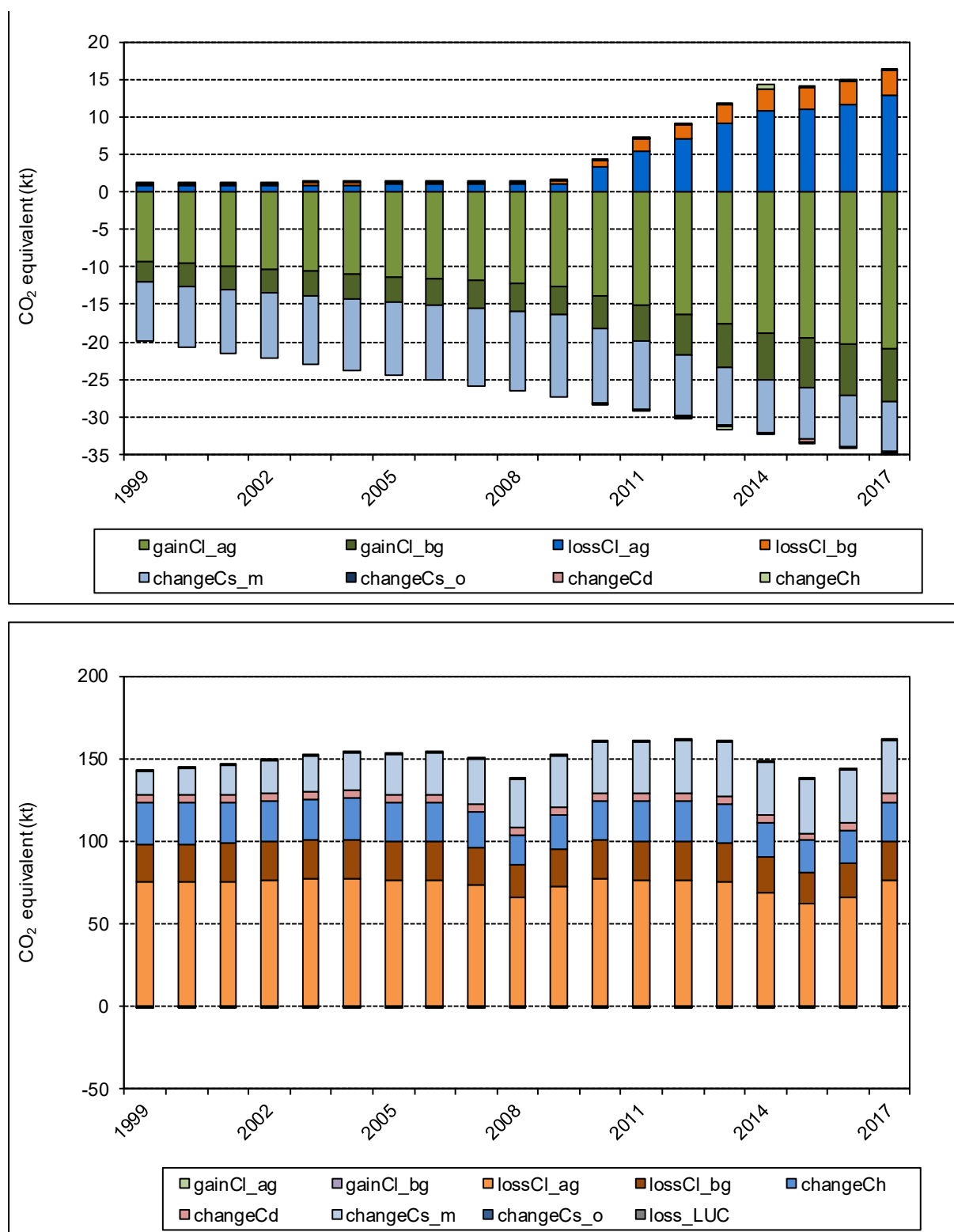


Figure 11-2 Net CO₂ eq removals (negative sign) and CO₂ eq emissions (positive sign) from Afforestation under Article 3, paragraph 3 (upper panel) and emissions from Deforestation under Article 3, paragraph 3 (lower panel) shown per carbon pool. For abbreviations see Table 11-1 and chp. 6.1.3.2. Note the different scale of the y-axis in both graphs.

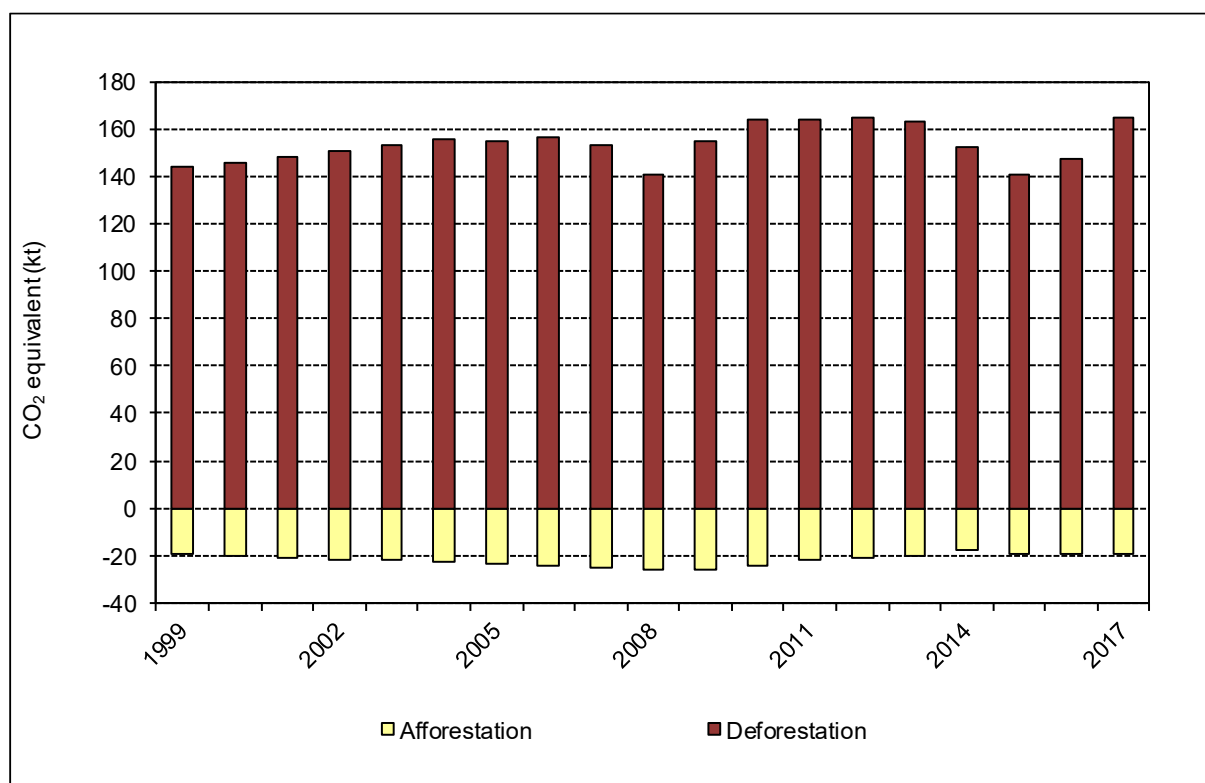


Figure 11-3 Net CO₂ eq removals (negative sign) of Afforestations under Article 3, paragraph 3 and CO₂ eq emissions (positive sign) of Deforestations under Article 3, paragraph 3.

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 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 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 HWPs originating from Deforestation and from Forest management. Based on the available datasets 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 Table 4.Gs1) and under the Kyoto Protocol (CRF 4(KP-I)C) as shown in Table 6-34.

11.5 Article 3.4

CO₂ eq emissions and removals differentiated for the reported carbon pools and net CO₂ eq emissions and removals of KP Article 3, paragraph 4 activity Forest management for the years 1999–2017 are shown in Figure 11-4. Associated data for selected years are listed in Table 11-1. The annual fluctuations of the CO₂ eq emissions and removals from Forest management are described in the text accompanying Figure 11-1.

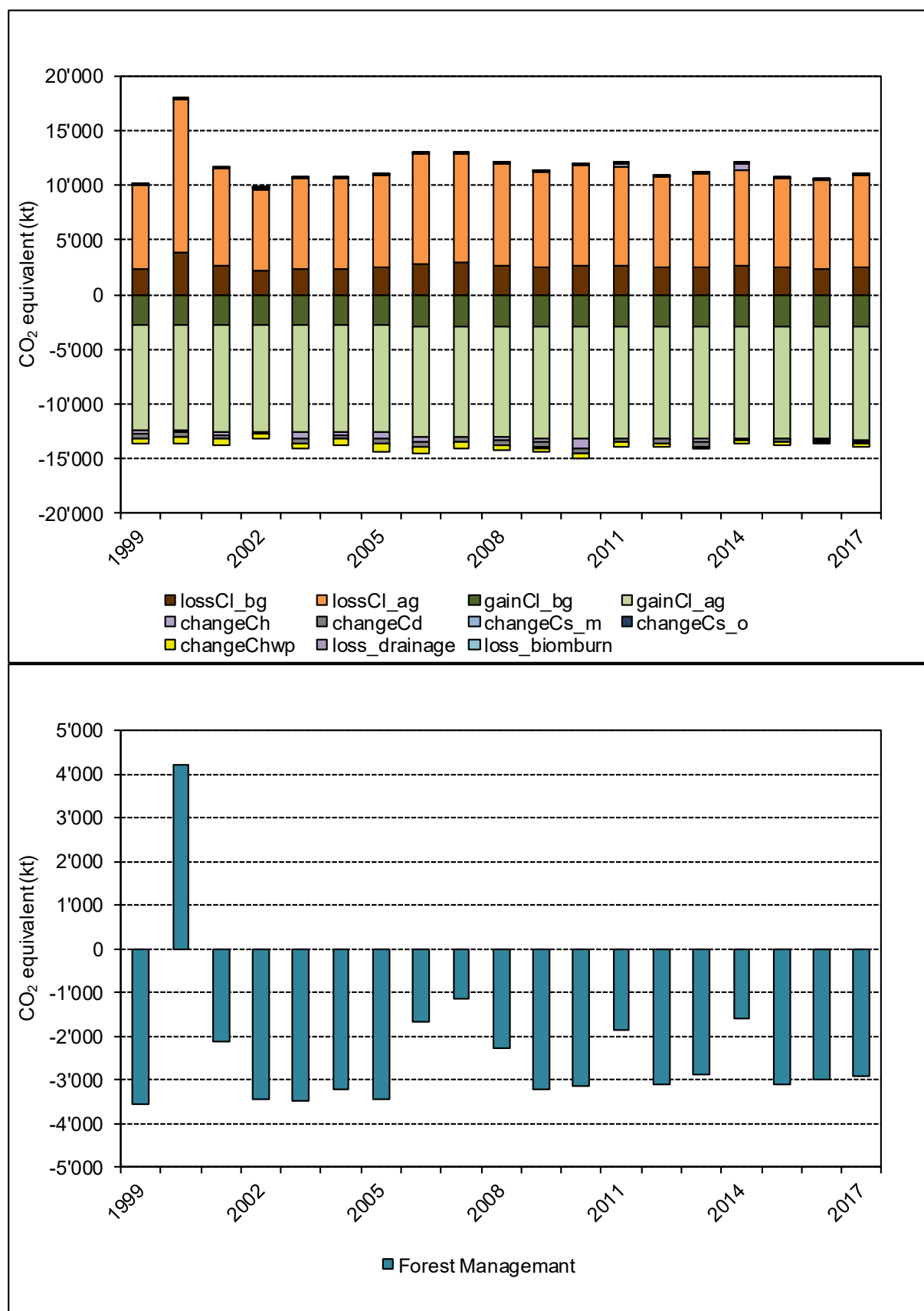


Figure 11-4 CO₂ eq emissions (positive sign) and CO₂ eq removals (negative sign) broken down for the reported carbon pools under Forest management (upper panel) and net CO₂ eq emissions and removals from Forest management (lower panel). For abbreviations see Table 11-1 and chp. 6.1.3.2. Note the different 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 the higher-elevation regions. Its 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.

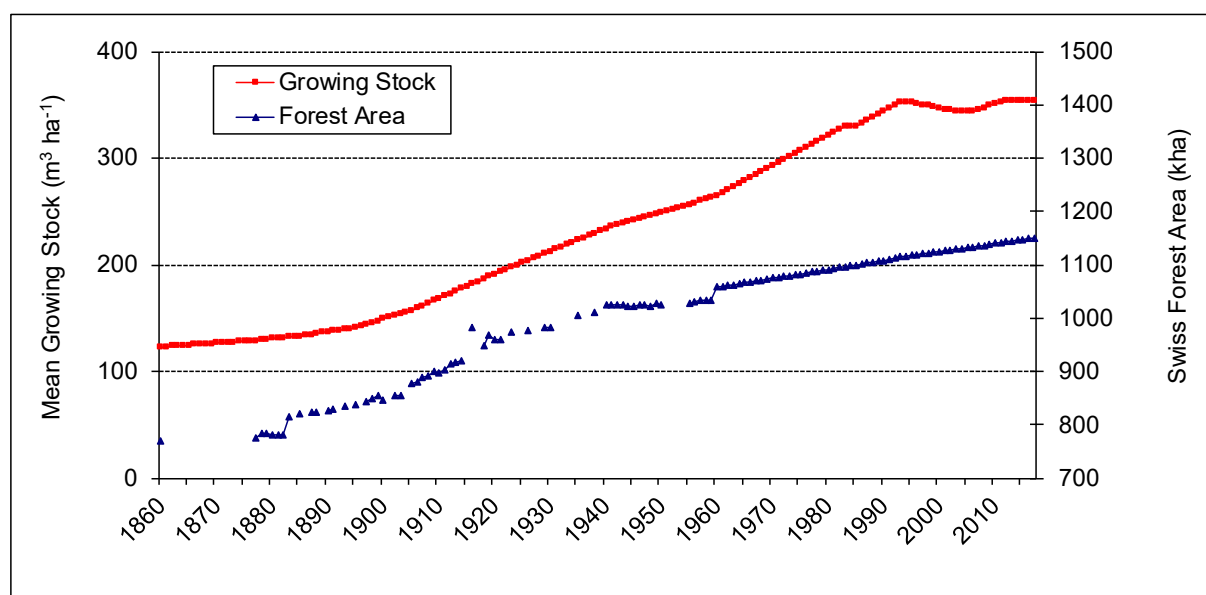


Figure 11-5 Historical mean growing stock (m³ ha⁻¹) and forest area (kha) in Switzerland.

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

CO₂ 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 is 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 and 2017 (FOEN 2017j). 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. With its three priority areas of 'optimised cascade use', 'climate-appropriate building and refurbishment' and 'communication, knowledge transfer and cooperation', the Wood Action Plan supports the implementation of the Wood Resource Policy (FOEN 2017j). Upon evaluation of the first (2009–2012) and second phase (2013–2016), the Wood Resource Policy has been updated and the Wood Action Plan extended until 2020. In 2017, a new programme phase of the Wood Action Plan started (2017–2020). Its focus and relationship to other policy instruments are described above.

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 CO₂ eq. yr⁻¹. The FMRL was subject to a technical assessment. Based on the technical assessment report (UNFCCC 2011a) and applying guidance of IPCC (2014), a technical correction of Switzerland's FMRL was implemented in FOEN (2015) as described in detail in FOEN (2016: chp. 11.5.2.3).

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 m³ 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; Switzerland's PSWS was calculated in Hofer & Altwegg (2008) and refined in Hofer et al.

(2011)) and (2) Wood Market Model (Pauli and Thees, 2009). A simple extrapolation of historical data (1990-2007) supported the increase of harvesting rates to this level.

The implementation of the BAU defined in FOEN (2011I) has been elaborated in the first technical correction in FOEN (2015) and in the second technical correction in Thürig et al. (2019), describing an exponential pathway to reach the harvesting level of 8.2 Mio m³ in 2020.

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. As a consequence, for the Swiss BAU-scenario it remains unclear, how the total amount of 8.2 million m³ merchantable wood should be distinctly assigned to sawn-wood, industrial wood and energy wood. In the Swiss NFI this "merchantable wood" corresponds closely to "merchantable timber including stem and branches ≥ 7 cm". The assignment into the different assortments was based on the mean distribution observed in the harvesting statistics 2005-2009 (Table 6-17; calculated as described in FOEN 2019g).

BAU harvesting volume: regional distribution

The BAU scenario aims at reaching 8.2 million m³ 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 chp. 1.2 and 3.1 in FOEN 2015q). Thürig et al. (2019) showed that the BAU scenario of increasing the harvesting amount to 8.2 million m³ merchantable timber can only be realized by intensifying harvesting in other production regions in Switzerland.

In practice, it can be assumed that not all branches ≥ 7 cm from harvested broadleaved trees are removed from the forest but remain there as dead wood. However, the amount of such branches is highly variable. Simulations of three different scenarios of the removed proportion of branches ≥ 7 cm of harvested broadleaved trees showed that the simulated CO₂-balance of total living biomass reacts very sensitive to the amount of branches removed from the forest: 1) 0% of branches removed (-0.08 Mt CO₂), 2) 35% of branches removed (-0.73 Mt CO₂), 3) 100% of branches (-1.13 Mt CO₂). In scenario 2, the percentage of deciduous timber was approximated to reach 33% of total harvest volumes as reported in recent harvesting statistics (Table 6-17).

Mortality equals "background level for natural disturbances"

For all three scenarios, mortality was adjusted to amount to 16.34% of the total mean cut and mortality ("losses in living biomass") from 1990-2009. This corresponds to the Swiss "background level for natural disturbances" (FOEN 2016c). Total harvesting amount was assumed to increase exponentially from 6.7 million m³ merchantable timber in the year 2007 to the level of 8.2 million m³ merchantable timber in the year 2020. After 2020, harvesting amount was assumed to remain constant.

11.5.2.3 Information on the main factors generating the accounted quantity

The main reason for the difference between the FMRL and the annually reported carbon balance of Forest Management, resulting in an accountable net sink, is the difference in harvesting rates: harvesting rates in 2013-2017 are lower as envisaged in the BAU-scenario.

The determination of the BAU-harvesting scenario for the FMRL is based on knowledge, data and policies before 2009 (FOEN 2008h) Pauli and Thees (2009), Hofer & Altwegg (2008) recalculated in Hofer et al. (2011). The BAU was based on the objective to substantially increase harvesting rates for two reasons: 1) mobilizing more domestic wood to respond to the increasing wood demand and 2) decreasing the high carbon stocks in Swiss forests in order to ensure the long-term stability of forests with respect to the protection function, biodiversity, wood production, etc. Due to the worldwide economic regression and the unfavorable exchange rate of the Swiss Franc impeding export of Swiss wood, harvesting levels did not increase as expected and remained approximately constant, i.e. fluctuated around 6.3 Mio m³ merchantable timber including stem and branches ≥ 7 cm between 2013-2017 according to the NF13-4 (or ca. 11 Mt CO₂ eq., see Figure 11-4 and Table 11-1).

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 in FOEN (2015).

For this submission, corrections originating from recalculations in this submission are listed in chp. 6.4.5, chp. 6.11.5, chp. 10.1.2.4 and chp. 10.1.2.8 and former submissions (since FOEN 2015). Other recalculations are based on improvements in the applied models Massimo (Massimo models changes in living biomass; Stadelmann et al. 2019) and Yasso07 (Yasso07 models changes in mineral soils, litter and dead wood; Didion and Thürig 2018) as well as on the incorporation of new pools. All calculation steps are described in FOEN (2019g).

Activity data for FMRL

The area under Forest management for the period 2013–2020 is calculated by linear extrapolation of the trend from the historical activity data 1990–2009. The area under Forest management is stratified per land-use type (productive forest CC12, unproductive forest CC13 and for 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 latest technical correction of the FMRL. Several updates and modifications related to land area data led to recalculations for 1990-2009 (see chp. 6.3.5 in this and former submissions):

- The most recent land-use data from the fourth area survey (AREA4) were included (SFSO 2018). They are based on aerial photographs from 2012 and 2017. The interpolation and projection procedures were adapted accordingly (see chp. 6.3.2 and Sigmaplan 2019).

- Along with the AREA4 survey the SFSO continuously performs consistency checks and, where appropriate, corrections in the data of AREA3 (2004–2009).
- The total area of the country recorded by the AREA survey increased by 10 ha to 4'129'052 ha (SFSO 2018). This modification is due to the inclusion of the most recent land survey data elaborated at the Federal Office of Topography (changes caused a.o. by glacial melting), defining the country's frontiers.
- As described in FOEN (2016), the definition of the land-use category CC13 (unproductive forest) in terms of land-use (LU) and land-cover (LC) codes was updated: The combinations LC47/LU222 and LC47/LU223 were defined as CC13 instead of CC34 (Copse). Consequently, the area of CC13 increased by approximately 15 kha. This update was made in order to improve the compatibility of the forest areas measured in the AREA surveys with the definition of forest for the Kyoto Protocol given in Switzerland's Initial Reports (FOEN 2006h; FOEN 2016c). In 2007 the LU/LC definitions for CC13 were derived on the basis of the AREA survey that covered only 20% of the territory. Now, the full cover of AREA was available and the LU/LC definition for CC13 could be derived without bias, using forest data from the National Forest Inventory (NFI) as a supporting dataset (Didion and Thürig 2013).
- A more complete, consistent and reliable dataset defining the geographical distribution of organic soils in Switzerland was integrated (Wüst-Galley et al. 2015). The new mapping approach differs largely from the method used so far, but the resulting change in total area of organic soils is small (from 28.3 to 27.7 kha).

Table 11-7 Activity data for 2013-2020 for the FMRL derived from linear extrapolation of historical data 1990–2009 stratified per soiltype: comparison between the recalculated activity data (upper table) and the activity data as used for the previous technical correction of the FMRL in FOEN (2015). The area under Forest management is stratified into mineral and organic soils, in productive forest CC12, unproductive forest CC13 and in lands changing between CC12 and CC13 and vice versa (see chp. 11.2.3).

Values TC FMRL, this submission

Mean 2013-2020 (kha)	Productive forest CC12	CC12 to CC13	CC13 to CC12	Unproductive forest CC13
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 TC FMRL, submission FOEN (2015)

Mean 2013-2020 (kha)	Productive forest CC12	CC12 to CC13	CC13 to CC12	Unproductive forest CC13
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

Modelling carbon stock changes in living biomass with MASSIMO

To model 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. (2019). Besides general improvements, also FMRL-specific modifications have been made since January 2014 (last technical correction described in FOEN 2015 and FOEN 2016d):

- General improvements: improved usability, better implementation of harvest interventions and more realistic tree regeneration.
- Validation of the model: The model was initialized with NFI 3 data. For the validation, it was driven by observed harvesting rates in NFI 4 (2009-2013; Abegg et al. 2014). As NFI 4 (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.

To ensure methodological consistency between the reference level and reporting for Forest management, 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, include:

- 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 new implementation of Massimo does not yet distinguish forest reserves. However, according to GeoPartner (2008, page 18) this affects only 15'509 ha or approximately 1.2% of the forest area.

Modelling carbon stock changes in dead wood, litter and mineral soil with Yasso07

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 and Thürig 2018).

The model was used for the calculation of the previous technical correction of Switzerland's FMRL (FOEN 2015). The most important revisions to the model application since 2015 relevant for the FMRL (see Thürig et al. 2019 for more details) estimate 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; and
- historic data on forest cover development on NFI sample plots since 1880.

In addition to these modifications, the following result in significant differences between the FMRL submitted in 2015 and the current estimates:

- new dead wood and litter production estimates from Massimo for the period 2007 – 2026;
- observed climate data for the years 2014 to 2017 replacing projected data;
- annual instead of averaged estimates consistent with the switch from the IPCC 2003 Good Practice Guidance for Land Use, Land-Use Change and Forestry to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

It is planned to further improve the application of Yasso07 for Switzerland as described in chp. 6.4.6.

Harvested wood products

- The most recent time series of the activity data (FAOSTAT database) is used. These data have been updated: the share of domestic to total HWP has been revised (chp.6.11.5).

- HWP from paper and paperboard is included in the FMRL according to chp. 6.11.5 and in response to UNFCCC (2018, ID#KL.7).

Other emissions and removals recalculated for the FMRL

Emissions from drainage from organic soils: based on the results of Abegg (2017), the share of drained organic soils under Forest land was reduced from 100% to 3%. This correction was made in response to UNFCCC (2018, ID#L.6 and ID#KL.3; see chp.6.4.2.10).

Pools or emissions and removals removed from the FMRL

CH₄ and N₂O 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 UNFCCC2018, D#KL.5; FOEN 2016d). By moving these emissions to the background level, CH₄ and N₂O emissions from wildfires had to be excluded from the contributing pools of the FMRL accordingly (see Table 11-14 in FOEN 2016).

Pools or emissions and removals not included in the FMRL so far

Emissions from controlled burning cover the emissions from burning of residues in forestry (addressing UNFCCC 2018, ID#KL.4). Since NIR submission 2017, these emissions are reported in the category Forest land within the LULUCF sector (see chp. 6.4.2.13 in FOEN 2017 and in this submission). The emissions from controlled burning were added as a pool to the FMRL (UNFCCC 2018, ID#KL.5; see FOEN 2017, chp. 6.4.5).

Calculation of the technical correction of the FMRL

Mean emission factors over the period 2013–2020 for living biomass, dead wood, litter and soil carbon for the BAU-scenario are summarized in Thürig et al. (2019). The emission factor for HWP for 2013–2020 is taken from FOEN (2019g).

These emission factors were then applied for the areas under Forest management stratified per land-use type and soil type (Table 11-7) in order to calculate total emissions and removals from living biomass, dead wood, litter and soil carbon in Swiss Forests stratified per land-use and per soil type (Table 11-8). Further, emissions from drainage of organic soils and emissions from forest fires were considered to calculate the corrected FMRL.

Table 11-8: Mean carbon stock changes (changeC) over the period 2013–2020 for the total area under Forest management. For the Forest management reference level carbon stock changes in living biomass (changeC_l), litter (changeC_h), dead wood (changeC_d), soil (changeC_s; including emissions of organic soils due to former drainage) and HWP (changeC_{HWP}) are considered plus emissions from controlled burning of forest residues (loss_{biomburn}). Positive values indicate a source, negative values indicate a sink of carbon. Stratification of Forest management land-use types: productive forest CC12, unproductive forest CC13 and changes between CC12 and CC13.

Pool	Land-Use Type under FM	changeC for FMRL (Mt CO ₂ y ⁻¹)
changeC _l	CC12	-0.82
	CC13	0.00
	CC12/CC13	0.10
	CC13/CC12	-0.01
	Total Living Biomass	-0.73
changeC _h , changeC _d , changeC _s	CC12	-0.86
	CC13	0.00
	CC12/CC13	0.01
	CC13/CC12	-0.02
	Total Soil, Litter, Dead Wood	-0.88
changeC _{HWP}	CC12	-0.89
loss _{biomburn}	CC12	0.005
Total FMRL_{cor}		-2.49

The technical correction of the FMRL on C stock changes in living biomass, dead wood, litter and soil carbon in Swiss Forests is summarized in Table 11-9. The technical correction equals the difference between the FMRL submitted in February 2011 (FOEN 2011I) and the corrected values for the FMRL and amounts to -2.71 Mt CO₂ eq. yr⁻¹.

Table 11-9: Summary of the technical correction of the FMRL. Values from FMRL as defined in FOEN (2011I), corrected values as described in FOEN (2015) and updated in FOEN (2016d) after the in-country review and corrected values as described in this submission (FOEN 2019) are listed per pool or source. Abbreviations as used in chp. 6.1.3.2 and Table 11-1.

Pool (Mt CO ₂ eq yr ⁻¹)	FMRL FOEN 2011	FMRLcor FOEN 2016d	FMRLcor FOEN 2019
changeC _l	0.48	-0.33	-0.73
changeC _h , changeC _d , changeC _s	-0.05	-0.59	-0.88
changeC _{HWP}	-0.21	-0.78	-0.89
non-CO ₂ -GHG from controlled burning	IE (in 5C2)	0.01	0.005
Total FMRL	0.22	-1.69	-2.49

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.

In the inventory years 2013, 2014, 2015, 2016 and 2017, no natural disturbances causing emissions exceeding the upper confidence interval (background level plus margin) occurred. Thus, no emissions from natural disturbances were excluded for 2013, 2014, 2015, 2016 and 2017.

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 so far.

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 6-34 and Figure 6-13. 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 emission 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 to Article 3, paragraph 4.

11.5.5 Information that indicates to what extent removals from Forest management offset the debit incurred under Article 3, Paragraph 3

This information will only be available at the end of the commitment period.

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 year 2017 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 is "5D Wastewater treatment and discharge, CH₄" with a contribution of 186.87 kt CO₂ 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 (-2'740.83 kt CO₂; CRF 4(KP)) encompasses net CO₂ 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. 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 2017.
- Afforestation and Reforestation (-18.86 kt CO₂; CRF 4(KP)) encompasses net CO₂ 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 both level and trend key category under Approaches 1 and 2 assessments in 2017 (Table 1-9).
- Deforestation (165.21 kt CO₂; CRF 4(KP)) encompasses net CO₂ emissions and is not a key category under the Kyoto Protocol because its contribution is lower 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 2 assessment in 2017 (Table 1-9).
- Harvested wood products (-166.07 kt CO₂; CRF 4(KP-I)C) is not a level key category because its contribution is smaller 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 level key category under Approach 2 assessment and trend key category category under Approaches 1 and 2 assessments in 2017.

11.7 Information Relating to Article 6

Switzerland does not host Joint Implementation projects.

12 Information on accounting of Kyoto Units

Responsibilities for Accounting	
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. Switzerland cooperates with Monaco regarding registry issues.

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 2018, have been submitted to the UNFCCC Secretariat electronically.

Overview of CP1 units

By the end of 2018, 241'826'246 AAUs were held in the Swiss Emissions Trading Registry (Table 12-1). In addition, 4'210'465 Emission Reduction Units (ERUs), 9'280'880 RMUs, 23'935'068 Certified Emission Reductions (CERs), and 114'793 Temporary Certified Emission Reductions (tCERs) were held in the Swiss Emissions Trading Registry. As all CP1 units in Party and Entity holding accounts have been carried over in 2017, there will not be any more changes in CP1 holdings.

Table 12-1 Total quantities of CP1 Kyoto Protocol units by account type at the end of 2018 (SEF table 4)

Account type	Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	ICERs
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	7'896'871	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	
ICER replacement account for expiry	NO	NO	NO	NO		
ICER replacement account for reversal of storage	NO	NO	NO	NO		NO
ICER replacement account for non-submission of certification report	NO	NO	NO	NO		NO
Total	241'826'246	4'210'465	9'280'880	23'935'068	114'793	NO

Overview of CP2 units

By the end of the reporting year 2018, a total balance of 5'794'523 AAUs and 28'248'056 CERs were held in the Swiss Emissions Trading Registry, of which 3'679'898 CERs have been voluntary cancelled (Table 12-2).

Table 12-2 Total quantities of CP2 Kyoto Protocol units by account type at the end of 2018 (SEF table 4)

Account type	Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	ICERs
Party holding accounts	NO	NO	NO	1'941'872	NO	NO
Entity holding accounts	NO	NO	NO	22'626'286	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	NO	NO	3'679'898	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	
ICER cancellation account for expiry						NO
ICER cancellation account for reversal of storage						NO
ICER cancellation account for non-submission of certification report						NO
tCER replacement account for expiry	NO	NO	NO	NO	NO	
ICER replacement account for expiry	NO	NO	NO	NO		
ICER replacement account for reversal of storage	NO	NO	NO	NO		NO
ICER replacement account for non-submission of certification report	NO	NO	NO	NO		NO
Total	5'794'523	NO	NO	28'248'056	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 2018, the Swiss Emissions Trading Registry had no discrepancies, no CDM notifications, no non-replacements including reversal of storage and failure of certification and no invalid units. Therefore, the SIAR tables R-2, R-3, R-4 and R-5 are empty and no actions and changes have been taken to address discrepancies.

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 national allocation plan is accessible under 'Allocation' in the Public Information menu. The report 'Accounts' provides a list of open accounts in the national registry. The 'Surrendering Obligation', and 'Surrendered units' per operator are also publicly accessible. The report 'Issued Attestations' lists all the issued attestations originating from domestic emission-reduction projects.

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. In the present case these conditions are not fulfilled. Therefore, the registry of Switzerland cannot make the information on acquiring and transferring accounts publicly available and considers them as confidential. 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. Therefore, this information is not publicly available. A statement on which information is considered as confidential can be found on the public website <https://www.emissionsregistry.admin.ch>.

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.

Information related to Article 6 projects is publicly accessible on the website <http://www.bafu.admin.ch/ji-e>. Switzerland does not host Joint Implementation (JI)-projects and therefore no issuance of ERUs has taken place.

12.5 Calculation of the Commitment Period Reserve (CPR)

The commitment period reserve and the assigned amount for the second commitment period is defined in 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 2018), Switzerland's assigned amount for the second commitment period is 361'768.524 kt CO₂ equivalent. The commitment period reserve is 325'591.672 kt CO₂ 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 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): 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): Change of cooperation arrangement	No change of cooperation arrangement occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(c): 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): 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): Change of discrepancies procedures	No change of discrepancies procedures occurred during the reported period
15/CMP.1 annex II.E paragraph 32.(f): Change of Security	Several new registry software versions were installed, major releases going live on the PROD environment in October and December 2018, which included updating SW-components, additional security features, hardening the registry infrastructure. No further details are provided for confidentiality reasons. However, it may be made available to the ERT upon approval of a specific request.
15/CMP.1 annex II.E paragraph 32.(g): 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): 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): 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):	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 Minimization of adverse effects	
Authors	Adrian Schilt (FOEN), Regine Röthlisberger (FOEN), Gabriela Blatter (FOEN), Daniel Maselli (SDC), Patrick Renz (SECO), Dina Spörri (FOEN), Antonia Sutter (SDC)
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 not assumed that Swiss climate change policies 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 have 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 those concerns about possible adverse impacts on other countries.

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 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 e.g. the Swiss emissions trading scheme,

the supplemental use of international carbon credits from the Clean Development Mechanism or the CO₂ levy on heating and process fuels are important measures to put a price on emissions of greenhouse gases (see Seventh National Communication (FOEN 2018d) for more details), that are then reflected in market prices and thus internalizing externalities.

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 reflected by changes in traffic volume (truck-kilometres), but also in reduced air pollution, a renewal of the heavy vehicle fleet and an increase of load per vehicle, i.e. fewer trucks transporting 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.

In 2008, Switzerland introduced the CO₂ levy on heating and process fuel 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 CO₂ emissions from use of heating and process fuels, may apply for exemption from the CO₂ levy, 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 CO₂ 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 CO₂ levy for CO₂ 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).

As analysed in detail in two studies, the overall economic impact of the Swiss climate policy is considered to be very small¹¹. 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, although 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 report¹². 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

¹¹ Ecoplan (2009): Volkswirtschaftliche Auswirkungen der Schweizer Post-Kyoto-Politik, im Auftrag des BAFU. BAFU (2010): Synthesebericht zur Volkswirtschaftlichen Beurteilung der Schweizer Klimapolitik nach 2012.

¹² Swiss Federal Council (2008): Subventionsbericht des Bundesrates vom 30.05.2008 (Appendix: <https://www.admin.ch/opc/de/federal-gazette/2008/6327.pdf>).

agriculture should be provided entirely in the form of direct payments)¹³. 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 brigade, oil and chemical emergency unit, civil protection and ambulances.

Worldwide subsidies for fossil fuels are estimated at 300 billion to 500 billion USD per annum, depending on the level of energy prices. This huge market distortion does not only produce severe fiscal problems 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 World Bank development project ESMAP (Energy Sector Management Assistance Program). The 2016 Annual Report of ESMAP is also supported by Switzerland 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 subsidize the use of environmentally unsound and unsafe technologies.

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 Environmental Goods Agreement (EGA) at the World Trade Organisation with the aim to liberalise environmental goods, including the diffusion and transfer of less-greenhouse-gas-emitting advanced fossil fuel technologies.

Furthermore, Switzerland is supporting the improvement and refit of inefficient gas-fired power plants in developing countries and advocates the use of the most efficient technologies available. 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

¹³

https://www.efk.admin.ch/images/stories/efk_dokumente/publikationen/_wirtschaft_und_verwaltung/wirtschaft_und_landwirtschaft/17500/17500BE_WiK_e.pdf

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 down-stream 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.

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. Further information is contained in chp. 7 of Switzerland's Seventh National Communication (FOEN 2018d).

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 are aimed 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: (i) enabling framework conditions for trade (ii) international competitiveness, and (iii) improving market access.

Regarding market access, trade between developing and industrial countries is often insufficiently developed respectively not diversified enough. On 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 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 firm conviction that an efficient 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 over all categories included in the KCA (level of disaggregation) and summary of Switzerland's combined KCA for the year 2017 including LULUCF categories, sorted by NFR code (first column). L1 = level, approach 1, T1 = trend, approach 1; L2 = level, approach 2, T2 = trend, approach 2.

SUMMARIES TO IDENTIFY KEY CATEGORIES			
Code	IPCC Category	GHG	Identification Criteria
1	Indirect CO ₂ emissions	CO ₂	
1A1	Energy industries: biomass	CH ₄	
1A1	Energy industries: biomass	N ₂ O	
1A1	Energy industries: Gaseous fuels	CH ₄	
1A1	Energy industries: Gaseous fuels	CO ₂	L1, T1
1A1	Energy industries: Gaseous fuels	N ₂ O	
1A1	Energy industries: Liquid fuels	CH ₄	
1A1	Energy industries: Liquid fuels	CO ₂	L1, T1
1A1	Energy industries: Liquid fuels	N ₂ O	
1A1	Energy industries: Other fuels	CO ₂	L1, L2, T1, T2
1A1	Energy industries: Other fuels	N ₂ O	
1A1	Energy industries: Solid fuels	CH ₄	
1A1	Energy industries: Solid fuels	CO ₂	
1A1	Energy industries: Solid fuels	N ₂ O	
1A2	Manufacturing industries and construction: Biomass	CH ₄	
1A2	Manufacturing industries and construction: Biomass	N ₂ O	
1A2	Manufacturing industries and construction: Gaseous fuels	CH ₄	
1A2	Manufacturing industries and construction: Gaseous fuels	CO ₂	L1, L2, T1, T2
1A2	Manufacturing industries and construction: Gaseous fuels	N ₂ O	
1A2	Manufacturing industries and construction: Liquid fuels	CH ₄	
1A2	Manufacturing industries and construction: Liquid fuels	CO ₂	L1, T1
1A2	Manufacturing industries and construction: Liquid fuels	N ₂ O	
1A2	Manufacturing industries and construction: Other fuels	CH ₄	
1A2	Manufacturing industries and construction: Other fuels	CO ₂	L1, T1
1A2	Manufacturing industries and construction: Other fuels	N ₂ O	
1A2	Manufacturing industries and construction: Solid fuels	CH ₄	
1A2	Manufacturing industries and construction: Solid fuels	CO ₂	L1, T1
1A2	Manufacturing industries and construction: Solid fuels	N ₂ O	
1A3a	Civil aviation: Liquid fuels	CH ₄	
1A3a	Civil aviation: Liquid fuels	CO ₂	T1
1A3a	Civil aviation: Liquid fuels	N ₂ O	
1A3b	Road transportation: Gasoline	CH ₄	T1
1A3b	Road transportation: Gasoline	CO ₂	L1, T1
1A3b	Road transportation: Gasoline	N ₂ O	T1, T2
1A3b	Road transportation: Biomass	CH ₄	
1A3b	Road transportation: Biomass	N ₂ O	
1A3b	Road transportation: Gaseous fuels	CH ₄	
1A3b	Road transportation: Gaseous fuels	CO ₂	
1A3b	Road transportation: Gaseous fuels	N ₂ O	
1A3b	Road transportation: Diesel	CH ₄	
1A3b	Road transportation: Diesel	CO ₂	L1, T1
1A3b	Road transportation: Diesel	N ₂ O	
1A3c	Railways: Biomass	CH ₄	
1A3c	Railways: Biomass	N ₂ O	
1A3c	Railways: Liquid fuels	CH ₄	
1A3c	Railways: Liquid fuels	CO ₂	
1A3c	Railways: Liquid fuels	N ₂ O	
1A3d	Domestic navigation: Biomass	N ₂ O	
1A3d	Domestic navigation: Biomass	CH ₄	
1A3d	Domestic navigation: Liquid fuels	CH ₄	
1A3d	Domestic navigation: Liquid fuels	CO ₂	
1A3d	Domestic navigation: Liquid fuels	N ₂ O	
1A3e	Other transportation: Gaseous fuels	CH ₄	
1A3e	Other transportation: Gaseous fuels	CO ₂	
1A3e	Other transportation: Gaseous fuels	N ₂ O	

Table A – 1 (continued)

SUMMARIES TO IDENTIFY KEY CATEGORIES			
Code	IPCC Category	GHG	Identification Criteria
1A4a	Commercial: Biomass	CH4	
1A4a	Commercial: Biomass	N2O	
1A4a	Commercial: Gaseous fuels	CH4	
1A4a	Commercial: Gaseous fuels	CO2	L1, T1
1A4a	Commercial: Gaseous fuels	N2O	
1A4a	Commercial: Liquid fuels	CH4	
1A4a	Commercial: Liquid fuels	CO2	L1, T1
1A4a	Commercial: Liquid fuels	N2O	
1A4b	Residential: Biomass	CH4	T1
1A4b	Residential: Biomass	N2O	
1A4b	Residential: Gaseous fuels	CH4	
1A4b	Residential: Gaseous fuels	CO2	L1, L2, T1, T2
1A4b	Residential: Gaseous fuels	N2O	
1A4b	Residential: Liquid fuels	CH4	
1A4b	Residential: Liquid fuels	CO2	L1, T1
1A4b	Residential: Liquid fuels	N2O	
1A4b	Residential: Solid fuels	CH4	
1A4b	Residential: Solid fuels	CO2	
1A4b	Residential: Solid fuels	N2O	
1A4c	Agriculture and forestry: Biomass	CH4	
1A4c	Agriculture and forestry: Biomass	N2O	
1A4c	Agriculture and forestry: Gaseous fuels	CH4	
1A4c	Agriculture and forestry: Gaseous fuels	CO2	
1A4c	Agriculture and forestry: Gaseous fuels	N2O	
1A4c	Agriculture and forestry: Liquid fuels	CH4	
1A4c	Agriculture and forestry: Liquid fuels	CO2	L1
1A4c	Agriculture and forestry: Liquid fuels	N2O	
1A5	Other (military): Biomass	CH4	
1A5	Other (military): Biomass	N2O	
1A5	Other (military): Liquid fuels	CH4	
1A5	Other (military): Liquid fuels	CO2	
1A5	Other (military): Liquid fuels	N2O	
1B2	Oil and natural gas energy production	CH4	L1, T1
1B2	Oil and natural gas energy production	CO2	
1B2	Oil and natural gas energy production	N2O	
2	Indirect CO2 emissions	CO2	L2, T1, T2
2A1	Cement production	CO2	L1, L2, T1
2A2	Lime production	CO2	
2A3	Glass production	CO2	
2A4	Other process uses of carbonates	CO2	
2B10	Chemical industry other	CO2	
2B10	Chemical industry other	CH4	
2B2	Nitric acid production	N2O	
2B5	Carbide production	CH4	
2B5	Carbide production	CO2	
2B8	Petrochemical and carbon black production	CO2	
2C1	Iron and steel production	CO2	
2C3	Aluminium production	CO2	T1
2C3	Aluminium production	PFC	T1
2C4	Magnesium production	SF6	
2C7	Other	CO2	
2D	Non-energy products from fuels and solvent use	CO2	
2E1	Semiconductor	PFC	
2E1	Semiconductor	SF6	
2E1	Semiconductor	HFC	

Table A – 1 (continued)

SUMMARIES TO IDENTIFY KEY CATEGORIES			
Code	IPCC Category	GHG	Identification Criteria
2E3	Photovoltaics	NF3	
2E4	Other electronic	PFC	
2F1	Refrigeration and air conditioning	HFC	L1, L2, T1, T2
2F1	Refrigeration and air conditioning	PFC	
2F2	Foam blowing agents	HFC	
2F4	Aerosols	HFC	
2F5	Solvents	HFC	
2G	Other product manufacture and use	CO2	
2G	Other product manufacture and use	HFC	
2G	Other product manufacture and use	PFC	
2G	Other product manufacture and use	N2O	T2
2G	Other product manufacture and use	SF6	L1
2H	Other	CO2	
3A	Enteric Fermentation	CH4	L1, L2, T1
3B1-3B4	Manure management	CH4	L1, L2
3B1-3B4	Manure management	N2O	
3B5	Indirect N2O emissions from manure management	N2O	L1, L2, T2
3Da	Direct emissions from managed soils	N2O	L1, L2, T2
3Db	Indirect emissions from managed soils	N2O	L1, L2, T1, T2
3G	Liming	CO2	
3H	Urea application	CO2	
4A1	Forest land remaining forest land	CO2	L1, L2, T1, T2
4A2	Land converted to forest land	CO2	L1, L2, T1, T2
4B1	Cropland remaining cropland	CO2	L1, L2, T1, T2
4B2	Land converted to cropland	CO2	
4C1	Grassland remaining grassland	CO2	L1, L2, T1, T2
4C2	Land converted to grassland	CO2	L1, L2, T1, T2
4D1	Wetland remaining wetland	CO2	
4D2	Land converted to wetland	CO2	
4E1	Settlements remaining settlements	CO2	
4E2	Land converted to settlements	CO2	L2
4F2	Land converted to other land	CO2	
4G	HWP Harvested wood products	CO2 biog.	L2, T1, T2
4II	Drainage and rewetting	CH4	
4II	Drainage and rewetting	N2O	
4III	Direct N2O from disturbance	N2O	
4IV	Indirect N2O	N2O	
4V	Biomass burning	N2O	
4V	Biomass burning	CH4	
5	Indirect CO2 emissions	CO2	
5A	Solid waste disposal	CO2	
5A	Solid waste disposal	CH4	L1, L2, T1, T2
5B	Biological treatment of solid waste	CH4	
5B	Biological treatment of solid waste	N2O	
5C	Incineration and open burning of waste	N2O	
5C	Incineration and open burning of waste	CO2	
5C	Incineration and open burning of waste	CH4	
5D	Wastewater treatment and discharge	CH4	L1, L2
5D	Wastewater treatment and discharge	N2O	L2
6	Other sources	N2O	
6	Other sources	CH4	
6	Other sources	CO2	
6	Indirect CO2 emissions	CO2	

Annex 2: Assessment of uncertainty

A2.1 Detailed results of Approach 1 uncertainty analysis

The table on the next pages shows the detailed results of Approach 1 uncertainty analysis. The structure of the table is identical to Table 3.2 of the 2006 IPCC Guidelines (IPCC 2006, vol. 1, chp. 3). For explanations to the columns see pp. 3.30–3.32 in vol. 1 of IPCC (2006).

Table A – 2 Results of Approach 1 uncertainty analysis, overall results are presented at the bottom of the last part of the table (corresponding to Table 3.2 of Volume 1, Chapter 3 of the IPCC 2006 Guidelines). The uncertainty analysis includes indirect CO₂ emissions.

IPCC Source category	Gas	Base year emissions or removals kt CO ₂ eq	Year 2017 emissions or removals kt CO ₂ eq	AD uncertainty %	EF uncertainty %	Combined uncertainty %	Contribution to variance by Category in 2017 %	Type A sensitivity %	Type B sensitivity %	Uncertainty in trend in nat. emissions introduced by EF uncertainty %	Uncertainty in trend in nat. emissions introduced by AD uncertainty %	Uncertainty introduced into the trend in total national emissions %
1A1	1. Energy industries	Biomass	0.44	0.22	10.00	28.28	30.00	2.08E-08	3.44E-06	4.29E-06	9.74E-05	1.32E-08
		Gaseous F.	0.11	0.22	5.00	29.58	30.00	2.00E-08	2.31E-06	4.21E-06	6.84E-05	5.57E-09
		Liquid F.	0.52	0.19	0.69	29.99	30.00	1.53E-08	5.36E-06	3.68E-06	1.61E-04	2.59E-08
		Solid F.	0.13	-	5.00	29.58	30.00	-	2.31E-06	-	6.83E-05	4.67E-09
		Gaseous F.	243.40	484.58	5.00	0.99	5.10	2.93E-03	5.23E-03	9.47E-03	5.19E-03	4.51E-03
		Liquid F.	685.81	348.52	0.69	0.08	0.69	2.78E-05	5.15E-03	6.81E-03	4.19E-04	4.38E-05
		Other F.	1'491.55	2'437.52	5.00	9.22	10.49	3.13E-01	2.16E-02	4.76E-02	1.99E-01	1.53E-01
		Solid F.	49.13	-	5.00	5.06	7.12	-	8.57E-04	-	4.34E-03	1.88E-05
		Biomass	22.58	15.04	10.00	79.37	80.00	6.95E-04	9.98E-05	2.94E-04	7.92E-03	8.00E-05
		Gaseous F.	0.13	0.26	5.00	79.84	80.00	2.02E-07	2.76E-06	5.01E-06	2.20E-04	4.98E-08
1A2	2. Manufacturing industries and construction	Liquid F.	1.11	0.29	0.69	80.00	80.00	2.53E-07	1.37E-05	5.61E-06	1.09E-03	1.19E-06
		Other F.	24.33	11.71	5.00	79.84	80.00	4.21E-04	1.95E-04	2.29E-04	1.56E-02	2.46E-04
		Solid F.	0.24	-	5.00	79.84	80.00	-	4.13E-06	-	3.30E-04	1.09E-07
		Biomass	4.25	1.98	10.00	28.28	30.00	1.70E-06	3.54E-05	3.88E-05	1.00E-03	1.30E-06
		Gaseous F.	0.46	1.01	5.00	29.58	30.00	4.44E-07	1.18E-05	1.98E-05	3.49E-04	1.42E-07
		Liquid F.	4.50	1.25	0.69	29.99	30.00	6.79E-07	5.40E-05	2.45E-05	1.62E-03	2.63E-06
		Other F.	0.77	0.54	5.00	29.58	30.00	1.28E-07	2.88E-06	1.06E-05	8.53E-05	1.29E-08
		Solid F.	0.31	0.22	5.00	29.58	30.00	2.08E-08	1.12E-06	4.29E-06	3.32E-05	2.02E-09
		Gaseous F.	1'049.69	2'284.78	5.00	0.99	5.10	6.51E-02	2.63E-02	4.47E-02	2.62E-02	1.00E-01
		Liquid F.	3'889.15	1'763.32	0.69	0.08	0.69	7.12E-04	3.33E-02	3.45E-02	2.71E-03	1.13E-03
1A3a	3. Transport, Domestic aviation	Other F.	192.36	401.56	5.00	9.22	10.49	8.51E-03	4.49E-03	7.85E-03	4.14E-02	4.79E-03
		Solid F.	1'274.70	427.76	5.00	5.06	7.12	4.45E-03	1.39E-02	8.36E-03	7.02E-02	8.42E-03
		Biomass	5.07	15.02	10.00	79.37	80.00	6.93E-04	2.05E-04	2.94E-04	1.63E-02	2.82E-04
		Gaseous F.	0.56	1.21	5.00	79.84	80.00	4.49E-06	1.39E-05	2.36E-05	1.11E-03	1.26E-06
		Liquid F.	13.14	10.68	0.69	80.00	80.00	3.50E-04	2.04E-05	2.09E-04	1.63E-03	2.71E-06
		Other F.	2.32	6.35	5.00	79.84	80.00	1.24E-04	8.35E-05	1.24E-04	6.67E-03	4.52E-05
		Solid F.	6.14	2.02	5.00	79.84	80.00	1.25E-05	6.77E-05	3.94E-05	5.41E-03	2.93E-05
		Kerosene	0.17	0.11	0.96	29.98	30.00	5.15E-09	8.44E-07	2.13E-06	2.53E-05	6.49E-10
		Kerosene	252.55	119.46	0.96	0.16	0.97	6.49E-06	2.07E-05	2.33E-03	3.27E-04	1.02E-05
		Kerosene	2.06	0.98	0.96	150.00	150.00	1.03E-05	1.67E-05	1.91E-05	2.60E-05	6.31E-06

Table A – 2 (continued)

IPCC Source category	Gas	Base year emissions or removals	Year 2017 emissions or removals	AD uncertainty	EF uncertainty	Combined uncertainty	Contribution to variance by Category in 2017	Type A sensitivity	Type B sensitivity	Uncertainty in trend in nat. emissions introduced by EF	Uncertainty in trend in nat. emissions introduced by AD	Uncertainty introduced into the trend in total national emissions
1A3b	Gasoline	97.84	12.10	0.69	36.99	37.00	9.61E-05	1.47E-03	2.36E-04	5.44E-02	2.29E-04	2.96E-03
	Biomass	-	0.15	10.00	59.16	60.00	3.68E-08	2.85E-06	2.85E-06	1.69E-04	4.04E-05	3.01E-08
	Gaseous F.	-	0.11	5.00	29.58	30.00	5.50E-09	2.20E-06	2.20E-06	6.52E-05	1.56E-05	4.50E-09
	Diesel	1.58	0.41	0.88	19.98	20.00	3.21E-08	1.95E-05	8.00E-06	3.90E-04	9.97E-06	1.52E-07
	Gasoline	11334.49	7196.35	0.69	0.13	0.70	1.21E-02	5.69E-02	1.41E-01	7.32E-03	1.36E-01	1.87E-02
	Gaseous F.	-	32.09	5.00	0.99	5.10	1.28E-05	6.27E-04	6.27E-04	6.23E-04	4.43E-03	2.01E-05
	Diesel	2632.59	7259.64	0.88	0.07	0.88	1.98E-02	9.59E-02	1.42E-01	6.54E-03	1.77E-01	3.14E-02
	Gasoline	134.18	17.60	0.69	50.00	50.00	3.71E-04	2.00E-03	3.44E-04	9.98E-02	3.34E-04	9.96E-03
	Biomass	-	2.67	10.00	149.67	150.00	7.71E-05	5.22E-05	5.22E-05	7.82E-03	7.39E-04	6.17E-05
	Gaseous F.	-	-	5.00	79.84	80.00	-	-	-	-	-	-
	Diesel	5.92	73.23	0.88	21.98	22.00	1.25E-03	1.33E-03	1.43E-03	2.92E-02	1.79E-03	8.55E-04
1A3c	Biomass	-	0.00	10.00	59.16	60.00	1.21E-13	5.18E-09	5.18E-09	3.06E-07	7.32E-08	9.91E-14
	Liquid F.	0.03	0.01	0.88	29.99	30.00	6.94E-11	2.69E-07	2.48E-07	8.08E-06	3.09E-07	6.54E-11
	Liquid F.	28.69	28.34	0.88	0.07	0.88	3.01E-07	5.36E-05	5.54E-04	3.65E-06	6.91E-04	4.77E-07
	Biomass	-	0.01	10.00	149.67	150.00	7.93E-10	1.68E-07	1.68E-07	2.51E-05	2.37E-06	6.34E-10
	Liquid F.	0.43	0.41	0.69	80.00	80.00	5.17E-07	5.91E-07	8.02E-06	4.73E-05	7.78E-06	2.30E-09
	Biomass	-	0.00	10.00	59.16	60.00	2.02E-11	6.69E-08	6.69E-08	3.96E-06	9.46E-07	1.65E-11
1A3d	Liquid F.	1.68	0.30	0.69	29.99	30.00	3.97E-08	2.34E-05	5.93E-06	7.02E-04	5.75E-06	4.93E-07
	Liquid F.	114.27	112.27	0.69	0.08	0.69	2.89E-06	2.02E-04	2.19E-03	1.64E-05	2.13E-03	4.53E-06
	Biomass	-	0.02	10.00	149.67	150.00	5.10E-09	4.25E-07	4.25E-07	6.36E-05	6.01E-06	4.08E-09
	Liquid F.	1.16	1.21	0.69	150.00	150.00	1.59E-05	3.56E-06	2.37E-05	2.30E-05	2.30E-05	2.86E-07
1A3e	Gaseous F.	0.07	0.02	5.00	29.58	30.00	2.38E-10	7.61E-07	4.59E-07	2.25E-05	3.25E-06	5.18E-10
	Gaseous F.	31.42	26.46	5.00	0.99	5.10	8.73E-06	3.07E-05	5.17E-04	3.05E-05	3.66E-03	1.34E-05
	Gaseous F.	0.02	0.01	5.00	79.84	80.00	6.02E-10	1.73E-08	2.74E-07	1.38E-06	1.94E-06	5.65E-12
	Biomass	9.22	4.53	10.00	28.28	30.00	8.85E-06	7.22E-05	8.85E-05	2.04E-03	1.25E-03	5.74E-06
1A4a	Gaseous F.	0.71	1.34	5.00	29.58	30.00	7.74E-07	1.38E-05	2.62E-05	4.08E-04	1.85E-04	2.01E-07
	Liquid F.	16.34	9.40	0.69	29.99	30.00	3.82E-05	1.01E-04	1.84E-04	3.03E-03	1.78E-04	9.22E-06
	Gaseous F.	990.06	1485.88	5.00	0.99	5.10	2.75E-02	1.18E-02	2.90E-02	1.17E-02	2.05E-01	4.23E-02
	Liquid F.	4260.86	2633.69	0.69	0.08	0.69	1.59E-03	2.28E-02	5.15E-02	1.86E-03	4.99E-02	2.50E-03
	Biomass	3.49	9.93	10.00	79.37	80.00	3.02E-04	1.33E-04	1.94E-04	1.06E-02	2.74E-03	1.19E-04
	Gaseous F.	0.53	0.79	5.00	79.84	80.00	1.90E-06	6.20E-06	1.54E-05	4.95E-04	1.09E-04	2.57E-07
	Liquid F.	10.35	6.43	0.69	80.00	80.00	1.27E-04	5.47E-05	1.26E-04	4.38E-03	1.22E-04	1.92E-05
	Biomass	109.92	24.62	10.00	28.28	30.00	2.62E-04	1.44E-03	4.81E-04	4.06E-02	6.80E-03	1.70E-03
	Gaseous F.	0.70	1.41	5.00	29.58	30.00	8.62E-07	1.54E-05	2.76E-05	4.57E-04	1.95E-04	2.47E-07
	Liquid F.	34.83	19.20	0.69	29.99	30.00	1.59E-04	2.32E-04	3.75E-04	6.96E-03	3.64E-04	4.86E-05
1A4b	Solid F.	4.73	0.75	5.00	29.58	30.00	2.43E-07	6.77E-05	1.47E-05	2.00E-03	1.04E-04	4.03E-06
	Gaseous F.	1450.97	2721.78	5.00	0.99	5.10	9.24E-02	2.77E-02	2.77E-02	3.76E-01	1.42E-01	1.42E-01
	Liquid F.	10099.07	5620.89	0.69	0.08	0.69	7.23E-03	6.61E-02	1.10E-01	5.39E-03	1.07E-01	1.14E-02
	Solid F.	58.40	9.27	5.00	5.06	7.12	2.09E-06	8.37E-04	1.81E-04	4.24E-03	1.28E-03	1.96E-05
	Biomass	25.84	22.45	10.00	79.37	80.00	1.55E-03	1.18E-05	4.39E-04	9.37E-04	6.20E-03	3.94E-05
	Gaseous F.	0.77	1.44	5.00	79.84	80.00	6.37E-06	1.47E-05	2.67E-05	1.28E-03	1.99E-04	1.42E-06
	Liquid F.	24.53	13.67	0.69	80.00	80.00	5.74E-04	1.60E-04	2.67E-04	1.28E-02	2.59E-04	1.65E-04
	Solid F.	0.28	0.04	5.00	79.84	80.00	6.13E-09	4.04E-06	8.74E-07	3.22E-04	6.18E-06	1.04E-07

Table A – 2 (continued)

IPCC Source category	Gas	Base year emissions or removals	Year 2017 emissions or removals	AD uncertainty	EF uncertainty	Combined uncertainty	Contribution to variance by Category in 2017	Type A sensitivity	Type B sensitivity	Uncertainty in trend in emissions introduced by EF	Uncertainty in trend in emissions introduced by AD	Uncertainty introduced into the trend in total national emissions
		kt CO ₂ eq	kt CO ₂ eq	%	%	%	%	%	%	%	%	%
1A4c	A. Fuel combustion activities	Biomass	1.97	0.36	10.00	30.00	5.53E-08	2.73E-05	7.00E-06	7.71E-04	9.89E-05	6.05E-07
		Gaseous F.	0.02	0.01	5.00	29.58	3.08E-11	1.57E-07	1.65E-07	4.65E-06	1.17E-06	2.30E-11
		Liquid F.	6.45	1.30	0.69	29.99	7.30E-07	8.71E-05	2.54E-05	2.61E-03	2.47E-05	6.83E-06
		Gaseous F.	41.45	19.01	5.00	0.99	4.51E-06	3.51E-04	3.72E-04	3.49E-04	2.63E-03	7.02E-06
		Liquid F.	485.09	403.23	0.69	0.08	3.72E-05	5.78E-04	7.78E-04	4.71E-05	7.85E-03	5.84E-05
		Biomass	0.51	1.42	10.00	79.37	6.22E-06	1.89E-05	2.78E-05	1.50E-03	3.93E-04	2.41E-06
		Gaseous F.	0.02	0.01	5.00	79.84	3.11E-10	1.87E-07	1.97E-07	1.50E-05	1.39E-06	2.26E-10
		Liquid F.	4.20	4.52	0.69	80.00	6.28E-05	1.51E-05	8.83E-05	1.21E-03	8.56E-05	1.47E-06
		Biomass	-	0.00	10.00	59.16	5.15E-14	3.37E-09	3.37E-09	2.00E-07	4.77E-08	4.21E-14
		Liquid F.	0.12	0.04	0.69	60.00	2.88E-09	1.28E-06	7.94E-07	7.68E-05	7.70E-07	5.90E-09
1A5	5. Other	Liquid F.	217.65	126.46	0.69	0.08	3.68E-06	1.32E-03	2.47E-03	1.08E-04	2.40E-03	5.76E-06
		Biomass	-	0.00	106.07	106.07	2.45E-10	9.30E-08	9.30E-08	9.87E-06	1.40E-05	2.92E-10
1B2	B. Fugitive emissions from fuels	Liquid F.	1.84	1.11	106.07	106.07	1.32E-05	1.04E-05	2.17E-05	1.11E-03	3.25E-03	1.18E-05
		Oil and natural gas and other emissions from energy production	336.27	191.92	5.00	29.58	1.59E-02	2.11E-03	3.75E-03	6.25E-02	2.65E-02	4.61E-03
1ind	Indirect emissions	CO ₂	26.34	31.17	5.00	8.66	4.68E-05	1.50E-04	6.09E-04	1.30E-03	4.31E-03	2.02E-05
		N ₂ O	0.60	0.01	5.00	79.84	2.28E-10	1.02E-05	1.68E-07	8.17E-04	1.19E-06	6.67E-07
2A1	1. Cement production	CO ₂	43.55	5.93	11.82	11.82	4.72E-06	6.43E-04	1.16E-04	7.61E-03	1.94E-03	6.16E-05
2A2	2. Lime production	CO ₂	2580.79	1759.82	2.00	4.00	2.97E-02	1.06E-02	3.44E-02	4.24E-02	9.73E-02	1.13E-02
2A3	3. Glass production	CO ₂	53.35	43.80	2.00	2.83	7.36E-06	7.43E-05	8.56E-04	1.49E-04	2.42E-03	5.88E-06
2A4	4. Other process uses of carbonates	CO ₂	15.25	7.17	2.00	3.61	3.21E-07	1.26E-04	1.40E-04	3.77E-04	3.97E-04	3.00E-07
2B2	2. Nitric acid production	N ₂ O	162.87	80.49	2.00	2.83	2.49E-05	1.27E-03	1.57E-03	2.53E-03	4.45E-03	2.62E-05
2B5	5. Carbide production	CH ₄	65.49	7.45	2.00	7.23	1.50E-06	9.96E-04	1.46E-04	7.20E-03	4.12E-04	5.20E-05
2B8	8. Petrochemical and carbon black production	CO ₂	1.74	2.87	2.00	20.00	1.59E-06	2.57E-05	5.60E-05	5.14E-04	1.58E-04	2.89E-07
2B10	10. Other (Niacin, Limestone pit)	CO ₂	15.72	24.61	2.00	10.20	3.02E-05	2.07E-04	4.81E-04	2.07E-03	1.36E-03	6.13E-06
2C1	1. Iron and steel production	CO ₂	94.08	90.89	2.00	10.20	4.12E-04	1.36E-04	1.78E-03	1.36E-03	5.02E-03	2.71E-05
2C3	3. Aluminium production	CO ₂	0.09	-	2.00	10.20	-	1.57E-06	-	1.57E-05	-	2.48E-10
2C4	4. Magnesium production	CO ₂	11.87	15.38	2.00	10.20	1.18E-05	9.35E-05	3.01E-04	9.35E-04	8.50E-04	1.60E-06
2C7	7. Other	CO ₂	9.20	11.68	2.00	5.39	1.90E-06	6.80E-05	2.28E-04	3.40E-04	6.46E-04	5.33E-07
2D	D. Non-energy products from fuels and solvent use	CO ₂	139.26	-	5.00	20.62	-	2.43E-03	-	4.86E-02	-	2.36E-03
2E1	1. Integrated circuit or semiconductor	CO ₂	116.46	-	6.36	9.00	-	2.03E-03	-	1.29E-02	-	1.67E-04
2E3	3. Photovoltaics	SF ₆	-	-	19.59	27.70	-	-	-	-	-	-
2E4	4. Heat transfer fluid	NF ₃	-	0.54	155.56	220.00	6.66E-06	1.05E-05	3.05E-05	3.52E-05	8.64E-05	8.70E-09
2F1	1. Refrigeration and air conditioning	HFC	56.27	0.18	10.00	14.14	4.73E-07	1.76E-06	8.93E-05	8.93E-04	1.56E-02	2.43E-04
2F2	2. Foam blowing agents	PFC	-	0.18	35.36	50.00	3.87E-08	3.51E-06	3.51E-06	1.24E-04	1.75E-04	4.62E-08
2F4	4. Aerosols	SF ₆	-	5.76	69.24	97.92	1.52E-04	1.13E-04	7.79E-03	1.13E-02	1.10E-02	1.82E-04
2F5	5. Solvents	NF ₃	-	7.57	43.26	61.18	1.03E-04	1.48E-04	1.48E-04	6.40E-03	9.05E-03	1.23E-04
		PFC	-	0.02	51.27	72.50	6.66E-06	1.05E-05	1.05E-05	1.63E-03	2.30E-03	7.96E-06
		HFC	-	0.02	51.27	72.50	7.43E-10	3.36E-07	3.36E-07	1.72E-05	2.43E-05	8.88E-10
		HFC	0.02	1405.76	10.18	14.39	1.96E-01	2.75E-02	2.75E-02	2.80E-01	3.95E-01	2.33E-01
		PFC	0.05	2.43	69.24	97.92	2.70E-05	4.65E-05	4.74E-05	3.22E-03	4.64E-03	3.19E-05
		HFC	-	29.26	94.36	133.45	7.31E-03	5.72E-04	5.72E-04	5.39E-02	7.63E-02	8.73E-03
		HFC	-	23.56	29.21	41.31	4.58E-04	4.70E-04	4.60E-04	1.90E-02	1.90E-02	5.43E-04
		HFC	-	1.31	38.07	53.85	2.37E-06	2.55E-05	2.55E-05	9.72E-04	1.37E-03	2.83E-06

Table A – 2 (continued)

	IPCC Source category	Gas	Base year emissions or removals	Year 2017 emissions or removals	AD uncertainty	EF uncertainty	Combined uncertainty	Contribution to variance by Category in 2017	Type A sensitivity	Type B sensitivity	Uncertainty in trend in nat. emissions introduced by EF uncertainty	Uncertainty in trend in nat. emissions introduced by AD uncertainty	Uncertainty introduced into the trend in total national emissions
			kt CO ₂ eq	kt CO ₂ eq	%	%	%	-	%	%	%	%	%
2G	G. Other product manufacture and use	CO ₂	6.15	37.08	10.00	14.14	1.32E-04	1.32E-04	6.17E-04	7.25E-04	6.17E-03	1.02E-02	1.43E-04
		HFC	-	51.63	43.92	62.11	4.93E-03	4.93E-03	1.01E-03	1.01E-03	4.43E-02	6.27E-02	5.89E-03
	H. Other	N ₂ O	106.44	31.17	1.00	79.99	80.00	2.98E-03	1.25E-03	6.09E-04	9.97E-02	8.61E-04	9.95E-03
		PFC	-	22.56	19.87	28.10	1.93E-04	1.93E-04	4.41E-04	4.41E-04	8.76E-03	1.24E-02	2.30E-04
2H	Indirect emissions	SF ₆	137.01	188.98	26.04	36.83	2.32E-02	2.32E-02	1.30E-03	3.69E-03	3.40E-02	1.36E-01	1.96E-02
2Ind		CO ₂	1.04	0.29	3.00	7.07	2.40E-09	2.40E-09	1.24E-05	5.69E-06	8.80E-05	2.41E-05	8.33E-09
3A	A. Enteric fermentation	CO ₂	355.98	87.47	77.55	109.68	4.42E-02	4.42E-02	4.50E-03	1.71E-03	3.49E-01	1.87E-01	1.57E-01
		CH ₄	3584.87	3293.60	6.45	16.95	1.71E+00	1.71E+00	1.85E-03	6.44E-02	3.14E-02	5.87E-01	3.46E-01
3B	B. Manure Management	CH ₄	868.63	746.63	6.45	54.42	7.92E-01	7.92E-01	5.55E-04	1.46E-02	3.00E-02	1.33E-01	1.86E-02
		N ₂ O	190.66	135.08	22.41	53.03	2.90E-02	2.90E-02	6.85E-04	2.64E-03	3.63E-02	8.37E-02	8.32E-03
3D	D a. Direct Emissions Managed Soils	N ₂ O	235.72	270.84	46.57	240.00	2.10E+00	2.10E+00	1.18E-03	5.29E-03	2.84E-01	3.49E-01	2.02E-01
		N ₂ O	1269.77	1176.15	15.41	107.42	7.81E+00	7.81E+00	8.44E-04	2.30E-02	9.06E-02	5.01E-01	2.59E-01
3G	D b. Indirect Emissions Managed Soils	CO ₂	567.00	407.28	28.80	169.50	2.35E+00	2.35E+00	1.93E-03	7.96E-03	3.27E-01	3.24E-01	2.12E-01
3H		CO ₂	22.25	32.84	40.00	5.00	8.41E-04	8.41E-04	2.54E-04	6.42E-04	1.27E-03	3.63E-02	1.32E-03
5A	A. Solid waste disposal	CO ₂	26.66	14.73	5.00	7.07	5.21E-06	5.21E-06	1.77E-04	2.88E-04	8.84E-04	2.04E-03	4.93E-06
		CH ₄	763.39	318.19	21.21	30.00	4.37E-02	4.37E-02	7.09E-03	6.22E-03	1.50E-01	1.87E-01	5.74E-02
5B	B. Biological treatment of solid waste	CH ₄	11.89	26.21	30.00	30.00	5.93E-04	5.93E-04	3.05E-04	5.12E-04	9.15E-03	2.17E-02	5.56E-04
		N ₂ O	5.22	9.76	30.00	42.43	8.23E-05	8.23E-05	9.98E-05	1.91E-04	2.99E-03	8.09E-03	7.45E-05
5C	C. Incineration and open burning of waste	CH ₄	8.89	5.10	10.00	59.16	4.49E-05	4.49E-05	5.54E-05	9.96E-05	3.28E-03	1.41E-03	1.27E-05
		CO ₂	53.73	9.56	10.00	38.73	7.01E-05	7.01E-05	7.50E-04	1.87E-04	2.91E-02	2.64E-03	8.51E-04
5D	D. Wastewater treatment and discharge	N ₂ O	16.78	35.45	10.00	38.73	9.64E-04	9.64E-04	4.00E-04	6.93E-04	1.55E-02	9.80E-03	3.36E-04
		CH ₄	130.55	186.87	32.00	36.00	3.89E-02	3.89E-02	1.38E-03	3.65E-03	4.95E-02	1.65E-01	2.98E-02
5Ind	Indirect emissions	N ₂ O	80.75	99.62	32.00	146.55	1.07E-01	1.07E-01	5.39E-04	1.95E-03	7.90E-02	8.81E-02	1.40E-02
		CO ₂	2.01	1.13	31.40	44.40	1.21E-06	1.21E-06	1.30E-05	2.21E-05	4.09E-04	9.80E-04	1.13E-06
6	Direct emissions	CH ₄	0.66	0.61	42.43	42.43	6.52E-07	6.52E-07	5.00E-07	1.20E-05	2.12E-05	7.21E-04	5.20E-07
		CO ₂	10.96	11.52	28.28	28.28	1.02E-04	1.02E-04	2.25E-04	2.25E-04	9.62E-04	9.01E-03	8.20E-05
6Ind	Indirect emissions	N ₂ O	0.60	0.51	106.07	106.07	2.86E-06	2.86E-06	3.32E-07	1.01E-05	3.52E-05	1.51E-03	2.28E-06
		CO ₂	1.04	1.06	52.48	52.48	2.94E-06	2.94E-06	2.48E-06	2.06E-05	1.30E-04	1.53E-03	2.36E-06

Table A – 2 (continued)

IPCC Source category	Gas	Base year emissions or removals	Year 2017 emissions or removals	AD uncertainty	EF uncertainty	Combined uncertainty	Contribution to variance by Category in 2017	Type A sensitivity	Type B sensitivity	Uncertainty in trend in nat. emissions introduced by EF uncertainty	Uncertainty in trend in nat. emissions introduced by AD uncertainty	Uncertainty introduced into the trend in total national emissions
		kt CO ₂ eq	kt CO ₂ eq	%	%	%	-	%	%	%	%	%
4. LULUCF	Drainage, rewetting and other management of organic and mineral soils	10.75	10.75	10.00	70.00	70.71	2.77E-04	2.26E-05	2.10E-04	1.58E-03	2.97E-03	1.13E-05
	N ₂ O	2.95	2.93	34.10	66.90	75.09	2.32E-05	5.75E-06	5.72E-05	3.85E-04	2.76E-03	7.76E-06
	N mineralization	36.99	37.11	83.50	135.00	158.74	1.66E-02	8.01E-05	7.25E-04	1.08E-02	8.56E-02	7.45E-03
	Indirect emissions	5.72	4.96	85.80	161.50	182.88	3.95E-04	2.68E-06	9.70E-05	4.34E-04	1.18E-02	1.39E-04
	Biomass burning	18.87	3.12	30.00	70.00	76.16	2.70E-05	2.68E-04	6.09E-05	1.88E-02	2.58E-03	3.59E-04
	N ₂ O	10.98	1.43	30.00	70.00	76.16	5.70E-06	1.63E-04	2.80E-05	1.14E-02	1.19E-03	1.32E-04
	A. Forest land	-1'112.27	-2'621.64	1.09	88.55	88.56	2.59E+01	3.18E-02	5.12E-02	2.82E+00	7.87E-02	7.96E+00
	1. Forest land remaining forest land	-609.84	-574.79	1.54	88.55	88.57	1.24E+00	5.99E-04	1.12E-02	5.30E-02	2.44E-02	3.41E-03
	2. Land converted to forest land	238.32	764.06	4.89	62.82	63.01	1.11E+00	1.08E-02	1.49E-02	6.77E-01	1.03E-01	4.69E-01
	B. Cropland	42.05	40.06	5.12	97.09	97.23	7.28E-03	4.95E-05	7.83E-04	4.81E-03	5.67E-03	5.53E-05
	1. Land converted to cropland	-275.58	316.32	5.23	374.75	374.78	6.74E+00	1.10E-02	6.18E-03	4.12E+00	4.58E-02	1.70E+01
	C. Grassland	98.52	225.84	5.31	38.39	38.75	3.67E-02	2.70E-03	4.41E-03	1.03E-01	3.31E-02	1.18E-02
	1. Grassland remaining grassland	67.54	66.05	61.90	72.24	95.13	1.89E-02	1.13E-04	1.29E-03	8.17E-03	1.13E-01	1.28E-02
	2. Land converted to grassland	20.23	38.11	3.95	19.08	19.48	2.64E-04	3.92E-04	7.45E-04	7.48E-03	4.16E-03	7.32E-05
	D. Wetlands	-48.63	-40.79	4.41	50.00	50.19	2.01E-03	5.09E-05	7.97E-04	2.54E-03	4.97E-03	3.12E-05
	E. Settlements	224.46	184.23	4.57	50.00	50.21	4.10E-02	3.14E-04	3.60E-03	1.57E-02	2.32E-02	7.86E-04
	1. Settlements remaining settlements	89.21	110.75	3.24	50.00	50.10	1.48E-02	6.09E-04	2.16E-03	3.04E-02	9.90E-03	1.02E-03
	2. Land converted to settlements	-1'304.70	-166.07	4.50	57.00	57.18	4.33E-02	1.95E-02	3.25E-03	1.11E+00	2.07E-02	1.24E+00
	F. Other land											
	2. Land converted to other land											
	G. Harvested wood products											
Total including LULUCF (emissions or uncertainty)		51'170	45'657	Percentage uncertainty in total inventory:								
				51.02	Trend uncertainty:							28.80
				7.14								5.37

Annex 3: Other detailed methodological descriptions for individual source or sink categories

A3.1 Sector Energy

A3.1.1 Emission from manufacturing industries and construction

The emission factors of precursors in the manufacturing industries and construction sector are given below. Further and more detailed emission factors can be found in Switzerland's Informative Inventory Report (FOEN 2019d).

Emission factors for greenhouse gases are given in 3.2.6.2.

Table A – 3 Emission factors 2017 of precursors from boiler in 1A2 Manufacturing industries and construction.

1A2 Boiler	NO _x	NM VOC	SO ₂	CO
	g/GJ			
Boiler gas oil	32	2	9	7
Boiler residual fuel oil	125	4	626	10
Boiler liquefied petroleum gas	19	2	0.5	8
Boiler petroleum coke	125	4	626	10
Boiler other bituminous coal	200	10	500	100
Boiler lignite	205	10	500	100
Boiler natural gas	19	2	0.5	8

A3.1.2 Civil aviation

This paragraph contains further information on the emission modelling. More complete information is provided in FOCA (2006, 2006a, 2007–2018) and on request for reviewers by FOCA.

Emission factors (1A3a)

Table A – 4 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 – 5 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 – 6 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-Honeywell
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 – 7 Extract of the output file of FOCA emission and fuel consumption modelling. Upper part: LTO, lower part: cruise (example for 2004). Emissions and fuel consumption in tonnes.

Airport	Distance	Type Traffic	Movements	Type	Aircraft ICAO	Engine Name	Fuel (LTO) tons	Emissions (LTO) in tons					
	Km		No.					CO ₂	H ₂ O	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

A3.1.3 Road transportation

Emission factors (1A3b)

The derivation of the emission factors for road vehicles is described in detail in TUG (2009), Keller et al. (2017), Hausberger and Matzer (2017). The emission factors are contained in the “The Handbook Emission Factors for Road Transport (HBEFA)” (version 3.3), which is available as a database (INFRAS 2017a). Some important features of the emission factor methodologies are summarised in this paragraph.

The emission factors have to be differentiated according to vehicle categories. Each category contains a number of vehicle classes, which differ by emission concepts. The following table illustrates the classes of the passenger cars. Similar “segmentations” hold for the other vehicle categories, too. Emission factors for vehicle classes are combined to average emission factors for vehicles categories weighted according to the fleet composition, which varies from year to year (see below).

Table A – 8 Vehicle segmentation of the passenger cars. Each segment is subdivided into three cubic capacities: <1.4 litre, 1.4-2.0 litres, >2.0 litres (INFRAS 2017a).

Fuel type	Vehicle segment
Gasoline	<ECE
	AGV82 (CH)
	PreEuro 3WayCat <1987
	PreEuro 3WayCat 1987-90
	ECE-15'00
	ECE-15'01/02
	ECE-15'03
	Euro-1
	Euro-2
	Euro-3
	Euro-4
	Euro-5
	Euro-6
Diesel	<1986
	1986-1988
	Euro-1
	Euro-2
	Euro-3
	Euro-4
	Euro-5 Diesel Particle Filter
	Euro-6 Diesel Particle Filter

The emission factors are classified by “traffic situations”. The scheme (see table below) distinguishes the traffic situations along 4 dimensions: urban/rural areas, 10 road types, speed limits and 4 levels of service. This leads to the definition of 276 different traffic situations in total. A traffic situation is characterised by these four parameters which induce a typical driving behaviour. (Because driving behaviour is not independent of the amount of traffic on that particular road, on the same segment different driving patterns may exist.) For the handbook several typical traffic situations have been defined, based on driving behaviour studies in Germany and in Switzerland (see INFRAS 2015b).

Table A – 9 Traffic situation-scheme in HBEFA 3.1 (INFRAS 2010). Every traffic situation is characterised by a typical driving pattern (i.e. a speed-time curve)

			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.	4 levels of service													
	Semi-Motorway	4 levels of service													
	TrunkRoad/Primary-Nat.	4 levels of service													
	Distributor/Secondary	4 levels of service													
	Distributor/Secondary(sinuous)	4 levels of service													
	Local/Collector	4 levels of service													
	Local/Collector(sinuous)	4 levels of service													
	Access-residential	4 levels of service													
Urban	Motorway-Nat.	4 levels of service													
	Motorway-City	4 levels of service													
	TrunkRoad/Primary-Nat.	4 levels of service													
	TrunkRoad/Primary-City	4 levels of service													
	Distributor/Secondary	4 levels of service													
	Local/Collector	4 levels of service													
	Access-residential	4 levels of service													

Traffic situations are defined independently of vehicle categories (LDV, HDV, 2-wheelers). But behind the same traffic situation each vehicle category may know its own “driving pattern” which may be expressed as a speed curve (i.e. speed time series). Emission factors originally are derived for these underlying driving patterns based on measurements performed on laboratory test benches. Emission factors per traffic situation are then calculated by attributing the driving patterns to different traffic situations (based on statistical analyses).

Emission factors for Switzerland are shown in the next table. They represent weighted averages over all traffic situations but separate emission factors for warm operating state of the running engine in g/vehicle-km from cold start excess emissions in g per start per vehicle.

Table A – 10 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. Cold start excess emissions are given in g/start.

Pollutant	Year	PC	LDV	HDV	Coach	Bus	MC	PC	LDV
		Emission factors in gramme per vehicle kilometre						Cold starts in gramme per start	
CH ₄	1990	0.026	0.038	0.019	0.019	0.059	0.281	0.67	0.72
CH ₄	1995	0.016	0.027	0.017	0.018	0.052	0.311	0.42	0.50
CH ₄	2000	0.010	0.017	0.013	0.017	0.038	0.313	0.28	0.29
CH ₄	2005	0.006	0.008	0.009	0.013	0.020	0.271	0.18	0.15
CH ₄	2010	0.003	0.003	0.004	0.008	0.018	0.185	0.12	0.08
CH ₄	2015	0.001	0.001	0.002	0.005	0.016	0.118	0.09	0.05
CO	1990	6.21	15.75	2.29	2.33	6.58	14.05	41.0	60.8
CO	1995	2.96	11.02	2.12	2.26	6.24	13.17	29.3	46.9
CO	2000	1.76	6.55	1.72	2.06	5.12	12.43	21.8	31.3
CO	2005	1.21	3.06	1.61	1.91	3.23	10.56	15.4	17.7
CO	2010	0.74	1.34	1.36	1.87	1.33	7.36	10.7	9.4
CO	2015	0.47	0.66	0.99	1.70	1.01	5.17	8.0	5.9
CO ₂ (fossil)	1990	243	244	796	927	1'274	83	109	141
CO ₂ (fossil)	1995	246	247	797	920	1'279	92	103	135
CO ₂ (fossil)	2000	238	250	758	891	1'236	94	100	128
CO ₂ (fossil)	2005	223	242	794	880	1'196	97	101	116
CO ₂ (fossil)	2010	204	236	778	871	1'134	104	106	107
CO ₂ (fossil)	2015	186	229	767	876	1'115	106	107	103
VOC	1990	0.72	1.14	0.81	0.81	2.48	3.71	7.12	6.84
VOC	1995	0.33	0.73	0.72	0.77	2.17	2.68	5.72	5.59
VOC	2000	0.16	0.37	0.54	0.70	1.59	2.13	4.63	4.14
VOC	2005	0.08	0.16	0.38	0.55	0.82	1.67	3.27	2.53
VOC	2010	0.04	0.07	0.16	0.32	0.25	1.14	2.29	1.39
VOC	2015	0.02	0.03	0.07	0.19	0.15	0.75	1.69	0.89
N ₂ O	1990	0.009	0.005	0.008	0.008	0.012	0.002	-0.000	0.002
N ₂ O	1995	0.013	0.007	0.009	0.008	0.012	0.002	0.002	0.005
N ₂ O	2000	0.011	0.008	0.009	0.008	0.011	0.002	0.004	0.008
N ₂ O	2005	0.005	0.007	0.008	0.007	0.009	0.002	0.006	0.011
N ₂ O	2010	0.003	0.006	0.031	0.014	0.017	0.002	0.008	0.015
N ₂ O	2015	0.003	0.005	0.042	0.022	0.029	0.002	0.009	0.018
NM VOC	1990	0.69	1.10	0.79	0.79	2.42	3.43	6.45	6.11
NM VOC	1995	0.31	0.70	0.70	0.75	2.11	2.37	5.30	5.10
NM VOC	2000	0.15	0.35	0.53	0.68	1.55	1.82	4.35	3.86
NM VOC	2005	0.07	0.15	0.37	0.53	0.80	1.40	3.09	2.38
NM VOC	2010	0.03	0.06	0.16	0.31	0.24	0.96	2.16	1.31
NM VOC	2015	0.02	0.03	0.07	0.19	0.13	0.63	1.60	0.84
NO _x	1990	1.04	2.13	11.12	12.00	17.87	0.11	0.56	0.03
NO _x	1995	0.71	1.74	10.29	11.39	17.32	0.14	1.19	0.53
NO _x	2000	0.56	1.52	9.06	10.56	15.84	0.15	1.19	0.57
NO _x	2005	0.43	1.30	7.53	9.32	13.16	0.16	0.74	0.24
NO _x	2010	0.34	1.08	4.84	7.50	9.69	0.14	0.37	0.02
NO _x	2015	0.35	0.94	2.98	5.99	7.25	0.13	0.17	-0.11
SO ₂	1990	0.041	0.092	0.708	0.824	1.133	0.011	0.018	0.044
SO ₂	1995	0.033	0.040	0.173	0.199	0.277	0.012	0.014	0.021
SO ₂	2000	0.023	0.033	0.131	0.154	0.214	0.008	0.010	0.016
SO ₂	2005	0.001	0.001	0.005	0.006	0.008	0.000	0.001	0.001
SO ₂	2010	0.001	0.001	0.005	0.006	0.007	0.001	0.001	0.001
SO ₂	2015	0.001	0.001	0.005	0.006	0.007	0.001	0.001	0.001

Table A – 11 Emission factors for N₂O based on COPERT for passenger cars (PC) and light duty vehicles (LDV) by Euro class (EMEP/EEA 2016). Start excess is the difference between cold and hot EF.

veh. category	fuel	euro class	EF (N ₂ O) hot mg/km	EF (N ₂ O) hot mg/km	start excess mg/km
PC	gasoline	EURO0	10.00	10.00	-
PC	gasoline	EURO1	26.15	18.68	-7.47
PC	gasoline	EURO2	12.86	12.68	-0.18
PC	gasoline	EURO3	1.52	8.33	6.81
PC	gasoline	EURO4	1.95	5.48	3.53
PC	gasoline	EURO5	2.21	2.11	-0.10
PC	diesel oil	EURO6	2.12	1.75	-0.37
PC	diesel oil	EURO0	-	-	-
PC	diesel oil	EURO1	2.00	-	-2.00
PC	diesel oil	EURO2	4.00	3.00	-1.00
PC	diesel oil	EURO3	9.00	15.00	6.00
PC	diesel oil	EURO4	9.00	15.00	6.00
PC	diesel oil	EURO5	9.00	15.00	6.00
PC	diesel oil	EURO6	11.00	9.00	-2.00
LDV	gasoline	EURO0	10.00	10.00	-
LDV	gasoline	EURO1	47.28	47.40	0.12
LDV	gasoline	EURO2	29.62	88.57	58.95
LDV	gasoline	EURO3	8.50	17.10	8.60
LDV	gasoline	EURO4	1.20	13.79	12.59
LDV	gasoline	EURO5	2.18	1.98	-0.20
LDV	diesel oil	EURO6	2.11	1.73	-0.38
LDV	diesel oil	EURO0	-	-	-
LDV	diesel oil	EURO1	2.00	-	-2.00
LDV	diesel oil	EURO2	4.00	3.00	-1.00
LDV	diesel oil	EURO3	9.00	15.00	6.00
LDV	diesel oil	EURO4	9.00	15.00	6.00
LDV	diesel oil	EURO5	9.00	15.00	6.00
LDV	diesel oil	EURO6	11.00	9.00	-2.00

Activity data (1A3b)

Activity data for the emission model are the mileages of the vehicle categories per traffic situation. To that aim, 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 on the basis of new registrations and by applying survival probabilities. Trends in traffic volume per vehicle category, 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 data by Swiss Federal Statistical Office (SFSO 2018f/g).
3. Assignment of the mileage to the traffic situations for all vehicle categories. This step requires the adoption of the traffic model: Each road segment carries its mileage and its traffic, which allows the assignment sought.

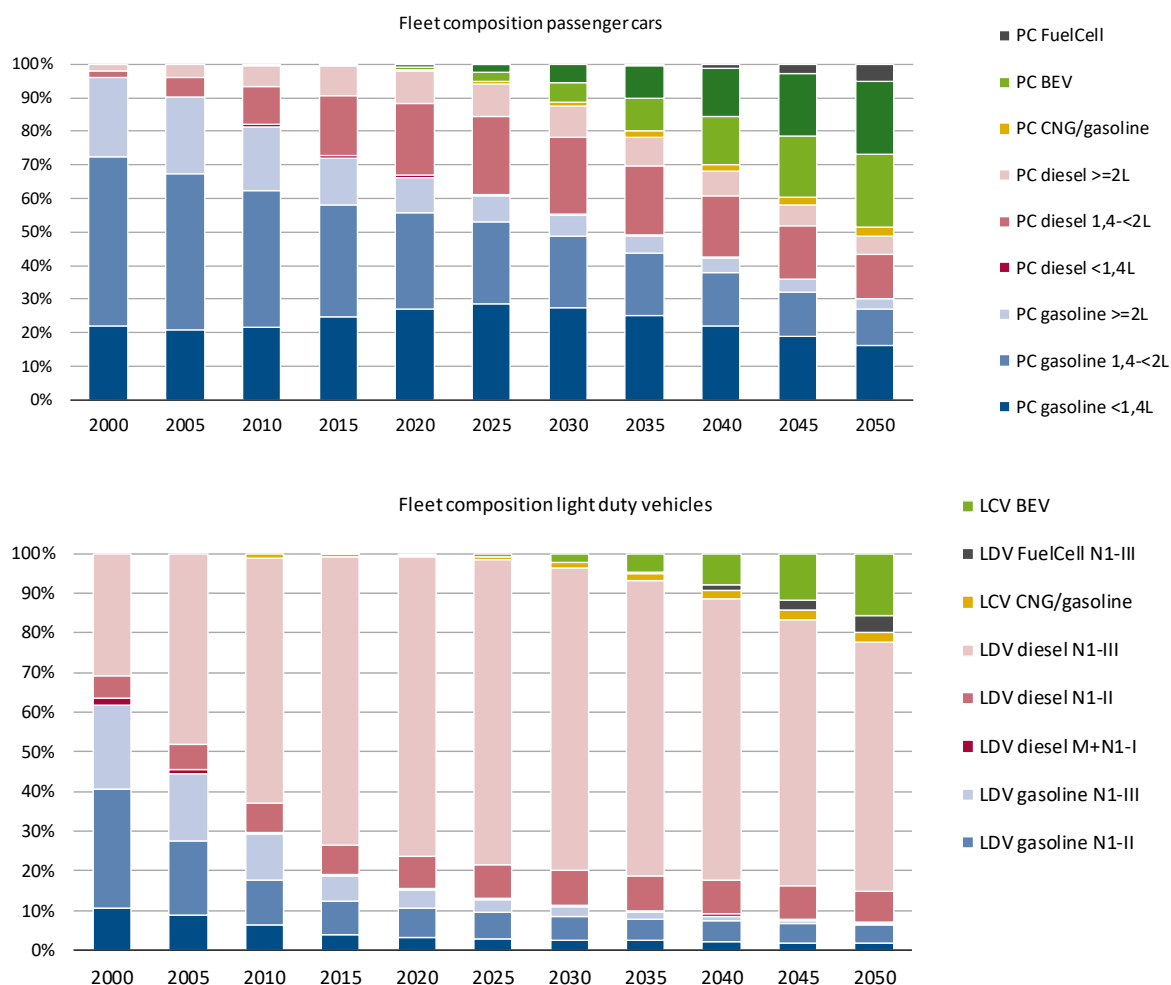


Figure A – 1 Fleet composition for passenger cars (PC, above) and light duty vehicles (LDV, below). The specifications refer to fuel type (diesel oil, gasoline etc.) and engine size (PC: L = litres, LDV N1-I etc.). Data source INFRAS (2017).

Modelling hot exhaust emissions (1A3b)

As a next step in the modelling process, the mileage classified by vehicle segments and traffic situations is multiplied with the emission factors resulting in hot exhaust emissions.

The results do not yet contain the emissions from fuel tourism and statistical differences. For this purpose a special procedure is carried out (described in chp. 3.2.9.2.2), providing the fuel consumption of fuel tourism and statistical differences. From that, the emissions are calculated by multiplication with mean emission factors (averaged over vehicle categories).

Cold start and evaporative emissions (1A3b)

The handbook also contains emission factors for modelling cold start excess emissions and evaporative emissions (diurnal and hot/warm soak and running losses). For a technical description the reader may refer to TUG (2009). Note that there are cold start excess emissions available for motor cycles.

Results show that for CO₂ the hot exhaust emissions contribute to about 97% of the total. Only 3% stem from cold start excess emissions. For CH₄, however, the picture is different. Only about 40% of the emission total is hot exhaust. More than 59% are cold start excess

emissions, the rest results from evaporative emissions. For N₂O, no cold start emission factors are available in INFRAS (2017a) due to lack of measurement data. However, the missing N₂O emissions have been estimated by means of emission factors provided by the COPERT model and which are provided in the EMEP Guidebook (EMEP/EEA 2016). For details see chp. 3.2.9.2.2.

A3.1.4 Non-road vehicles: supplementary activity data

The following table shows some aggregated information on stock numbers and annual operation hours of non-road vehicles. 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 (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

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

Category	1980	1990	2000	2010	2020	2030
million operating hours per year						
Construction machinery	15.7	19.0	21.4	23.8	25.6	26.9
Industrial machinery	17.8	29.0	48.4	47.5	47.1	47.0
Agricultural machinery	39.9	38.8	37.7	33.0	30.6	29.0
Forestry machinery	2.4	2.8	2.6	2.3	2.0	1.9
Garden-care / hobby appliances	14.6	25.7	39.3	149.7	190.8	201.3
Navigation machinery	3.7	3.9	3.5	3.4	3.4	3.4
Railway machinery	0.5	0.8	0.8	0.5	0.5	0.5
Military machinery	0.8	0.9	0.9	0.9	0.9	0.9
Total	95	121	155	261	301	311

A3.1.5 Sulphur dioxide (SO₂)

Table A – 13 shows sulphur contents and SO₂ emission factors per fuel type. Explanations:

- For liquid and solid fuels the SO₂ 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 the Swiss Petroleum Association (EV), reports by the Federal Customs Administration (FCA) 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 SO₂.
 - $$EF_{SO_2} = \frac{M_{SO_2}}{M_S} * \frac{S}{NCV} = 2 \frac{S}{NCV}$$
- Gas oil: starting from 1990 and for each fifth subsequent year up to and including 2015 the values for the SO₂ emission factors are based on five-year averages (eg. 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, FCA 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, as of 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 SO₂/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 SO₂/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 SO₂ emission factors. Legal limits that did not change in a specific year are printed in grey color.

Year	Maximum legal limit of sulphur content						
	Diesel oil	Gasoline	Gas oil (Euro)	Natural gas	Res. fuel oil	Res. fuel oil	Coal
	ppm	ppm	ppm	ppm	Class A, %	Class B, %	%
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
2010-2017	10	10	1000	190	1.0	2.8	1-3

Year	Effective sulphur content			
	Diesel oil ppm	Gasoline ppm	Gas oil ppm	Res. fuel oil %
1990	1400	200	1600	0.97
1991	1300	200	1300	0.89
1992	1200	200	1200	0.86
1993	1000	200	1000	0.87
1994	434	200	1350	0.77
1995	341	200	1170	0.78
1996	372	200	1160	0.78
1997	353	200	1250	0.70
1998	402	200	926	0.83
1999	443	200	650	0.62
2000	272	142	680	0.66
2001	250	121	830	0.82
2002	235	101	798	0.78
2003	200	81	700	0.79
2004	10	8.0	700	0.76
2005	10	8.0	799	0.78
2006	10	8.0	699	0.74
2007	10	8.0	630	0.71
2008	10	8.0	641	0.67
2009	7.6	5.3	549	0.92
2010	6.7	4.7	519	0.88
2011	6.6	5.0	417	0.90
2012	7.0	5.3	503	0.91
2013	7.1	4.8	224	0.90
2014	6.8	4.8	341	1.11
2015	7.7	4.5	348	1.93
2016	7.0	4.6	159	1.92
2017	7.7	5.2	146	0.98

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	0.5	NE	440	NO	350	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			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			380	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	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			626	23.1		

* grey 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 depending from equipment type between 0.5% to 20% (see Table 4-46). 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 informations 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	0.8	kg
	2002	0.7	kg
	2014	0.6	kg
	Extrapolation of other years		
Lifetime		15	years
Production			
Import of precharged equipment		100	%
Operation			
Annual losses		8.5	%
Recharge of losses (6.8% of 8.5%)		70	%
Additional service losses over lifetime		10	%
Disposal			
Export rate		31-72	%
Share with total loss of refrigerant		40	%
Disposal loss of professional recovery		15	%
Assumed reuse of recovered chemical		80	%

Since 1991 HFC-134a has been used to replace ODS in the mobile air conditioning sector leading to a considerable stock of about 2'126 t of HFC-134a in registered cars at present. A phase-out of HFC-134a is expected in the near future due to regulations in the European Union and their implementation in Switzerland. AC-refrigerant exceeding a GWP of 150 is not allowed for new car models since 2011. Since 2017, no new car with AC-refrigerant exceeding GWP 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. 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 2017 (excluding sold vehicles from former years in stock). Most of them switched to HFO (HFO-1234yf or HFO-1234ze), few models apply CO₂ (R744). A complete replacement of HFC-134a was assumed for all new vehicles sold in 2017.

Table A – 15 Bottom up calculations to identify 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

Table A – 16 Results and structure of emission calculations of HFC-134a from mobile air conditioning of cars for the inventories 1990 to 2017.

HFC-134a	Activity			Emissions				Recharge	
	Input with vehicles	Stock	Disposed	Production	Stock incl. Recharge	Disposal	Total	import in bulk	recovered and reused
	[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	114	0	NO	10	0	10	4	0
1996	79	190	0	NO	17	0	17	7	0
1997	107	292	0	NO	27	0	27	12	0
1998	151	434	0	NO	40	0	40	19	0
1999	175	597	0	NO	55	0	55	28	0
2000	175	756	0	NO	69	0	69	38	0
2001	191	927	0	NO	85	0	85	49	0
2002	180	1'081	0	NO	99	0	99	59	0
2003	166	1'217	0	NO	112	0	112	69	0
2004	165	1'349	0	NO	124	0	124	78	0
2005	158	1'470	0	NO	135	0	135	87	0
2006	168	1'597	1	NO	146	0	147	94	0
2007	174	1'724	3	NO	158	0	158	101	1
2008	173	1'841	9	NO	169	3	171	107	3
2009	156	1'927	20	NO	177	6	183	111	7
2010	169	2'019	25	NO	185	7	192	115	9
2011	185	2'108	40	NO	193	11	205	115	14
2012	181	2'167	64	NO	199	15	213	112	23
2013	155	2'190	72	NO	201	19	220	113	26
2014	136	2'189	77	NO	201	21	222	113	27
2015	133	2'181	82	NO	200	21	222	111	29
2016	117	2'149	86	NO	197	23	220	108	32
2017	50	2'045	95	NO	188	24	212	104	34

A3.3 Agriculture

Additional data for estimating CH₄ 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		16.1-23.1 ^c	0	305 days of lactation	72	6.90	117.3 - 137.4
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	

^aData source: RAP 1999 and calculations according to Soliva 2006.

^bMilk production in kg/day is calculated by dividing the average annual milk production per head by 305 days (lactation period).

^cdata source: Swiss farmers union (MISTA 2015).

^ddata source: IPCC 2006 and Zeltz et al. 2012.

^eFor 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.

Annex 3: Other detailed methodological descriptions for individual source or sink categories

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)

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)

Annex 3: Other detailed methodological descriptions for individual source or sink categories

Population Size		1000 head																													
		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		
Cattle	Cattle	1855.2	1828.9	1782.6	1745.1	1755.4	1748.3	1747.1	1672.9	1640.9	1608.7	1583.0	1611.4	1593.7	1570.2	1544.5	1554.7	1586.9	1571.8	1604.3	1597.5	1591.2	1577.4	1564.6	1567.5	1562.8	1554.3	1555.4	1544.6		
	Mature Dairy Cattle	783.1	749.5	763.5	744.5	749.7	738.6	736.0	711.6	687.3	663.5	669.4	669.4	657.9	638.3	621.0	620.7	618.1	614.8	608.4	599.0	598.2	591.2	586.6	587.4	586.6	587.4	583.3	575.8	599.2	
	Other Mature Cattle	12.0	14.0	17.0	18.0	20.0	23.0	28.0	32.0	38.0	41.2	44.9	50.6	58.1	65.1	70.0	78.5	87.3	93.5	98.4	100.4	111.3	110.7	111.4	116.0	118.0	117.9	120.8	123.4		
	Growing Cattle	1060.1	1034.4	1002.1	982.6	985.7	985.6	983.0	929.3	884.0	873.7	886.7	886.7	886.7	886.7	886.7	886.7	886.7	886.7	886.7	886.7	886.7	886.7	886.7	886.7	886.7	886.7	886.7	886.7		
	Fattening Calves	112.3	111.4	109.5	111.1	107.1	112.0	106.0	108.1	116.4	103.3	114.7	114.4	113.9	111.3	105.6	101.5	100.5	107.3	113.5	111.1	103.1	101.9	102.5	102.6	107.0	107.6	107.0	107.6		
	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		
	Breeding Cattle 1st Year	346.4	336.7	324.0	306.2	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	223.2	224.5	221.6	215.7	210.4	207.7	209.5	210.2	217.3	209.3		
	Breeding Cattle 2nd Year	253.3	251.9	250.5	238.7	237.2	236.6	243.0	232.9	217.4	187.5	221.9	219.7	219.7	219.7	205.4	204.7	210.2	210.2	210.2	210.2	210.2	210.2	210.2	210.2	210.2	210.2	210.2	210.2		
	Breeding Cattle 3rd Year	150.7	148.4	146.7	142.3	141.4	139.4	139.9	139.3	139.3	139.3	139.3	139.3	139.3	139.3	139.3	139.3	139.3	139.3	139.3	139.3	139.3	139.3	139.3	139.3	139.3	139.3	139.3	139.3		
	Fattening Cattle	187.8	174.8	157.8	168.0	163.5	192.9	179.6	165.4	163.1	210.2	147.1	148.5	141.7	144.1	144.7	149.3	148.0	156.1	109.6	111.7	110.8	108.9	106.3	103.0	101.3	98.5	97.1	97.8		
Sheep	Fattening Cattle	395.2	409.4	414.7	424.0	405.4	386.7	418.6	420.4	423.3	433.5	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	398.8	398.3		
	Fattening Sheep	190.6	200.8	207.0	211.1	207.2	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	229.7	227.3	228.2	221.8	219.3	216.2	209.5	204.0	205.0	206.9		
	Milksheep	4.3	4.0	3.8	3.5	3.0	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		
	Piglets	179.0	172.6	170.5	1691.8	1588.7	1445.6	1379.4	1394.9	1467.0	1453.3	1498.2	1528.9	1537.5	1609.5	1634.8	1573.1	334.3	366.5	344.8	336.1	338.4	350.9	352.7	344.7	333.3	339.2	330.0	314.4	313.7	
	Fattening Pig over 25 kg	1024.6	986.6	972.8	942.0	855.5	767.9	778.7	779.6	837.4	734.4	750.9	762.5	767.9	751.7	753.2	798.7	786.1	768.9	763.2	779.5	788.1	787.2	775.5	748.1	758.8	777.3	765.3	768.1		
	Fattening Sows	129.3	126.0	124.9	125.3	117.1	106.9	98.8	104.3	110.9	101.2	104.8	108.0	106.6	105.8	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	
	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	36.3	35.9	36.3	36.5	34.9	32.6	33.1	33.5	32.3	31.4	29.4	28.4	28.7	27.9	28.7		
	Boars	8.4	8.1	8.0	8.2	7.7	7.1	6.3	6.4	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	2.9	2.7	2.6	2.7		
	Buffalo		0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.5	0.6	0.7	0.8	0.7	0.8	0.8	0.7	0.9	0.9	0.8		
	Deer	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	
Bisons > 3 years		0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	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		
Llamas < 2 years		0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.4	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	6.6		
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	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.8	0.7	0.6	0.6	0.6	0.6	0.6	0.6		
Alpacas < 2 years		0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.3	0.5	0.5	0.7	0.7	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		
Alpacas > 2 years		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.1	0.1	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	0.8		
Fallow 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		
Red Deer		0.0	0.0	0.0	0.1	0.1	0.4	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	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		
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		
Horses																															
Mules and Asses	Horses < 3 years	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	53.5	56.1	57.7	59.0	60.2	62.1	57.2	58.0	57.2	57.2	55.5	55.7	55.5			
	Horses > 3 years	6.1	6.5	7.0	7.4	9.2	11.0	10.7	10.0	10.0	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			
	Mules and Asses	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		
	Mules	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		
	Asses	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	0.5	0.5	0.5	0.5	0.7	0.7	0.7	0.7	0.7		
	Poultry ¹⁾																														
	Growners	5938.2	5648.6	5501.6	6408.8	6330.3	6250.7	6440.5	6552.5	6739.6	6807.5	6983.0	6899.5	7338.6	7587.3	8060.7	8260.4	7670.2	8228.5	8542.8	8800.4	9024.9	9477.7	9954.6	10079.4	10234.3	10824.6	10984.2	11501.6		
	Layers	718.9	664.2	709.6	719.2	716.8	714.4	732.1	732.9	739.5	760.9	831.7	745.3	753.9	809.0	863.1	867.7	888.4	901.8	919.0	966.7	925.5	969.7	1075.6	1064.5	1195.6	1033.0	955.3	1084.0		
	Broilers	2019.9	2198.6	2095.5	2390.2	3101.6	3230.2	3393.2	3542.0	3502.3	3747.4	3807.8	3907.3	4296.2	4518.4	4970.8	5060.4	4481.3	5002.4	5302.9	5234.9	5456.2	5580.1	5984.1	6282.1	6360.3	6878.7	6878.3	7151.3		
	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	125.9	138.8	138.8	138.8	137.1	115.5	53.8	52.4	58.1	57.8	57.1	55.1	57.2	49.8	70.9	77.1		
Other Poultry	60.9	58.8	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	24.5	24.1	26.1	14.2	14.7	15.9	23.2	29.0	25.1	20.2	27.7	22.6	28.8			
Rabbits	27.9	28.6	25.3	23.9	24.0	20.6	82.1	94.9	93.8	95.6	93.8	94.8	91.7	91.8	86.1	85.7	82.4	79.8	85.5	90.0	91.4	99.2	111.7	107.3	105.6	112.4	105.3	103.5			
Livestock NCAC	Total Sheep	0.0	0.0	0.0	0.0	0.0	0.0	53.4	66.9	67.1	87.3	66.9	69.3	66.7	68.7	63.4	62.4	60.3	58.8	63.4	65.5	62.5	65.0	73.8	68.7	67.9	73.8	68.7	66.5		
	Fattening Sheep	0.0	0.0	0.0	0.0	0.0	0.0	26.7	33.3	33.1	34.8	34.0	34.5	34.8	32.1	31.4	30.1	30.0	33.1	34.6	33.2	36.5	43.7	39.7	42.2	39.1	42.2	37.8			
	Milksheep	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.4	0.6	0.8	0.9	0.9	0.9	0.9	0.7	0.6	0.5	0.6	0.6	0.7	0.6	0.4	0.3	0.4	0.3	0.3			
	Total Goats	0.0	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	14.8	13.6	12.9		
	Goat Places	0.0	0.0	0.0																											

Other Poultry: Geese, Ducks, Ostriches, Quails

Additional data for estimating CH₄ and N₂O emission from 3B Manure management

Table A – 20 Data for estimating manure management CH₄ 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	259 - 304	15.34 ^c	8.8 - 9.1	4.08 - 4.82	0.24
Other Mature Cattle	650	60	251	13.70 ^c	8	5.50	0.18
Fattening Calves	124	65	47	2.02 ^a	8	0.92	0.18
Pre-Weaned Calves	195	65	60	2.99 ^a	8	0.74	0.18
Breeding Calves	85	65	44	2.19 ^a	8	0.54	0.18
Breeding Cattle (4-12 months)	210	60	90	4.88 ^a	8	1.98	0.18
Breeding Cattle (> 1 year)	450	60	144	7.78 ^a	8	3.15	0.18
Fattening Calves (0-4 months)	115	65	57	3.00 ^a	8	0.97	0.18
Fattening Cattle (4-12 months)	361	60	126	6.84 ^a	8	2.77	0.18
Sheep	NA	60	21 - 24	1.08-1.24 ^c	8	0.40 ^b	0.19
Swine	NA	75	26 - 32	NA	2	0.32 ^{b#}	0.45
Buffalo	NA	55	129 - 147	7.00-7.96 ^c	8	3.25	0.10
Camels	NA	60 ^d	31 - 38	1.68-2.05 ^c	8	0.68	0.26
Deer	NA	60	51 - 60	2.74-3.24 ^c	8	1.29	0.19
Goats	NA	60	24 - 28	1.34-1.40 ^c	8	0.30 ^b	0.18
Horses	NA	70	107 - 108	7.73-7.88 ^c	4	1.90	0.33
Mules and Asses	NA	70	39 - 40	2.79-2.83 ^c	4	0.94 ^b	0.33
Poultry	NA	NA	1.1 - 1.6 ^e	NA	NA	0.01 ^{b#}	0.37 [#]
Rabbits	NA	NA	1.2	NA	NA	0.10 ^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

Annex 3: Other detailed methodological descriptions for individual source or sink categories

[illegible]

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					
	%				%				%				%				%				%					
	Liquid / Slurry	Pasture range and	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid manure	Paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid manure	Paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid manure	Paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid manure	Paddock	Digesters	Other (Deep litter, Poultry manure)		
Mature Dairy Cattle	63.6	27.6	8.3	0.5	0.0	65.6	24.5	9.5	0.4	0.0	65.2	16.3	18.0	0.5	0.0	67.2	13.7	17.7	1.4	0.0	66.7	14.5	16.9	2.0	0.0	
Mature Dairy Cattle	41.1	32.2	26.3	0.5	0.0	39.2	34.2	26.2	0.4	0.0	39.7	20.7	38.0	0.5	0.0	49.3	20.3	29.0	1.4	0.0	47.6	18.0	32.4	2.0	0.0	
Other Mature Cattle	47.4	31.8	15.7	0.5	4.5	48.4	30.9	15.8	0.4	4.5	42.1	25.5	27.3	0.5	4.6	45.3	24.0	24.7	1.4	4.7	44.5	25.0	22.7	2.0	5.8	
Growing Cattle (weighted average)	14.5	0.0	0.0	0.5	85.1	14.9	0.0	0.0	0.4	84.7	21.5	0.0	0.3	0.5	77.6	21.6	0.0	0.2	1.4	76.8	16.5	0.0	0.2	81.3	22.9	
Fattening Calves	41.1	32.2	26.3	0.5	0.0	39.2	34.2	26.2	0.4	0.0	41.2	21.0	37.3	0.5	0.0	49.8	18.7	30.1	1.4	0.0	44.3	32.9	20.9	2.0	0.0	
Pre-Weaned Calves	36.8	48.6	14.1	0.5	0.0	37.9	47.5	14.2	0.4	0.0	33.6	38.8	27.0	0.5	0.0	40.7	34.6	23.3	1.4	0.0	43.0	31.6	20.9	3.8	0.0	
Breeding Cattle 1st Year	45.2	29.0	25.4	0.5	0.0	47.2	26.8	25.6	0.4	0.0	37.7	33.4	38.4	0.5	0.0	41.2	20.9	36.5	1.4	0.0	42.8	20.9	34.3	2.0	0.0	
Breeding Cattle 2nd Year	50.4	29.1	20.0	0.5	0.0	51.3	28.0	20.3	0.4	0.0	47.1	22.5	34.8	0.5	0.0	46.4	21.4	31.8	1.4	0.0	45.9	21.6	30.6	2.0	0.0	
Breeding Cattle 3rd Year	70.0	24.1	0.0	0.5	5.5	66.3	27.7	0.0	0.4	5.6	67.3	26.8	2.2	0.5	3.2	62.1	29.0	4.3	1.4	3.2	57.3	32.9	4.0	2.0	3.9	
Fattening Cattle	0.0	30.1	0.0	69.9	0.0	0.0	30.3	0.0	69.7	0.0	0.0	33.2	0.0	66.8	0.0	0.0	33.3	0.0	66.7	0.0	0.0	33.7	0.0	66.3	0.0	63.0
Sheep (weighted average)	0.0	0.0	30.7	0.0	69.3	0.0	0.0	30.7	0.0	69.3	0.0	0.0	33.5	0.0	66.5	0.0	0.0	34.5	0.0	65.5	0.0	0.0	36.7	0.0	63.3	
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	33.5	0.0	66.5	0.0	0.0	34.5	0.0	65.5	0.0	0.0	36.7	0.0	63.3	
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	26.1	0.0	73.9	0.0	0.0	24.1	0.0	75.9	0.0	0.0	22.8	0.0	77.2	
Swine (weighted average)	98.6	0.0	0.0	1.4	0.0	98.5	0.0	0.0	1.5	0.0	97.3	0.3	0.1	2.2	0.0	92.0	0.1	1.2	6.6	0.0	90.6	0.3	0.1	9.0	0.0	
Piglets	98.6	0.0	0.0	1.4	0.0	98.5	0.0	0.0	1.5	0.0	96.9	0.8	0.0	2.2	0.0	92.3	0.7	0.4	6.6	0.0	88.7	2.3	0.0	9.0	0.0	
Fattening Pig over 25 kg	98.6	0.0	0.0	1.4	0.0	98.5	0.0	0.0	1.5	0.0	97.3	0.3	0.2	2.2	0.0	91.8	0.0	1.5	6.6	0.0	90.9	0.0	0.1	9.0	0.0	
Dry Sows	98.6	0.0	0.0	1.4	0.0	98.5	0.0	0.0	1.5	0.0	97.7	0.0	0.1	2.2	0.0	92.3	0.1	1.0	6.6	0.0	90.8	0.0	0.2	9.0	0.0	
Nursing Sows	98.6	0.0	0.0	1.4	0.0	98.5	0.0	0.0	1.5	0.0	97.1	0.7	0.0	2.2	0.0	92.5	0.5	0.3	6.6	0.0	90.9	0.2	0.0	9.0	0.0	
Bears	98.6	0.0	0.0	1.4	0.0	98.5	0.0	0.0	1.5	0.0	97.0	0.5	0.2	2.2	0.0	92.2	0.0	1.2	6.6	0.0	89.2	1.2	0.6	9.0	0.0	
Buffalo (weighted average)	NA	NA	NA	NA	NA	47.5	26.8	25.6	0.0	0.0	38.2	23.5	38.4	0.0	0.0	42.4	21.1	36.5	0.0	0.0	44.5	21.2	34.3	0.0	0.0	
Bisons < 3 years	45.6	29.0	25.4	0.0	0.0	47.5	26.8	25.6	0.0	0.0	38.2	23.5	38.4	0.0	0.0	42.4	21.1	36.5	0.0	0.0	44.5	21.2	34.3	0.0	0.0	
Bisons > 3 years	45.6	29.0	25.4	0.0	0.0	47.5	26.8	25.6	0.0	0.0	38.2	23.5	38.4	0.0	0.0	42.4	21.1	36.5	0.0	0.0	44.5	21.2	34.3	0.0	0.0	
Camels (weighted average)	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	
Lamas < 2 years	0.0	0.0	30.7	0.0	69.3	0.0	0.0	30.7	0.0	69.3	0.0	0.0	33.5	0.0	66.5	0.0	0.0	34.5	0.0	65.5	0.0	0.0	36.7	0.0	63.3	
Lamas > 2 years	0.0	0.0	30.7	0.0	69.3	0.0	0.0	30.7	0.0	69.3	0.0	0.0	33.5	0.0	66.5	0.0	0.0	34.5	0.0	65.5	0.0	0.0	36.7	0.0	63.3	
Alpacas < 2 years	0.0	0.0	30.7	0.0	69.3	0.0	0.0	30.7	0.0	69.3	0.0	0.0	33.5	0.0	66.5	0.0	0.0	34.5	0.0	65.5	0.0	0.0	36.7	0.0	63.3	
Alpacas > 2 years	0.0	0.0	30.7	0.0	69.3	0.0	0.0	30.7	0.0	69.3	0.0	0.0	33.5	0.0	66.5	0.0	0.0	34.5	0.0	65.5	0.0	0.0	36.7	0.0	63.3	
Deer (weighted average)	0.0	0.0	30.7	0.0	69.3	0.0	0.0	30.7	0.0	69.3	0.0	0.0	33.5	0.0	66.5	0.0	0.0	34.5	0.0	65.5	0.0	0.0	36.7	0.0	63.3	
Fallow Deer	0.0	0.0	30.7	0.0	69.3	0.0	0.0	30.7	0.0	69.3	0.0	0.0	33.5	0.0	66.5	0.0	0.0	34.5	0.0	65.5	0.0	0.0	36.7	0.0	63.3	
Red Deer	0.0	0.0	30.7	0.0	69.3	0.0	0.0	30.7	0.0	69.3	0.0	0.0	33.5	0.0	66.5	0.0	0.0	34.5	0.0	65.5	0.0	0.0	36.7	0.0	63.3	
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	12.2	0.0	87.8	0.0	0.0	10.0	0.0	90.0	0.0	0.0	11.6	0.0	88.4	
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	12.2	0.0	87.8	0.0	0.0	10.0	0.0	90.0	0.0	0.0	11.6	0.0	88.4	
Horses (weighted average)	0.0	93.2	6.8	0.0	0.0	0.0	93.2	6.8	0.0	0.0	0.0	76.1	23.9	0.0	0.0	78.7	21.3	0.0	0.0	0.0	74.4	25.6	0.0	0.0	0.0	
Horses < 3 years	0.0	93.2	6.8	0.0	0.0	0.0	93.2	6.8	0.0	0.0	0.0	61.8	38.2	0.0	0.0	61.7	38.3	0.0	0.0	0.0	66.4	33.6	0.0	0.0	0.0	
Horses > 3 years	0.0	93.2	6.8	0.0	0.0	0.0	93.2	6.8	0.0	0.0	0.0	79.3	20.7	0.0	0.0	81.9	18.1	0.0	0.0	0.0	75.6	24.4	0.0	0.0	0.0	
Mules and Asses (weighted average)	0.0	93.2	6.8	0.0	0.0	0.0	93.2	6.8	0.0	0.0	0.0	76.9	23.1	0.0	0.0	75.2	24.8	0.0	0.0	0.0	79.3	20.7	0.0	0.0	0.0	
Mules	0.0	93.2	6.8	0.0	0.0	0.0	93.2	6.8	0.0	0.0	0.0	76.9	23.1	0.0	0.0	75.2	24.8	0.0	0.0	0.0	79.3	20.7	0.0	0.0	0.0	
Asses	0.0	93.2	6.8	0.0	0.0	0.0	93.2	6.8	0.0	0.0	0.0	76.9	23.1	0.0	0.0	75.2	24.8	0.0	0.0	0.0	79.3	20.7	0.0	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	2.6	0.0	97.4	0.0	0.0	3.7	0.0	96.3	0.0	0.0	2.7	0.0	97.3	
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	0.2	0.0	99.8	0.0	0.0	1.5	0.0	98.5	0.0	0.0	1.2	0.0	98.8	
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	5.1	0.0	94.9	0.0	0.0	7.3	0.0	92.7	0.0	0.0	6.1	0.0	93.9	
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	0.6	0.0	99.4	0.0	0.0	1.2	0.0	98.8	0.0	0.0	0.3	0.0	99.7	
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	3.1	0.0	96.9	0.0	0.0	3.1	0.0	96.9	0.0	0.0	1.9	0.0	98.7	
Other Poultry *	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	3.1	0.0	96.9	0.0	0.0	1.2	0.0	98.8	
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	100.0	0.0	0.0	0.0	0.0	
Livestock NCAC (weighted average)	0.0	93.2	6.8	0.0	0.0	0.0	88.5	7.1	0.0	3.4	0.0	37.3	27.7	0.0	35.0	0.0	33.8	30.1	0.0	36.2	0.0	39.5	28.1	0.0	32.4	
Fattening Sheep Non-Agr.	0.0																									

* Other Poultry: Geese, Ducks, Ostriches, Quails

Annex 3: Other detailed methodological descriptions for individual source or sink categories

Mitrogen Excretion		kg N/head or place/year																													
		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		
Other Mature Cattle	Mature Dairy Cattle	1004	100.7	100.9	101.1	101.3	101.5	102.0	102.5	103.0	103.4	103.9	104.4	104.8	105.9	106.9	108.0	109.1	110.1	110.3	110.4	110.5	110.7	111.0	111.2	111.4	111.6	111.6	111.6	111.6	
	Other Mature Cattle	850	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	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	32.7	32.7	32.9	32.8	32.7	32.8	33.0	33.1	33.1	33.3	33.3	32.9		
	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	14.6	15.0	15.3	15.7	16.0	16.4	16.8	17.2	17.6	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	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	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	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	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	34.6	35.0	35.3	35.7	36.0	36.4	36.8	37.2	37.6	38.0	38.4	38.8	39.2	
	Sheep (weighted average)	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	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
Milke sheep		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	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	
Piglets		14.0	14.0	13.9	13.7	13.5	13.3	13.2	12.8	12.5	11.3	10.9	10.4	10.0	9.9	9.7	9.6	9.4	9.2	9.3	9.4	9.4	9.4	9.3	9.2	9.1	9.2	9.2	9.2	9.2	
Fattening Pig over 25 kg		18.2	18.1	18.0	18.0	17.9	17.8	17.7	16.6	16.6	15.5	14.9	14.3	13.7	13.4	13.2	12.9	12.6	12.3	12.4	12.5	12.6	12.4	12.2	12.0	11.8	11.6	11.6	11.6	11.6	
Dry Sows		22.6	22.6	22.6	22.6	22.6	22.6	22.1	21.7	21.2	20.8	20.3	19.9	19.4	19.5	19.6	19.7	19.7	19.8	19.9	20.0	20.1	21.0	22.0	23.0	24.0	25.0	25.0	25.0	25.0	
Nursing Sows		49.3	49.3	49.3	49.3	49.3	49.3	47.6	46.0	44.3	42.7	41.1	39.4	37.8	38.4	38.9	39.5	40.1	40.7	40.0	39.2	38.5	39.0	39.6	40.1	40.6	41.2	41.2	41.2	41.2	41.2
Boars		18.9	18.9	18.9	18.9	18.9	18.9	18.3	17.8	17.2	16.6	16.1	15.5	14.9	15.1	15.2	15.3	15.4	15.7	15.9	16.2	16.2	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	
Buffalo (weighted average)		NA	NA	36.5	37.8	37.1	37.3	37.1	37.3	37.1	37.3	34.9	41.1	37.5	38.8	37.4	38.5	38.7	38.0	34.9	34.4	38.5	37.3	38.4	36.9	36.9	36.4	36.4	36.4	35.9	35.9
		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	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	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
	Cannels (weighted average)	NA	NA	NA	NA	NA	NA	15.3	15.3	14.0	14.1	13.0	13.3	13.7	13.3	13.3	12.8	12.8	12.8	12.8	12.8	12.6	12.7	12.8	12.8	12.7	12.6	12.6	12.6	12.6	
	Lamas < 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	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	
	Lamas > 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	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	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	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)	NA	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	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
		Fallow 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	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
Red Deer		11.2	11.2	11.2	11.2	11.1	11.1	11.1	11.1	11.1	11.2	11.3	11.3	11.4	11.1	11.3	11.1	11.1	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
Goat Places		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	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.8	43.8	43.8	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	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	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	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	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	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)		NA	0.6	0.6	0.6	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	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	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	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	
	Turkeys	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	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	
	Broilers	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	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 *	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	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	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)	NA	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8
		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	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
		Milke sheep 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	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	NA	12.0	11.2	11.0	11.1	11.8	11.2	11.4	11.2	11.1	11.2	11.6	11.2	10.9	11.1	10.8	10.7	11.8	11.9	12.0	11.5	11.4	11.4	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	42.0	42.0	42.0												

Asses/vul=Agri.

Additional data for estimating N₂O emissions from 3D Agricultural soils

Table A – 24 Additional data for estimating N₂O emission from crop residues.

2017		Total crop production t DM	Nitrogen incorporated with crop residues F _(CR) t N	N ₂ O emissions from crop residues t N ₂ O
1. Cereals	Wheat	433'122	1'815	28.51
	Barley	174'906	892	14.01
	Maize	138'086	1'300	20.42
	Oats	8'679	54	0.85
	Rye	10'560	45	0.70
	Other:			
	Triticale	43'710	214	3.37
	Spelt	17'252	158	2.48
	Mix of Fodder Cereals	1'099	6	0.09
	Mix of Bread Cereals	64	0	0.00
	Millet	147	4	0.06
2. Pulse	Dry Beans	2'570	102	1.60
	Peas (Eiweisserbsen)	12'207	359	5.64
	Soybeans	4'796	197	3.10
	Leguminous Vegetables	2'988	311	4.89
	Lupines	315	13	0.20
3. Tuber and Root	Potatoes	98'838	361	5.67
	Other:			
	Fodder Beet	8'128	59	0.92
	Sugar Beet	339'852	2'425	38.11
5. Other	Fruit	32'996	308	4.84
	Grass	5'846'708'878	26'813	421.34
	Green Corn	121'083	115	1.81
	Non-Leguminous Vegetables	59'479	703	11.05
	Rape	69'851	1'197	18.82
	Renewable Energy Crops	855	15	0.23
	Silage Corn	712'255	420	6.59
	Sunflowers	13'982	296	4.65
	Tobacco	1'147	30	0.47
	Berries	2'334	41	0.64
	Vine	20'073	351	5.52
	Oil Squash	6	0	0.00
	Oil Hemp	23	1	0.02
	Oil Flax	364	3	0.05
	Hops	19	0	0.00
	Medicinal Plants and Herbs	374	31	0.48
Total Non-leguminous		2'309'285	10'842	170.37
Total Leguminous		22'876	983	15.44
Total excluding grass		2'332'161	11'825	185.82
Total including grass		5'849'041'039	38'637	607.16

Table A – 25 Additional data for estimating N₂O emission from crop residues (fractions).

2017		Residue/ Crop ratio kg/kg	Dry matter fraction of residue kg/kg	Nitrogen content of residues 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	0.0204
	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 NH₃ and NO_x emission factors for 3Db Indirect N₂O 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
		%																											
NH ₃ from application of animal manure N (F _{RC,MAN})		24.28	24.20	24.27	24.21	24.26	24.31	23.97	23.62	23.27	22.91	22.58	22.25	21.86	22.03	22.22	22.42	22.68	22.90	22.38	21.75	21.16	20.99	20.78	20.60	20.42	20.25	20.23	20.21
Mature Dairy Cattle		26.69	26.71	26.73	26.75	26.76	26.78	26.52	26.25	25.98	25.69	25.40	25.10	24.78	24.96	25.13	25.30	25.47	25.63	25.00	24.38	23.76	23.44	23.12	22.80	22.49	22.18	22.18	22.16
Other Mature Cattle		24.16	24.06	23.97	23.87	23.78	23.68	23.35	22.96	22.61	22.23	21.76	21.29	20.78	21.44	22.07	22.65	23.20	23.72	23.31	22.88	22.45	22.28	22.11	21.94	21.77	21.60	21.60	21.60
Growing Cattle (weighted average)		24.47	24.46	24.45	24.47	24.52	24.54	24.16	23.82	23.40	22.93	22.60	22.10	21.62	22.03	22.42	22.80	23.19	23.57	23.02	22.47	21.92	21.73	21.57	21.38	21.19	21.01	21.01	21.01
Sheep (weighted average)		3.73	3.86	3.99	4.12	4.26	4.39	4.34	4.28	4.23	4.17	4.11	4.05	3.99	4.38	4.78	5.19	5.61	6.04	5.86	5.69	5.54	5.40	5.26	5.12	4.96	4.81	4.81	4.81
Swine (weighted average)		21.52	21.42	21.32	21.22	21.12	21.02	20.82	20.61	20.37	20.10	19.81	19.47	19.10	19.34	19.58	19.84	20.09	20.38	19.77	19.17	18.57	18.67	18.77	18.85	18.95	19.06	19.06	19.07
Buffalo (weighted average)		NA	NA	25.24	25.29	25.33	25.38	25.11	24.81	24.49	24.16	23.79	23.40	22.99	23.34	24.05	24.40	24.70	24.92	24.07	23.40	22.75	22.50	22.24	21.99	21.73	21.48	21.48	21.48
Camels (weighted average)		3.72	3.85	3.99	4.12	4.25	4.38	4.33	4.29	4.24	4.19	4.14	4.09	4.04	4.44	4.85	5.28	5.72	6.18	5.94	5.71	5.50	5.39	5.27	5.16	5.04	4.92	4.92	4.92
Deer (weighted average)		3.72	3.85	3.99	4.12	4.25	4.38	4.33	4.29	4.24	4.19	4.14	4.09	4.04	4.44	4.85	5.28	5.72	6.18	5.94	5.71	5.50	5.39	5.27	5.16	5.04	4.92	4.92	4.92
Goats		3.83	3.97	4.10	4.24	4.37	4.51	4.39	4.27	4.15	4.03	3.91	3.79	3.68	4.66	5.99	7.06	8.09	9.07	7.72	6.31	4.82	5.02	5.23	5.44	5.65	5.86	5.86	5.86
Horses (weighted average)		3.75	3.88	4.01	4.15	4.28	4.41	4.29	4.16	4.01	3.86	3.70	3.53	3.34	3.55	3.75	3.96	4.16	4.36	4.50	4.65	4.80	4.87	4.95	5.02	5.10	5.18	5.19	5.19
Mules and Asses (weighted average)		3.75	3.88	4.01	4.15	4.28	4.41	4.29	4.16	4.01	3.86	3.70	3.53	3.34	3.55	3.75	3.96	4.16	4.36	4.50	4.65	4.80	4.87	4.95	5.02	5.10	5.18	5.19	5.19
Poultry (weighted average)		13.04	13.53	14.02	14.51	14.99	15.47	15.14	14.82	14.49	14.16	13.81	13.49	13.18	12.86	12.55	12.30	12.12	11.79	12.40	13.11	13.83	14.04	14.27	14.51	14.76	15.03	14.99	14.99
Rabbits		9.66	9.66	9.66	9.66	9.66	9.59	9.52	9.44	9.37	9.29	9.22	9.14	9.12	9.09	9.06	9.03	9.00	9.07	9.14	9.21	9.21	9.21	9.21	9.21	9.21	9.21	9.21	9.21
Livestock NCAC (weighted average)		3.75	3.88	4.01	4.15	4.28	4.42	4.30	4.19	4.08	3.97	3.84	3.73	3.60	3.99	4.40	4.89	5.28	5.65	5.59	5.33	5.19	5.17	5.16	5.14	5.13	5.13	5.13	5.13
NH ₃ from urine and dung N deposited on PR&P (F _{RC,MAN})		4.65	4.66	4.67	4.68	4.69	4.69	4.72	4.74	4.76	4.78	4.78	4.78	4.79	4.82	4.86	4.90	4.92	4.95	4.91	4.87	4.84	4.85	4.86	4.87	4.88	4.90	4.92	4.94
Mature Dairy Cattle		4.67	4.67	4.66	4.66	4.66	4.65	4.65	4.64	4.64	4.64	4.64	4.63	4.63	4.63	4.62	4.61	4.61	4.60	4.60	4.59	4.59	4.59	4.59	4.59	4.59	4.59	4.59	4.59
Other Mature Cattle		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	4.57	4.57	4.57
Growing Cattle (weighted average)		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	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
Swine (weighted average)		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
Buffalo (weighted average)		NA	NA	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	4.56	4.56	4.56	4.56	4.56	4.57	4.56	4.56	4.56	4.56	4.56	4.56
Camels (weighted average)		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
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
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
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
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
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	42.10	42.15	42.20	42.24	42.22	42.22
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
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
NH ₃ from commercial fertiliser N (F _{RC,MAN})		6.18	5.61	5.63	5.85	6.04	6.05	6.04	5.80	5.37	5.39	5.42	4.98	4.98	4.67	4.82	4.67	4.46	4.84	4.69	4.38	4.71	4.80	4.85	5.07	5.24	5.61	5.52	5.44
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	13.10	13.10
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	3.12	3.07	2.99	3.11	3.12	3.04	3.37	2.82	2.82
Recycling Fertilisers (weighted average)		17.60	18.12	18.63	19.17	19.60	19.97	19.78	19.70	19.61	19.21	18.81	17.67	15.96	15.06	14.20	13.52	12.96	12.06	10.76	9.35	9.68	10.10	10.70	11.04	11.29	11.54	11.80	11.92
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
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
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
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
NO _x from applied fertilisers (F _{RC,NOX})		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 (F _{RC,NOX})		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 N₂O emission from managed soils.

Nitrogen pools and flows		1990-2003														2004-2017	
		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Deposition	Animals manure N applied to soils	111'980	110'280	107'753	105'620	104'588	102'268	100'121	95'616	93'207	88'918	86'098	84'710	82'070	81'272	80'708	82'187
	Commercial fertiliser	75'085	75'390	75'318	70'487	68'846	67'018	64'629	58'402	56'433	58'841	57'969	61'422	59'352	56'512	56'740	55'425
	Sum volatilised N (NH ₃ and NO _x)	33'559	32'747	32'120	31'374	31'102	30'588	29'651	27'599	26'527	25'367	24'510	23'934	22'986	22'602	22'705	23'074
	NH ₃ emissions from commercial fertilisers	4'644	4'229	4'242	4'120	4'037	4'058	3'906	3'271	3'031	3'158	3'142	3'057	2'963	2'940	2'735	2'590
	NH ₃ emissions from applied animal manure	27'188	26'784	26'154	25'572	25'395	24'864	23'997	22'582	21'684	20'374	19'440	18'847	17'938	17'905	17'930	18'426
	NH ₃ emissions from pasture, range and paddock	625	637	642	639	652	658	754	815	877	918	1'018	1'099	1'173	1'166	1'153	1'169
	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	616	607	593	581	575	562	526	526	513	489	474	466	451	447	444	452
	NO _x emissions from PR&P	74	75	76	75	76	77	88	95	101	106	117	127	135	133	131	132
	Sum leaching and run-off	50'377	49'338	48'819	50'631	49'030	49'054	45'710	43'137	43'245	41'000	45'734	43'932	41'787	38'536	38'288	40'739
Leaching and run-off	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	11'852	11'411	11'978	11'464	10'811	10'751	10'399
	Leaching and run-off from applied animal manure	23'077	22'727	22'206	21'766	21'554	21'076	20'448	19'352	18'692	17'668	16'949	16'519	15'853	15'549	15'292	15'420
	Leaching and run-off from pasture, range and paddock	2'767	2'816	2'832	2'813	2'866	2'892	3'263	3'483	3'700	3'818	4'195	4'487	4'728	4'626	4'499	4'481
	Leaching and run-off from crop residues	8'150	8'038	8'038	7'981	7'803	7'803	8'040	7'884	7'944	7'593	7'835	7'439	7'538	7'139	7'455	7'257
	Leaching and run-off from mineralisation of SOM	910	222	220	3'545	3'032	3'471	258	1'003	1'592	270	5'343	3'509	2'204	411	292	3'181
	Animals manure N applied to soils	111'980	110'280	107'753	105'620	104'588	102'268	100'121	95'616	93'207	88'918	86'098	84'710	82'070	81'272	80'708	82'187
	Commercial fertiliser	75'085	75'390	75'318	70'487	68'846	67'018	64'629	58'402	56'433	58'841	57'969	61'422	59'352	56'512	56'740	55'425
	Sum volatilised N (NH ₃ and NO _x)	33'559	32'747	32'120	31'374	31'102	30'588	29'651	27'599	26'527	25'367	24'510	23'934	22'986	22'602	22'705	23'074
	NH ₃ emissions from commercial fertilisers	4'644	4'229	4'242	4'120	4'037	4'058	3'906	3'271	3'031	3'158	3'142	3'057	2'963	2'940	2'735	2'590
	NH ₃ emissions from applied animal manure	27'188	26'784	26'154	25'572	25'395	24'864	23'997	22'582	21'684	20'374	19'440	18'847	17'938	17'905	17'930	18'426
Leaching and run-off	NH ₃ emissions from pasture, range and paddock	625	637	642	639	652	658	754	815	877	918	1'018	1'099	1'173	1'166	1'153	1'169
	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	616	607	593	581	575	562	526	526	513	489	474	466	451	447	444	452
	NO _x emissions from PR&P	74	75	76	75	76	77	88	95	101	106	117	127	135	133	131	132
	Sum leaching and run-off	50'377	49'338	48'819	50'631	49'030	49'054	45'710	43'137	43'245	41'000	45'734	43'932	41'787	38'536	38'288	40'739
	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	11'852	11'411	11'978	11'464	10'811	10'751	10'399
	Leaching and run-off from applied animal manure	23'077	22'727	22'206	21'766	21'554	21'076	20'448	19'352	18'692	17'668	16'949	16'519	15'853	15'549	15'292	15'420
	Leaching and run-off from pasture, range and paddock	2'767	2'816	2'832	2'813	2'866	2'892	3'263	3'483	3'700	3'818	4'195	4'487	4'728	4'626	4'499	4'481
	Leaching and run-off from crop residues	8'150	8'038	8'038	7'981	7'803	7'803	8'040	7'884	7'944	7'593	7'835	7'439	7'538	7'139	7'455	7'257
	Leaching and run-off from mineralisation of SOM	910	222	220	3'545	3'032	3'471	258	1'003	1'592	270	5'343	3'509	2'204	411	292	3'181

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 2017 as published by the Swiss Federal Office of Energy (SFOE 2018). Diagram languages are German and French. The energy balance is also provided in tabular form in Table A – 28.

Fig. 5 Detailliertes Energieflussdiagramm der Schweiz 2017 (In TJ)
Flux énergétique détaillé de la Suisse en 2017 (en TJ)

BFE, Schweizerische Gesamtenergiestatistik 2017 (Fig. 5)
OFEN, Statistique globale suisse de l'énergie 2017 (fig. 5)

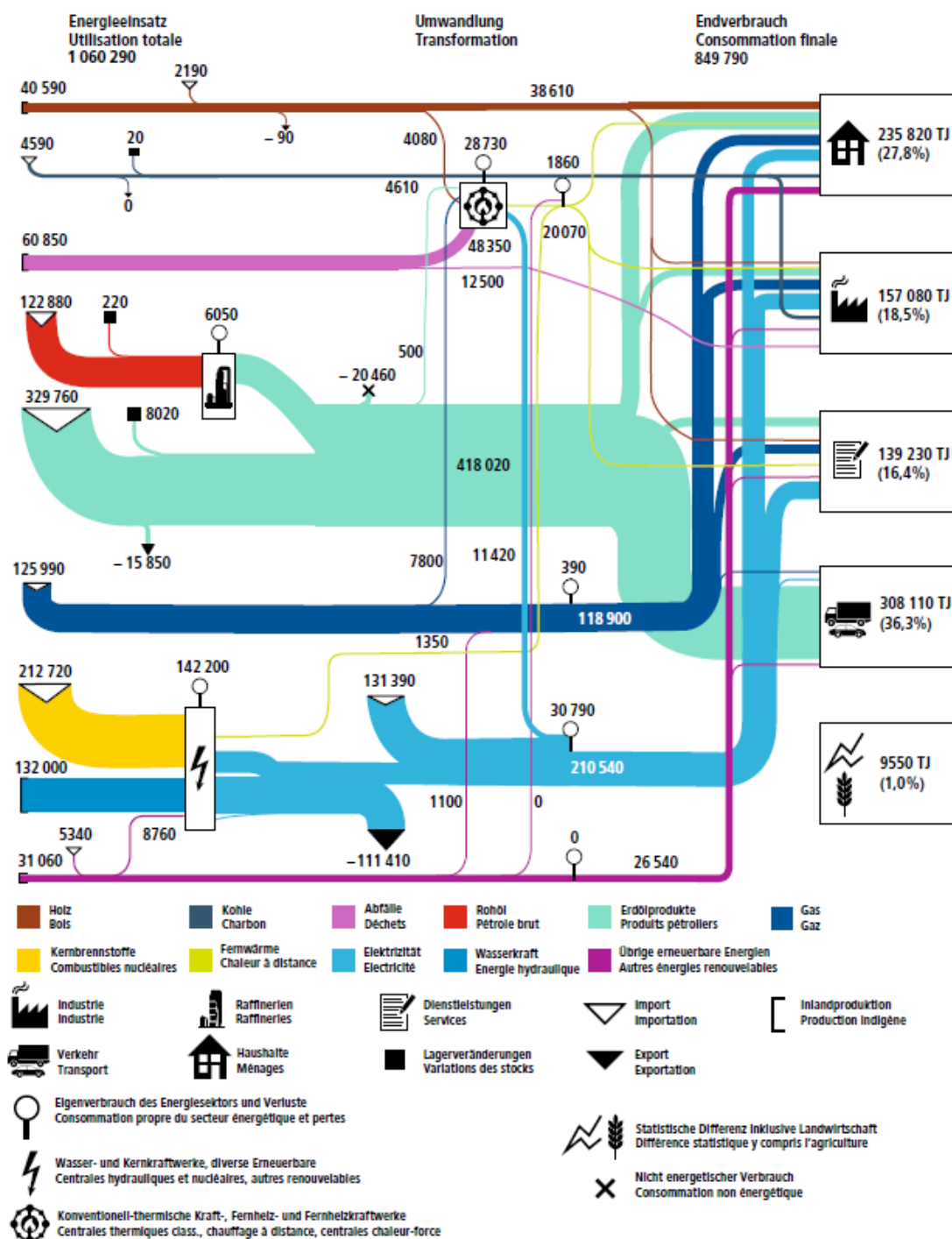


Figure A – 2 Energy flow in Switzerland 2017 in TJ (SFOE 2018)

Table A – 28 Switzerland's energy balance 2017 (SFOE 2018) in TJ¹⁴.[illegible]

A4.2 Differences between 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

¹⁴ Liechtenstein's consumption of liquid fuels is included in the numbers (see chapter below on Final Swiss energy consumption).

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 GHG 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 – 29 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 – 29. 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 and gas oil

The IEA numbers include diesel 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 UNFCCC. 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 (LPG)

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 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 – 29 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.		Consumption	
Gg	IEA	CRF	IEA	CRF	IEA	CRF	IEA	CRF	IEA	CRF	IEA	CRF
Crude oil	4'488	4'546					0	1	0		4'488	4'547
Refinery feedstocks	3						1		2		6	
Additives/blending components	51						-1		2		52	
											4'546	4'547
Motor gasoline	1'850	1'838					-9	-6	4	15	1'830	1'832
Aviation gasoline	7						-2		-1		4	
Kerosene type jet fuel	1'354	1'362			-1'367	-1'352		2	6		-7	12
Other Kerosene	3										3	
											0	12
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		-300	-299
Liquefied petroleum gases (LPG)	50	54	-24	-25						0.1	26	29
White spirit & SBP	7								-1		6	
											32	29
Bitumen	317	318	-2	-2							315	317
Lubricants	86	72	-38	-16					7		55	56
Petroleum coke	73	47									73	47
Naphtha	1						5		-1		5	
Paraffin waxes	1										1	
Non-specified oil products / other oil	4	63	-	-23			-	-6			4	33
											10	33
Liquid fuels											11'039	11'052
Anthracite	7										7	
Other bituminous coal	123	152					36	32			159	184
Lignite	66	62					-4				62	62
Coke oven coke	18										18	
Solid fuels											246	246
Natural gas (TJ, NCV)	126'014	125'627									126'014	125'627
Fugitive emissions (TJ, NCV)		389										389
Gaseous fuels											126'014	126'016

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 Table 1.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 National Swiss 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 asl). These measurements are used for estimating emissions of fluorinated greenhouse gases (HFCs, SF₆) 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 HFC and SF₆, 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 HFCs and SF₆ emissions, only observations at the high-Alpine station Jungfraujoch are evaluated, which reflect 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 trajectories 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 HFCs and SF₆ 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 centered 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 SF₆, with comparably low emissions and a higher degree of uncertainty, a 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.

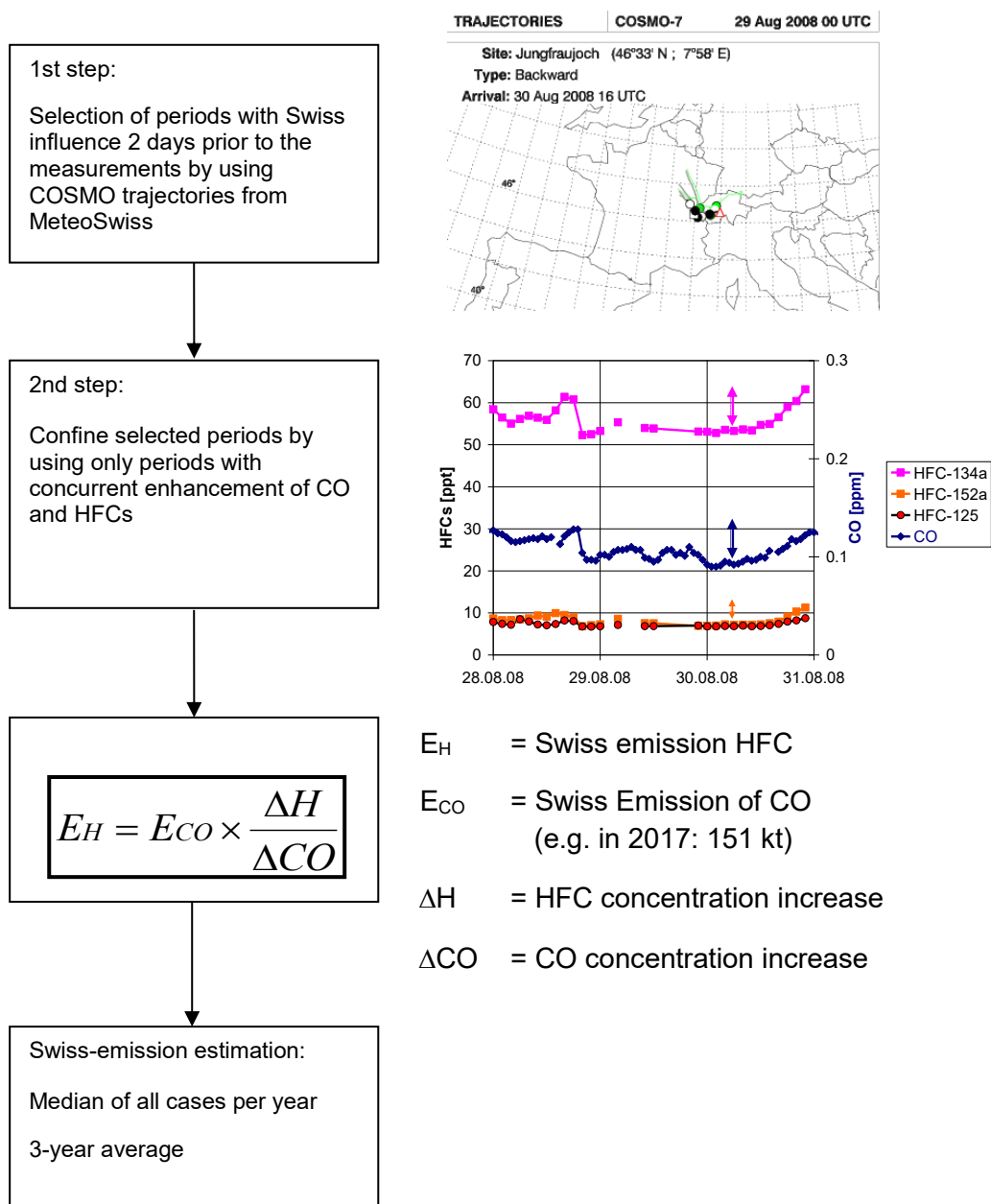


Figure A – 3 Description of the procedure to estimate annual emissions of HFCs from Switzerland by using continuous measurements of HFCs at Jungfraujoch (Switzerland).

Results and discussion

In the following, Swiss emissions of five HFCs (HFC-134a, HFC-125, HFC-152a, HFC-143a, HFC-32) and of SF₆ 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 as propellant, as tracer gas in research and in cooling mixtures in the industrial and commercial refrigeration as well as in stationary air conditioners and heat pumps. The stock of HFC-134a in MACs and the related emissions have been steadily increasing until 2016. In most recent years numbers are declining due to the replacement of HFC-134a in this application. After 2007 both the emission 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 2010 until around 2013, whereas the measurement-based estimate shows no clear trend. Overall, the agreement between the two methods was excellent from 2001 – 2007; while a discrepancy of ca. 40% is observed since 2012 (Figure A – 4).

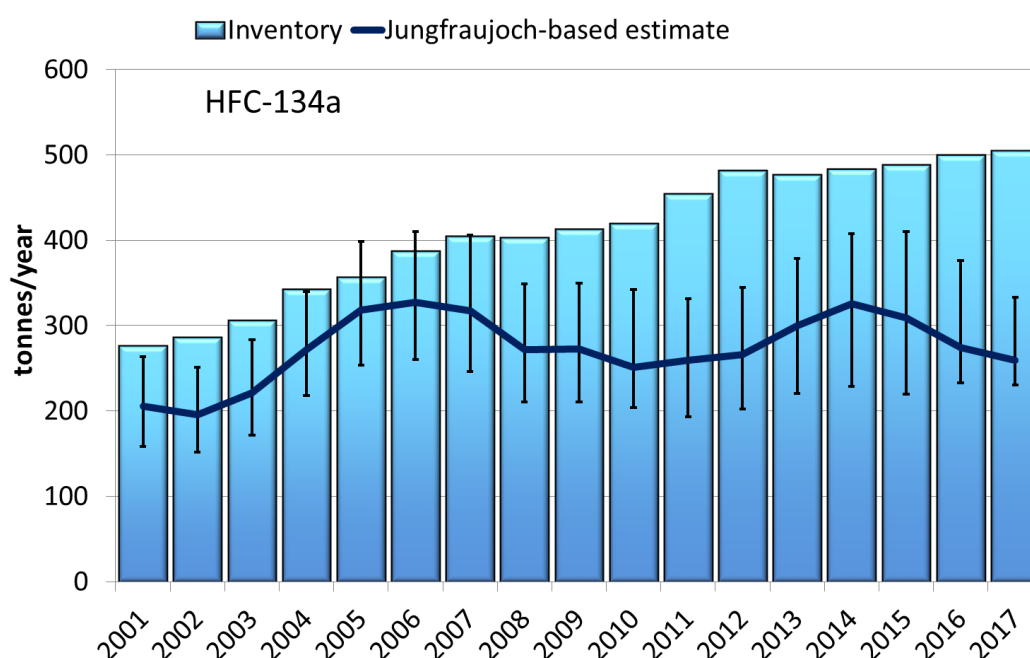


Figure A – 4 Comparison of HFC-134a emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

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 lower than in the inventory but, especially in recent years, both methods agree well within their uncertainties (Figure A – 5).

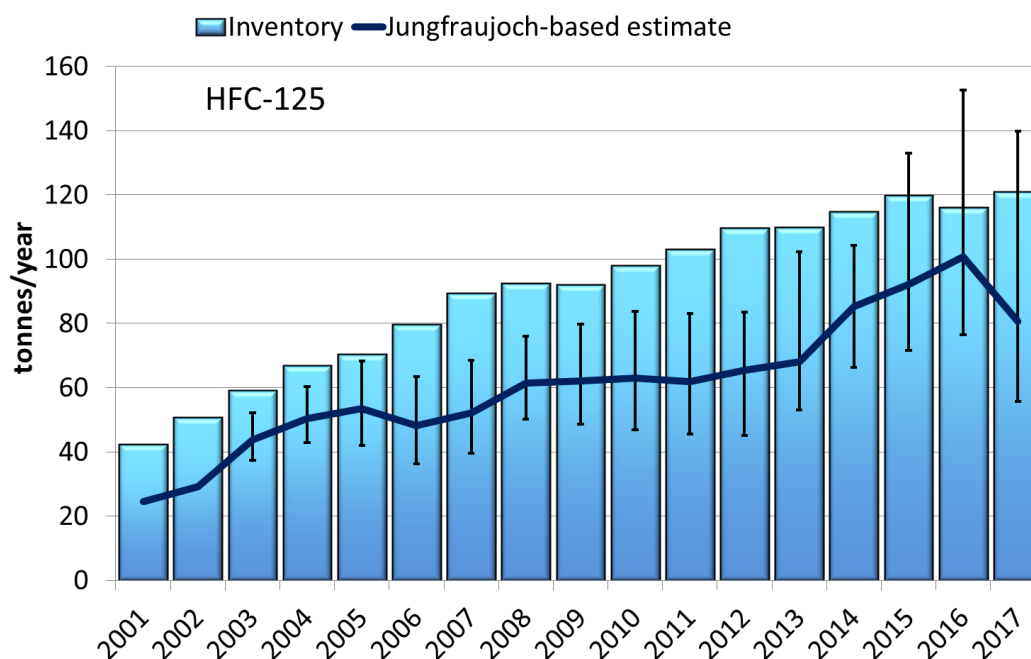


Figure A – 5 Comparison of HFC-125 emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

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 inventory¹⁵. 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).

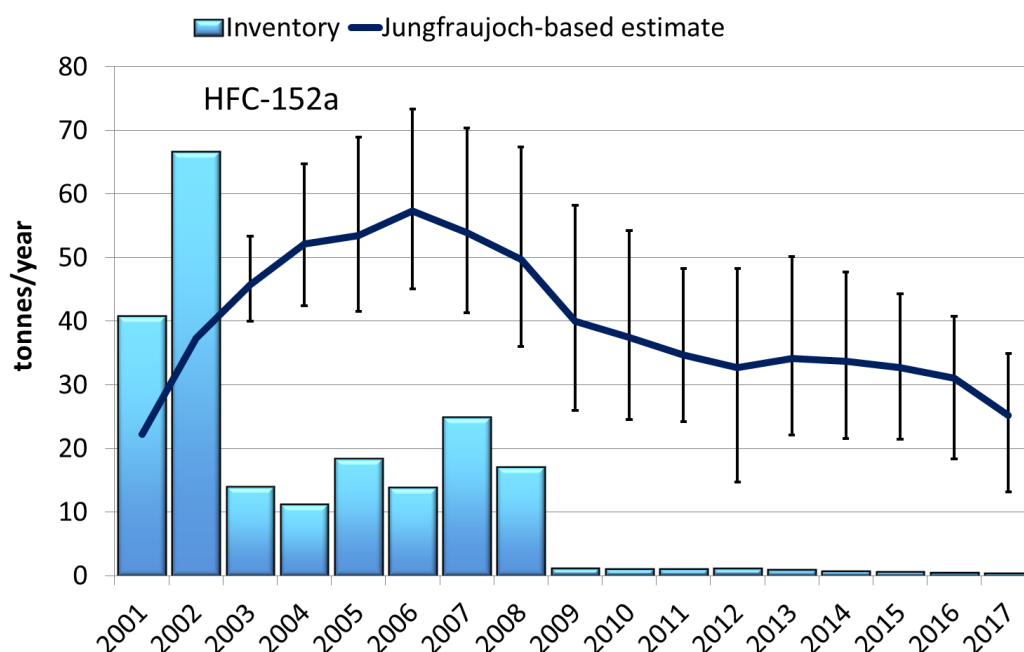


Figure A – 6 Comparison of HFC-152a emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

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. Since 2014, there is a very good agreement between the two methods and a slight decrease in emissions in most recent years, which is seen by both methods. A similar trend can also be seen in measurement-based estimated HFC-125 emissions (see Figure A – 5).

The measurement-based estimates of HFC-32 are consistently lower (by about 40%) than the data from the inventory, however the systematic increase throughout the whole observation period is well captured by both methods. In contrast to HFC-125 and HFC-143a, emissions of HFC-32 do not decrease in most recent years. 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.

¹⁵ 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.

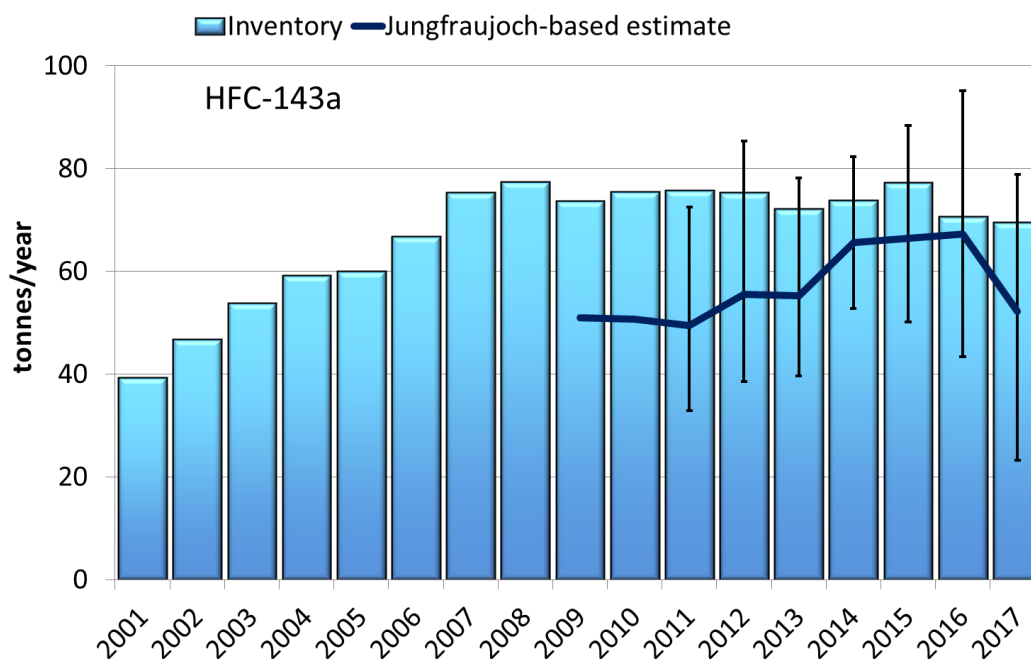


Figure A – 7 Comparison of HFC-143a emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

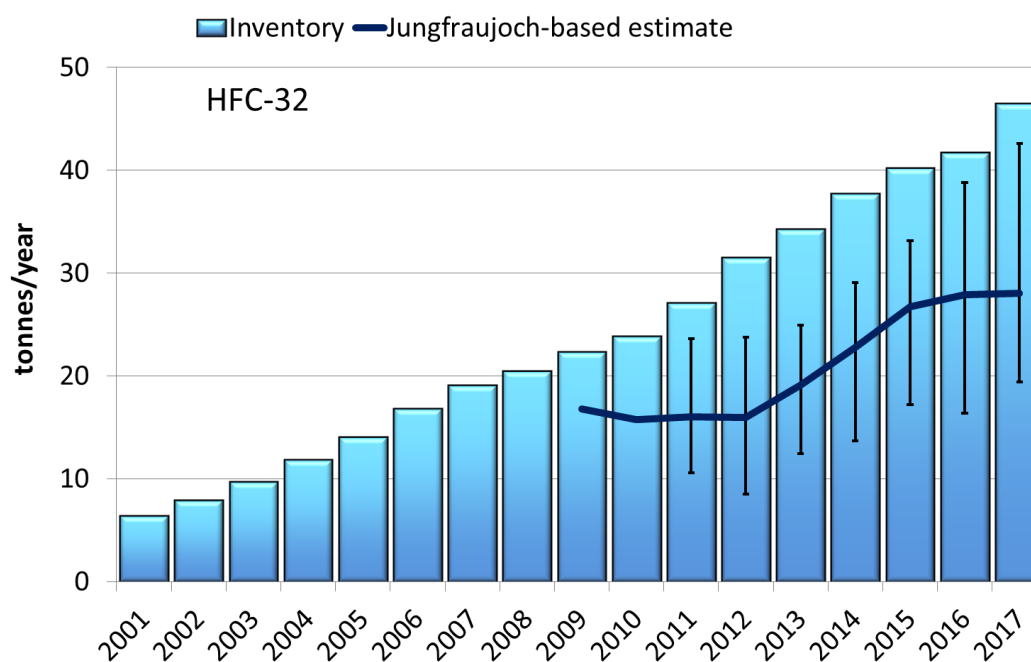


Figure A – 8 Comparison of HFC-32 emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

Sulfur hexafluoride (SF₆)

Until 2010, emissions of SF₆ 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. Emission estimates for both methods show a remarkable similarity in the trend, except for the 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 SF₆ emissions were estimated between 2010 and 2015 and could be the result of the increased disposal of insulating windows (all SF₆ released) during this period. Since then, the inventory assumes decreasing emissions, which seems to be confirmed by observations (Figure A – 9).

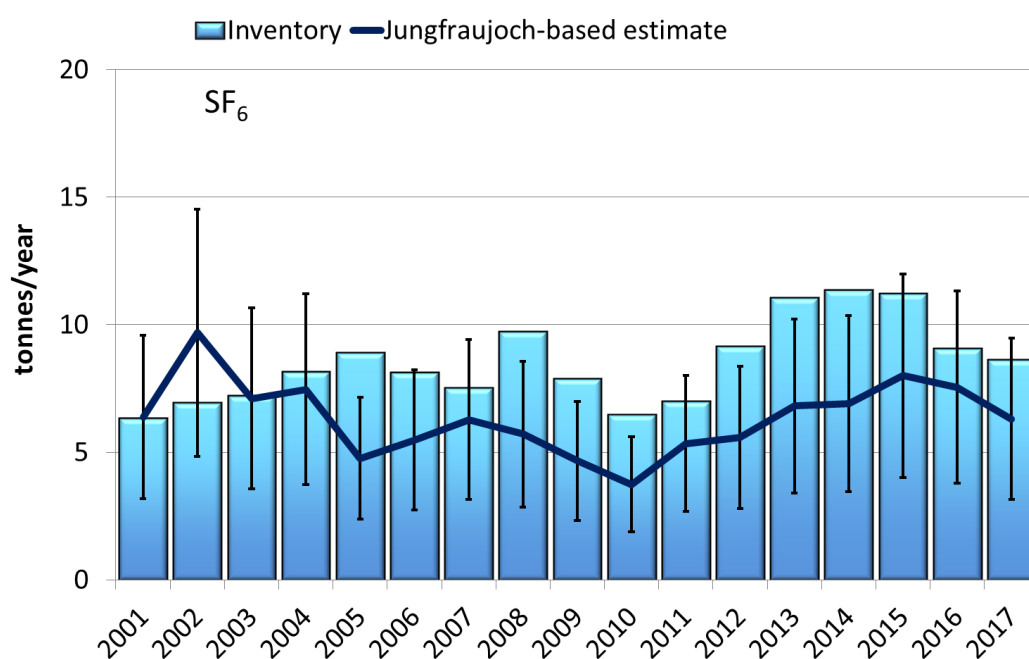


Figure A – 9 Comparison of SF₆ emissions from Switzerland: Inventory and estimates from measurements at Jungfrauoch.

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 Zürich 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 consists of four sites that continuously measure the atmospheric concentration of carbon dioxide (CO₂) and methane (CH₄). 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 2019), 3 of the 4 sites (Beromünster, Lägern-Hochwacht, Gimmiz) are still operational, whereas the measurements

at Frübüel 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 analyze 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 Jungfrauoch (Empa) and Schauinsland (Germany, UBA, mountain top).

Furthermore, high precision measurements of N₂O commenced in March 2017 at the tall tower site Beromünster. Together with N₂O observations from Jungfrauoch and Schauinsland for the first time these measurements allow the estimate of Swiss N₂O emissions by inverse modelling similar to CH₄.

Here, the results of inverse modelling to validate total Swiss CH₄ and N₂O emissions are reported. A previous analysis was 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 some questions regarding the spatial and temporal distribution of the emissions and the sensitivity to boundary conditions (i.e., CH₄ 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 the previous NIR (FOEN 2018). Here, results for CH₄ are given for the period 2013 to 2017, whereas for N₂O for the first time inverse modelling results are given for a period in 2017/2018.

Methods

The inversion approach applied here was described in detail in Henne et al. (2016). It is based on so called 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). 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 combining source sensitivities with a map of 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 modeling” an optimized (*a posteriori*) emission distribution within and around Switzerland 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 to the total concentration. Additional tests including this baseline concentration from global-scale CH₄ models are discussed at the end of this annex.

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 *a priori* emissions for Switzerland the MAIOLICA CH₄ 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 CH₄ 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 CH₄ also was applied to N₂O for the period March 2017 to April 2018 (Henne et al. 2019). In addition to the grid-resolved inversion used for CH₄, an additional sector-based inversion system was set-up for N₂O, allowing for the distinction between emissions from different source sectors, but at a reduced spatial resolution. *A priori* emissions for the N₂O 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).

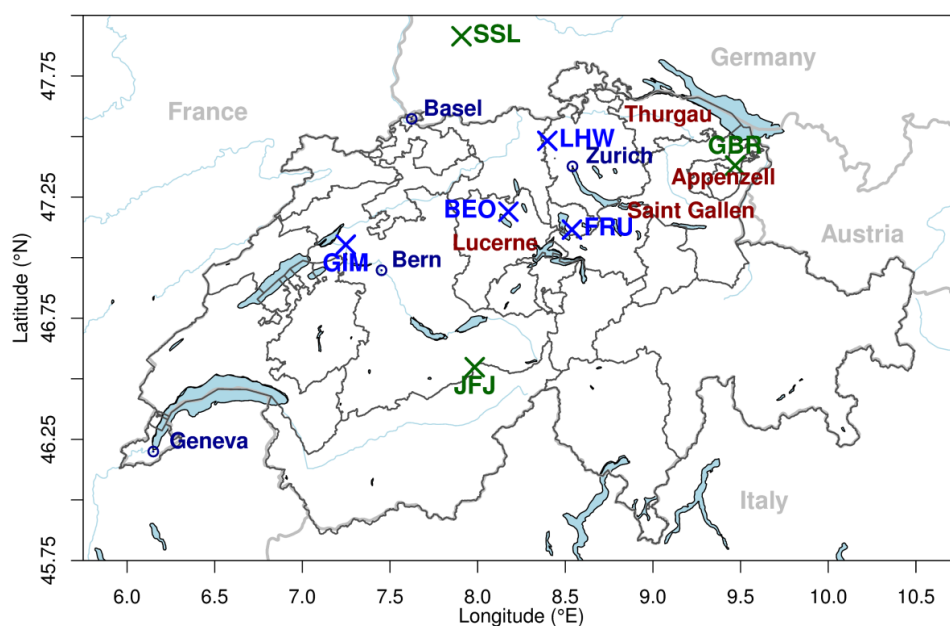


Figure A – 10: Map of Switzerland illustrating the location of CarboCount-CH sites (blue), supplementary sites (green), cantonal borders (gray), major cities (dark blue), and selected canton names (red). The sites are: Beromünster (tall tower, BEO), Lägern Hochwacht (mountain top, tower, LHW), Gimmiz (flat, tower, GIM), Fröhlebühl (mountain, near surface, FRU), Gäbris (mountain top, GBR), Schauinsland (mountain top, SSL), and Jungfrauoch (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 CH₄ emissions for the period 2013 to 2017 was 201 ± 16 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 in very close agreement with the NIR values reported in submission 2019 for the same period, which decreased from 200 to 194 kt yr⁻¹ (CRF Table 10s3) with a 1- σ uncertainty range of ± 18 kt yr⁻¹ for the reporting year 2017.

For the mentioned period, the NIR suggests a minor CH₄ emission reduction of 5.5 kt, whereas the inversion estimates showed larger inter-annual variability: 199 ± 17 , 204 ± 11 , 213 ± 14 , 191 ± 21 kt yr⁻¹ and 195 ± 11 kt yr⁻¹ for the years 2013 to 2017 (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.

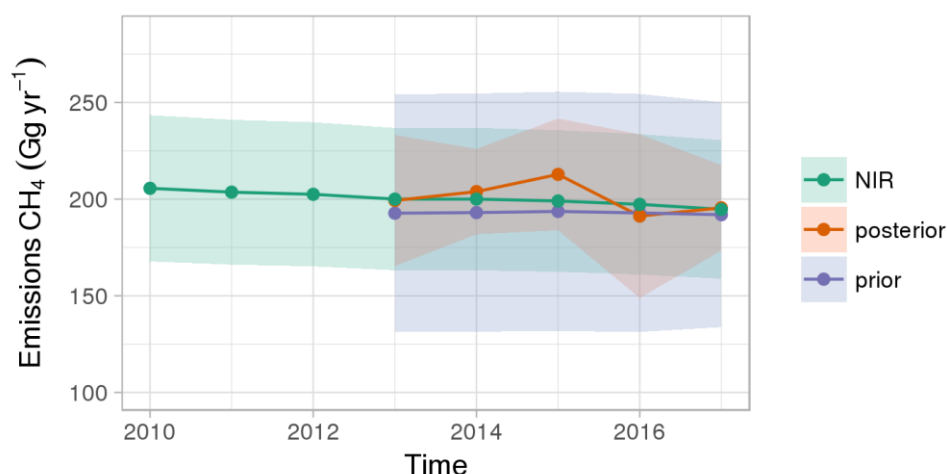


Figure A – 11: Time series of total Swiss CH₄ emissions as reported in the present NIR (green), used as *a priori* information in the inverse modelling (purple), and as estimated by the inverse modelling (*a posteriori*, orange). The uncertainty ribbons give the 95% confidence (2 σ) level of all values.

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 waste water treatment reported in the NIR.

The *a posteriori* results for the five analyzed years 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. The possible

reasons for this emission maximum are discussed below along with the use of additional observations from this area.

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 our 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.

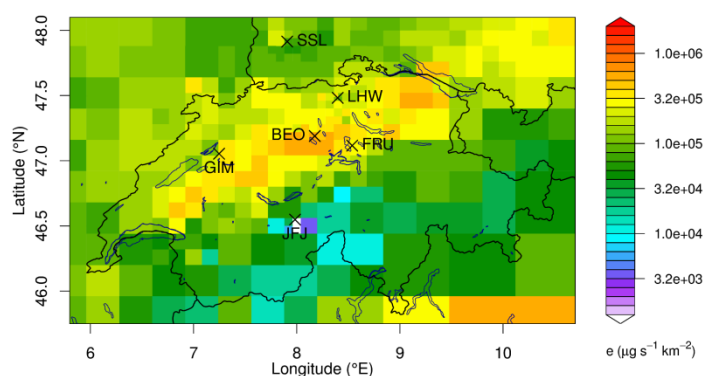


Figure A – 12: Spatial distribution of *a priori* emissions. Within Switzerland the distribution follows that derived by Hiller et al. (2014), scaled to the bottom-up estimates of the NIR (2016), outside Switzerland the bottom-up inventory of TNO/MACC (Kuenen et al., 2014) was used.

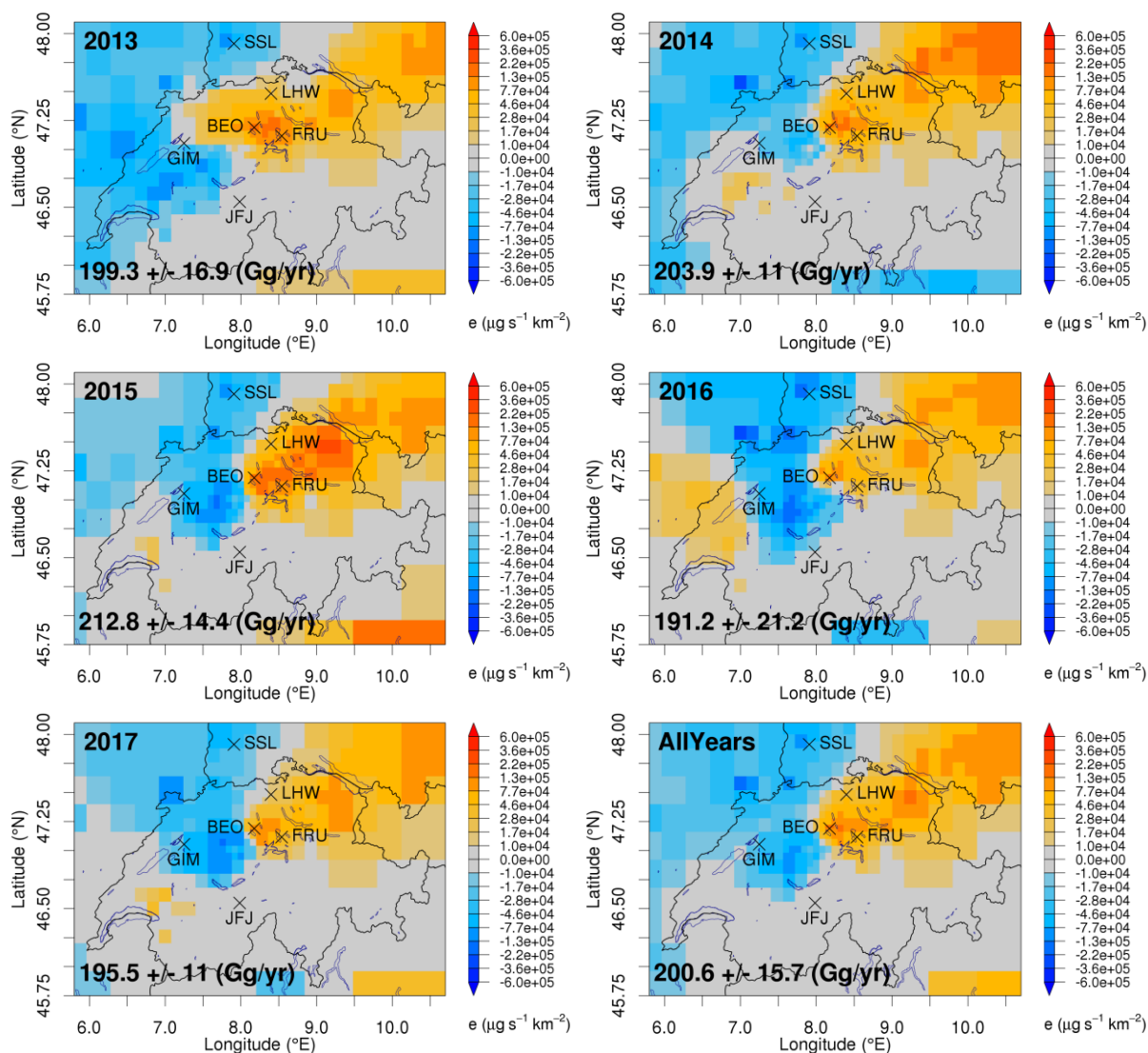


Figure A – 13: Absolute difference between *a posteriori* and *a priori* mean annual emissions (mean over 8 sensitivity runs). The numbers given in the plots refer to the total *a posteriori* Swiss emissions and their uncertainty (1σ level) for the given year.

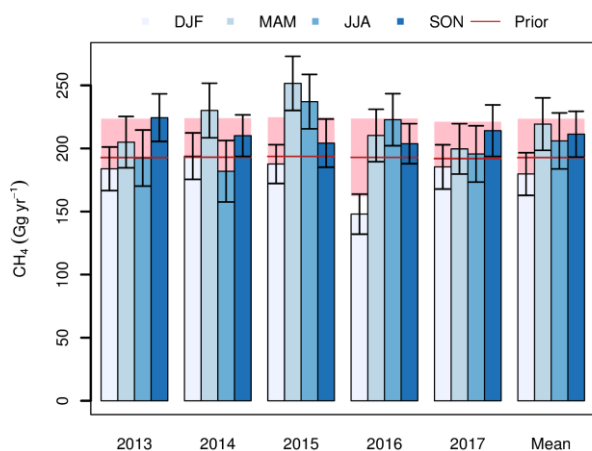


Figure A – 14: Seasonality of Swiss CH_4 emissions. *A priori* values and their uncertainties are given as red lines and red shaded areas. *A posteriori* emissions are given as blue bars and uncertainty bars for different seasons (DJF: December, January, February; MAM: March, April, May; JJA: June, July, August; SON: September, October, November). All uncertainties refer to 1σ confidence intervals.

Nitrous oxide emisisions

With the newly established N₂O observations at the Beromünster tall tower site, it was possible to estimate Swiss N₂O emissions by inverse methods at the country scale for the first time (Henne et al. 2019). The best estimate of annual N₂O emissions for the investigated period in 2017/2018 was 10.9 ± 1.7 Gg yr⁻¹, which compares to 8.2 ± 1.7 Gg yr⁻¹ given in this NIR for the year 2017 (1- σ confidence level). Due to the large uncertainties connected to both numbers, these estimates are not significantly different. The relative uncertainty of the inverse modelling estimate (16%) was somewhat smaller than that of the NIR estimate (20%). The relatively large uncertainty range of the inverse method was calculated from the spread of 26 sensitivity inversions (Figure A – 15). These sensitivity tests comprised, but were not limited to, 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.

Most of the larger emissions 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) (Figure A – 16). The general increase from agricultural lands and (semi-)natural ecosystems may partly be explained by solely natural N₂O emissions, which were not taken into account in the applied *a priori* inventory, since they are not part of the NIR. Lower than *a priori* emissions were assigned to other types of anthropogenic emission sectors such as transport, heating, and wastewater treatment. However, the changes in these 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 this result is provided by the grid inversion, 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 $\pm 40\%$ of the annual total. 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. The month-to-month variability in soil emissions was clearly linked to two environmental controls, soil temperature and soil water filled pore space, explaining 86% of the observed variability.

The tendency to larger than reported N₂O emissions obtained here for Switzerland compares well with other recent inverse estimates of N₂O emissions in Europe. Some of these studies also highlight a similarly pronounced seasonality (Ganesan et al. 2015, Brown et al. 2018).

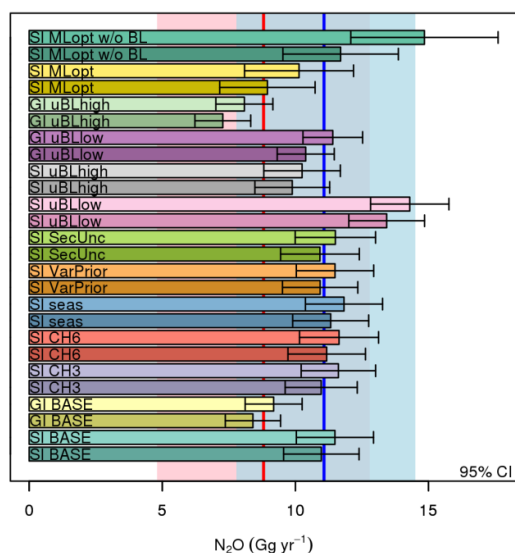


Figure A – 15: Overview of total Swiss N₂O emission estimates for all sensitivity inversions (labels). The darker (lighter) bars always represent the sensitivity runs using the lower (upper) particle release height in the transport model. The error bars give the individual *a posteriori* uncertainty (2σ), whereas the thick vertical lines and shaded areas give the average *a posteriori* (blue) and *a priori* (red) estimates over all sensitivity inversions.

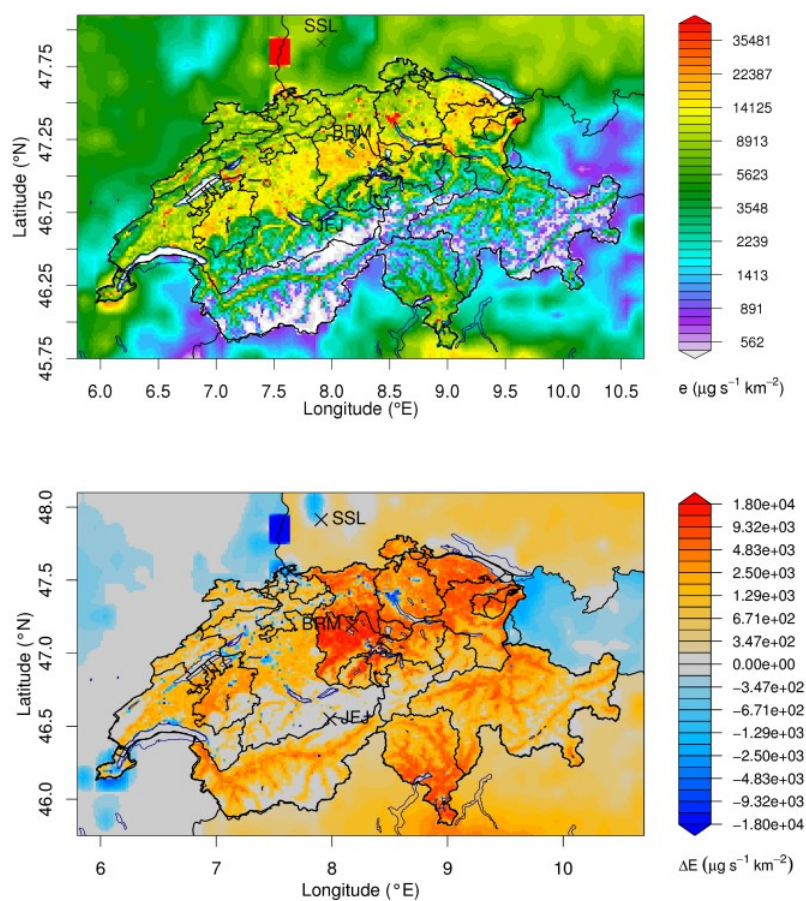


Figure A – 16: (Top) mean *a priori* and (bottom) *a posteriori* minus *a priori* emission distribution over all sensitivity inversions for the period 2017 March to 2018 April.

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 – 30. 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 – 30: 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 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 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: "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 ₂ O per kg N handled instead of kg N ₂ O-N per kg N handled.	Problem in the CRF web application.
Table3s1; Table3.As1; Table3.As2; Table3.B(a)s1; Table3.B(a)s2; 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. Solved with comment in documentation boxes of tables Table3.As1, Table3.B(a)s1, Table3.B(b)
Table4	N ₂ O from 4(IV) (indirect emissions) are not separated in the categories 4A/B/C/D/E/F and just shown in table 4(IV). But are summarized in the total sum in table 4 without been displayed in this table 4. The sum is correct (with indirect emissions)	Inaccuracy in the CRF web application.
Table4	There are empty cells in the CH ₄ and N ₂ O columns; numbers and/or notation keys are not inserted	Problem in the CRF Reporter.
Table4(V)	"Values" and "IEF" in lines 9 and 10 are missing.	Problem in the CRF Reporter.

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.
Table8s4	PFC emissions from 2G2 are also displayed under 2G4.	Problem in the CRF web application.
Table10s2	Empty cell for CO2 captured in the year 2005	Problem in the CRF web application.
Table10s4	For N ₂ O in sector 4 LULUCF the sum is not just the displayed sum of N ₂ O emissions from the categories 4A+4B+4C+4D+4E+4F (rows 39 to 46) but including indirect N ₂ O from 4(IV). The sum is correct (with indirect emissions).	Inaccuracy in the CRF web application.
4(KP-I)A.2	Information items: every row is shown twice. This is not necessary.	Could eventually be written directly into green cells and additional lines could be deleted. => will be postponed to the next submission.
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.
4(KP-II)1	Under A.2, B.1, B.4, B.5 a line with "not applicable" appears.	Could be written directly into green cells and additional lines with "not applicable" could be deleted. => will be postponed to the next submission.
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 – 31 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. green cells: NEW comments for the submission at hand.

NFR Code CRF [UNECE]	EMIS Title	NFR Code CRF [UNECE]	EMIS Title
1 A 1 a	Kehrichtverbrennungsanlagen	2 D 3 a [2 D 3 g]	Klebstoff-Produktion
1 A 1 a	Sondermüllverbrennungsanlagen	2 D 3 a [2 D 3 g]	Lösungsmittel-Umschlag und -Lager
1 A 1 a & 5 A	Kehrichtdeponien	2 D 3 a [2 D 3 g]	Pharmazeutische Produktion**
1 A 1 a & 5 B 2	Vergärung IG (industriell-gewerblich)	2 D 3 a [2 D 3 g]	Polyester-Verarbeitung
1 A 1 a & 5 B 2	Vergärung LW (landwirtschaftlich)	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 A 4 d	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
1 A 3 a & 1 A 5	Flugverkehr	2 G 4 [2 D 3 i]	Öl- und Fettgewinnung
1 A 3 b -viii	Strassenverkehr	2 G 4 [2 D 3 i]	Papier- und Karton-Produktion**
1 A 3 c	Schiennenverkehr	2 G 4 [2 D 3 i]	Parfum- und Aromen-Produktion**
1 A 3 e	Gastransport Kompressorstation	2 G 4 [2 D 3 i]	Tabakwaren Produktion**
1 A 4 b i	Holzkohle-Verbrauch	2 G 4 [2 D 3 i]	Textilien-Produktion
1 A 4 b i	Lagerfeuer	2 G 4 [2 D 3 i]	Wissenschaftliche Laboratorien
1 A 4 c i	Gastrocknung**	2 G 4 [2 G]	Korrosionsschutz im Freien
1 B 2 a iv	Raffinerie, Leckverluste	2 G 4 [2 G]	Betonzusatzmittel-Anwendung
1 B 2 a v	Benzinumschlag Tanklager	2 G 4 [2 G]	Coiffeursalons
1 B 2 a v	Benzinumschlag Tankstellen	2 G 4 [2 G]	Fahrzeug-Unterbodenschutz**
1 B 2 b ii & 1 B 2 c ii	Gasproduktion und Flaring	2 G 4 [2 G]	Feuerwerke
1 B 2 b iv-vi	Netzverluste Erdgas	2 G 4 [2 G]	Flächenenteisung Flughäfen
1 B 2 c	Raffinerie, Abfackelung	2 G 4 [2 G]	Flugzeug-Enteisung
1 Energy Model***	Energie New	2 G 4 [2 G]	Frostschutzmittel Automobil
1A	Holzfeuerungen	2 G 4 [2 G]	Gas-Anwendung
1A2gvi, 1A3c, 1A3e, 1A4aii/biii/cii, 1A5b (without military aviation)	Off-Road	2 G 4 [2 G]	Gesundheitswesen, übrige**
2 A 1	Zementwerke Rohmaterial	2 G 4 [2 G]	Glaswolle Imprägnierung*
2 A 1	Zementwerke übriger Betrieb	2 G 4 [2 G]	Holzschutzmittel-Anwendung
2 A 2	Kalkproduktion, Rohmaterial*	2 G 4 [2 G]	Klebstoff-Anwendung
2 A 2	Kalkproduktion, übriger Betrieb*	2 G 4 [2 G]	Kosmetik-Institute
2 A 4 d	Kehrichtverbrennungsanlagen Karbonat**	2 G 4 [2 G]	Kühlschmiermittel-Verwendung
2 A 4 d	Karbonatanwendung weitere	2 G 4 [2 G]	Medizinische Praxen**
2 A 5 a	Gips-Produktion übriger Betrieb**	2 G 4 [2 G]	Pflanzenschutzmittel-Verwendung
2 A 5 a	Kieswerke	2 G 4 [2 G]	Reinigung Gebäude IGD**
2 B 1	Ammoniak-Produktion*	2 G 4 [2 G]	Schmierstoff-Verwendung
2 B 10 [2 B 10 a]	Ammoniumnitrat-Produktion*	2 G 4 [2 G]	Spraydosen IndustrieGewerbe
2 B 10 [2 B 10 a]	Chlorgas-Produktion*	2 G 4 [2 G]	Tabakwaren Konsum
2 B 10 [2 B 10 a]	Essigsäure-Produktion*	2 G 4 [2 G]	Steinwolle-Imprägnierung*
2 B 10 [2 B 10 a]	Formaldehyd-Produktion	2 H 1	Faserplatten Produktion**
2 B 10 [2 B 10 a]	PVC-Produktion	2 H 1	Zellulose Produktion übriger Betrieb*
2 B 10 [2 B 10 a]	Salzsäure-Produktion*	2 H 1	Spanplatten Produktion*
2 B 10 [2 B 10 a]	Schwefelsäure-Produktion*	2 H 2	Bierbrauereien
2 B 10	Kalksteingrube*	2 H 2	Branntwein Produktion
2 B 10	Niacin-Produktion*	2 H 2	Brot Produktion
2 B 2	Salpetersäure Produktion*	2 H 2	Fleischräuchereien
2 B 5	Graphit und Siliziumkarbid Produktion*	2 H 2	Kaffeeröstereien
2 C -2 G	Synthetische Gase	2 H 2	Müllereien
2 C 1	Eisengiessereien Elektroschmelzöfen	2 H 2	Wein Produktion
2 C 1	Eisengiessereien übriger Betrieb	2 H 2	Zucker Produktion
2 C 1 & 1 A 2 a	Stahl-Produktion Elektroschmelzöfen**	2 H 3	Sprengen und Schiessen
2 C 1	Stahl-Produktion übriger Betrieb**	2 I	Holzbearbeitung
2 C 1	Stahl-Produktion Walzwerke**	2 L	NH3 aus Kühlanlagen
2 C 7 a	Buntmetallgiessereien Elektroöfen**	3	Landwirtschaft
2 C 7 c	Verzinkereien	3 B	Tierhaltung
2 C 7 c	Batterie-Recycling*	3 C	Reisanbau
2 D 1	Schmiermittel-Anwendung	3 D c	Landwirtschaftsflächen
2 D 1	Schmiermittel-Verbrauch B2T	5 B 1	Kompostierung
2 D 2	Paraffinwachs-Anwendung	5 B 2	Biogasaufbereitung (Methanverlust)
2 D 3 a [2 D 3 d]	Farben-Anwendung Bau	5 C 1 [5 C 1 a]	Abfallverbrennung illegal
2 D 3 a [2 D 3 d]	Farben-Anwendung andere	5 C 1 [5 C 1 b i]	Kabelabbrand
2 D 3 a [2 D 3 d]	Farben-Anwendung Haushalte**	5 C 1 [5 C 1 b iii]	Spitalabfallverbrennung
2 D 3 a [2 D 3 d]	Farben-Anwendung Holz	5 C 1 [5 C 1 b iv]	Klärschlammverbrennung
2 D 3 a [2 D 3 d]	Farben-Anwendung Autoreparatur**	5 C 1 [5 C 1 b v]	Krematorien
2 D 3 a [2 D 3 e]	Elektronik-Reinigung	5 C 2 / 4 V A 1 (Forstwirtschaft)	Abfallverbrennung Land- und Forstwirtschaft und Private
2 D 3 a [2 D 3 e]	Metalreinigung	5 D 1 [5 D]	Kläranlagen kommunal (Luftschadstoffe)
2 D 3 a [2 D 3 e]	Reinigung Industrie übrige	5 D 2 [5 D]	Kläranlagen industriell (Luftschadstoffe)
2 D 3 a [2 D 3 f]	Chemische Reinigung**	5 D 1 / 5 D 2 [5 D]	Kläranlagen GHG
2 D 3 a [2 D 3 g]	Druckfarben Produktion	5 E	Shredder Anlagen
2 D 3 a [2 D 3 g]	Farben-Produktion	6 A d	Brand- und Feuerschäden Immobilien
2 D 3 a [2 D 3 g]	Feinchemikalien-Produktion**	6 A d	Brand- und Feuerschäden Motorfahrzeuge
2 D 3 a [2 D 3 g]	Gummi-Verarbeitung**	6 A d	Brand- und Feuerschäden Motorfahrzeuge
2 D 3 a [2 D 3 g]	Klebband-Produktion		

* confidential process

** confidential EMIS comment

*** work in progress

Cursive: process not relevant for the years after 1990.

New comment for the current submission.