Federal Office for the Environment (FOEN)

Emissions scenarios without measures
1990-2030

Final report
Zurich and Lausanne, 4 May 2016

Mario Betschart, Bettina Schäppi, Rolf Iten, Jürg Füssler (INFRAS)
Marc Vielle, Philippe Thalmann (EPFL)

INFRAS
Research and Consulting
www.infras.ch

Imprint

Commissioned by

Federal Office for the Environment (FOEN)
Climate Division
CH-3003 Bern

The FOEN is an agency of the Federal Department of the Environment, Transport, Energy and Communications (DETEC).

Contractors

Philippe Thalmann, EPFL

Rolf Iten, INFRAS

Authors

Mario Betschart, Bettina Schäppi, Rolf Iten, Jürg Füssler (INFRAS)

Marc Vielle, Philippe Thalmann (EPFL)

EPFL ENAC IA LEURE, Station 16, 1015 Lausanne

Tel. +41 21 693 93 93

INFRAS, Binzstrasse 23, 8045 Zurich

Tel. +41 44 205 95 95

FOEN support

Regine Röthlisberger, Paul Filliger, Isabel Junker, Adrian Schilt, Roger Ramer (FOEN)

Content

Executive Summary

The goal of this study is to estimate the net impact of all measures implemented in the context of the Swiss energy and climate policies on CO_2 emissions from combustion processes between 1990 and 2030. The study provides a projection of CO_2 emissions until 2030 under the assumption of continuation of existing measures and contrasts these emissions with a scenario excluding all policies and measures introduced after 1990. The study does not estimate the evolution of CO_2 emissions from non-combustion processes, other (non-CO_2) greenhouse gas emissions and the impact of measures on these emissions. Nor does it simulate a scenario with additional measures that are currently discussed but not decided or that may become necessary in the future if it appears that the emission targets cannot be met with existing measures alone.

Methodological approach

The strength of this study is the combination of a detailed bottom-up assessment of individual mitigation measures with a computable general equilibrium (CGE) model of the economy (GEMINI-E3, Bernard and Vielle, 2008). The scenario of the Swiss economy with existing measures ("WEM scenario") is based on existing economic and emissions data from 1990 to 2014 or 2015, as available, and forecasts beyond, up to 2030. A counterfactual scenario of the Swiss economy without these measures ("WOM scenario") is derived from the WEM scenario by subtracting the estimated effects of Swiss energy and climate policies (chap. 2). GEMINI-E3 is a multi-country, multi-sector, recursive dynamic CGE model – similar to CGE models implemented and applied by other modelling teams and institutions (EPPA, OECD-Env-Linkage, etc.) – and allows for a full set of supply, demand and price responses. The standard model is based on the assumption of total flexibility in all markets, both macroeconomic markets such as the capital and the exchange markets (with the associated prices being the real rate of interest and the real exchange rate, which are then endogenous), and microeconomic or sector markets (goods, factors of production).

Abatement measures simulated in this study

Since 1990, various abatement measures were implemented under the Swiss energy and climate policies, addressing the transport, buildings and industrial sectors (see Table 1 for a general overview). For the simulations with GEMINI-E3 similar measures are clustered and their impacts are estimated only at this aggregated level. For each measure, CO_2 savings and related financial data (such as investments, costs, subsidies and taxes) are estimated based on existing impact assessment studies. Table 1 distinguishes between non-price measures and price measures, depending on whether they directly modify prices or costs for consumers or firms.

To avoid double counting, the costs and effects – particularly in terms of CO_2 emission reductions – of non-price measures are estimated through a bottom-up impact assessment (chap. 3), while the costs and effects of price measures are estimated through a top-down impact assessment (chap. 4).

Table 1: List of measures leading to CO_2 emission reductions since 1990

Cluster	Description	Time period	Cumulative savings 1990-2030
Non-price measures (bottom-up assessment)			
Energy in buildings (sect. 3.2)	**National buildings refurbishment programme (parts A and B) and cantonal programmes** Financial incentives for buildings refurbishment, since 2000 at the cantonal level and since 2010 at the national level. The current programme is assumed to continue until 2020, but its effects will extend beyond.	2000-2020	20 Mt CO_2
	Building codes of the cantons (reduction of CO_2 emissions from buildings) Regulations are implemented at cantonal level starting in the early 1980s. Since 1992 the so-called MuKEn regulations („Mustervorschriften der Kantone im Energiebereich") are in force.	1990-2030	59 Mt CO_2
SwissEnergy programme (sect. 3.3)	**Promotion of energy efficiency and use of renewable energy sources** The SwissEnergy programme consists of two phases, "Energie 2000" (1991-2000) and "EnergieSchweiz" (2001-2010). It includes several voluntary measures promoting energy efficiency and the use of renewable energy sources by private households, the services sector as well as industry.	1990-2020	25 Mt CO_2

Table 1: List of measures leading to CO_2 emission reductions since 1990			
Cluster	**Description**	**Time period**	**Cumulative savings 1990-2030**
Transport (sect. 3.4)	**EcoDrive (part of SwissEnergy programme)** The EcoDrive programme promotes fuel-efficient driving techniques for passenger cars and freight transport vehicles. In order to avoid double counting, the EcoDrive programme is not included in the SwissEnergy programme (sect. 3.3), but accounted for separately in the transport cluster.	2001-2030	3 Mt CO_2
	Heavy vehicle charges (since 2001) A charge is applied to passenger and freight transport vehicles > 3.5 t gross weight. The charge level depends on kilometres travelled on Swiss roads, vehicle-specific maximum authorised gross weight, and emissions according to EURO classes.	2001-2030	3 Mt CO_2
	CO_2 emission regulations for new passenger cars (since 2012) From July 2012 to the end of 2015, CO_2 emission regulations for new passenger cars in Switzerland were similar to those of the EU: average emissions of new cars had to decrease to 130 g CO_2/km by 2015. This ceiling is extended unchanged to 2030. Due to a further lowering of these limits in the EU, it is assumed that cars that are more efficient will also penetrate the Swiss market. **Energy label for new motor vehicles (since 1990)** The energy label informs buyers about the fuel consumption and CO_2 emissions per km. **Voluntary agreement of Swiss car importers (2002-2008)** In 2002, a voluntary agreement on fuel efficiency was signed by the Association of Swiss Car Importers and the Swiss government. The aim of the agreement was the stepwise reduction of average fuel consumption from 8.4 l/100km to 6.4 l/100km between 2000 and 2008. The voluntary agreement was replaced by CO_2 emission regulations for new passenger cars.	1990-2030	29 Mt CO_2
Renewable electricity production (sect. 3.5)	**Feed-in tariff for renewable power generation** For eligible technologies, the feed-in tariff covers the difference between the cost of production and the market price for electricity supplied to the grid. The feed-in tariff is assumed to increase stepwise from 0.6 Rp./kWh in 2009 to 1.3 Rp./kWh in 2017.	2009-2030	Overall, electricity generation policy is assumed to contribute cumulative savings of 21 Mt CO_2

Table 1: List of measures leading to CO_2 emission reductions since 1990

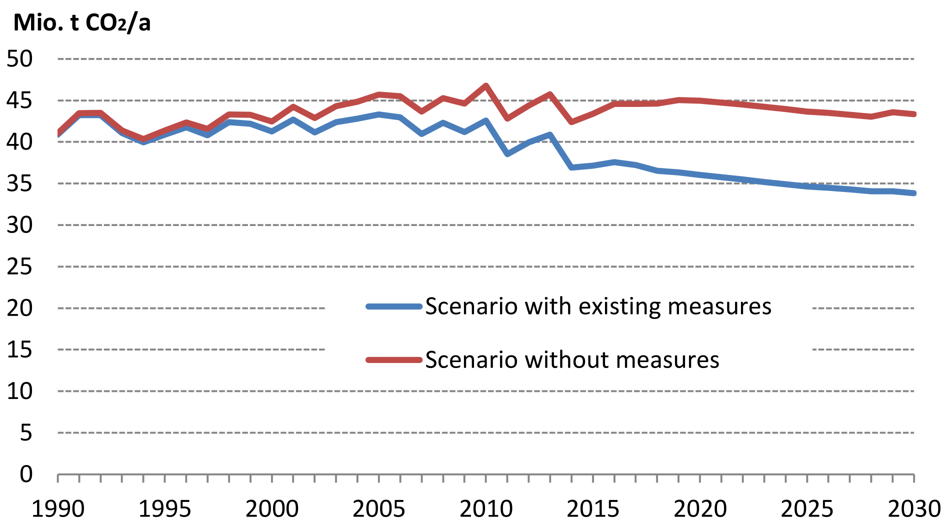
Cluster	Description	Time period	Cumulative savings 1990-2030
Price measures or measures modelled as such (top-down assessment) [1]			
CO_2 prices (sect. 4.3.1)	**CO_2 levy on heating and process fuels** CO_2 levy on heating and process fuels since 2008, increasing over time depending on the achievement of predefined reduction targets (2008/09: 12 CHF/t CO_2; 2010-2013: 36 CHF/t CO_2; 2014/15: 60 CHF/t CO_2; since 2016: 84 CHF/t CO_2). According to the calculations of the model, the levy has to be raised to 120 CHF/t CO_2 in 2018.	2008-2030	
	Emissions trading scheme (ETS) The Swiss ETS was introduced in 2008. Companies participating in the ETS are exempted from the CO_2 levy. Since 2013, participation in the Swiss ETS is mandatory for greenhouse gas intensive industries. The cap is reduced by 1.74% per year. As a consequence, the model estimates that the carbon price within the ETS will rise from 14 CHF/t CO_2 in 2013 to 130 CHF/t CO_2 in 2020.	2008-2030	
	Negotiated reduction commitments (nonETS) For some companies, an exemption from the CO_2 levy is also possible if they commit to an emission reduction target (nonETS). For these companies, the abatement they committed to is implemented through a shadow price on emissions (PriceNonETS), assumed to be equal to the Swiss CO_2 levy.	2008-2030	
Emission offset from gas-fired power plants (sect. 4.3.3)	**Obligation to offset emissions from gas-fired power plants** Combined-cycle gas turbine (CCGT) plants are introduced in the model when needed to balance the electricity market. According to the CO_2 Act, they are required to compensate their emissions, with a minimum share of 50% domestic compensation, i.e. obtained from the other sectors. The rest can be compensated by using international emission reduction units. The price of foreign certificates (linked to international compensation) is fixed to 10 CHF/t CO_2.	2019-2030	
Compensation for transport fuel use (sect. 4.3.2)	**Partial compensation of CO_2 emissions from transport fuel use** The CO_2 emissions that result from the use of transport fuels must be compensated in the following proportions (CO_2 Ordinance of 30 November 2012, art. 89): ▪ 2013 and before: 0% ▪ 2014-2015: 2% ▪ 2016-2017: 5% ▪ 2018-2019: 8% ▪ 2020: 10% We assume that the 10% compensation is maintained from 2021 to 2030.	2014-2030	21 Mt CO_2

[1] For price measures, no bottom-up estimation of impacts is provided.

Main results

In the WEM scenario, CO_2 emissions from energy combustion (source category 1A) decrease from 40.9 million tonnes in 1990 to 36.0 million tonnes in 2020. Taking into account that 50% of emissions from electricity generation using natural gas will be compensated through international compensation (in addition to the 50% domestic compensation already counted), total CO_2 emissions will equal 35.9 million tonnes, which represents a 12.2% reduction with respect to 1990 levels (without climate compensation). Emissions from energy combustion further decline to 33.5 million tonnes (including the international compensation) in 2030, which amounts to a 18.1% reduction relative to 1990 (without climate compensation).

Figure 1: CO_2 emissions in the WEM and WOM scenarios (1990-2030, no climate compensation)



Without the mitigation measures implemented since 1990, CO_2 emissions from energy combustion would have reached 45.7 million tonnes in 2013 (compared to actual emissions of 40.9 million tonnes) and they would further decline slowly to 45.0 million tonnes in 2020 and 43.3 million tonnes in 2030. Thus, the implemented measures (Table 1) reduced CO_2 emissions by 10.6% relative to a scenario without measures in 2013, and would reduce them by 20.1% in 2020 (with international compensation) and by 22.8% in 2030. Over the period 1990-2030, mitigation measures lead to cumulated reductions of CO_2 emissions from energy combustion of 192 million tonnes, or 10.7% of the cumulated emissions in the WOM scenario.

The greatest CO_2 savings relative to 1990 are obtained in industry and in residential and administrative buildings (Table 2). In contrast, CO_2 emissions in the energy sector (energy conversion, in particular electricity generation) remain close to their peak level of 2005, about 50%

above their 1990 level, due to the penetration of gas-fired power plants to replace the first decommissioned nuclear power plants[2]. Nevertheless, the energy sector will emit much less CO_2 than in a scenario without measures. Emissions from the transport sector exceed the 1990 level during the full period until 2030, although they are decreasing since 2008 and would fall below the 1990 level if compensations realised in other sectors were subtracted from its own sectoral emissions.

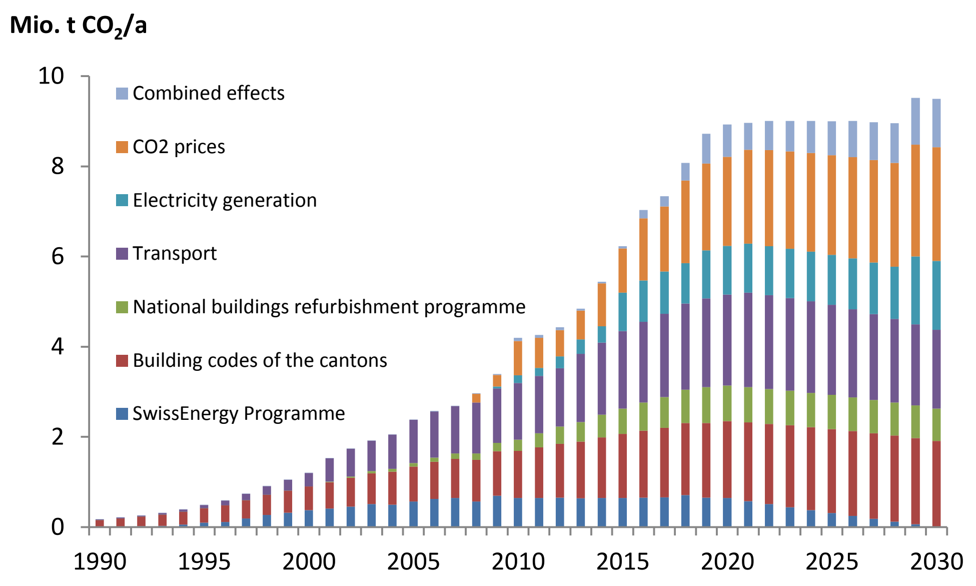
Table 2: CO_2 emissions from energy combustion in different sectors in the WEM and WOM scenarios (Mt)

Sector	1990	2010		2020		2030	
		WEM	WOM	WEM	WOM	WEM	WOM
Energy (1A1)	2.5	3.8	4.0	3.5	5.2	4.0	6.6
Industries (1A2)	6.4	5.8	6.1	4.6	5.9	4.1	5.3
Transport (1A3)	14.4	16.2	17.4	15.5	16.9	14.7	15.8
Other sectors (1A4)	17.4	16.6	19.1	12.4	16.9	11.0	15.5
Services (1A4a)	*5.2*	*5.2*	*6.1*	*4.1*	*6.0*	*4.1*	*6.1*
Households (1A4b)	*11.6*	*11.0*	*12.5*	*7.8*	*10.4*	*6.4*	*8.9*
Others (1A4c)	*0.5*	*0.5*	*0.5*	*0.5*	*0.6*	*0.5*	*0.5*
Military (1A5)	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Total domestic (1A)	**40.9**	**42.6**	**46.8**	**36.0**	**45.0**	**33.8**	**43.3**
International compensation CCGT				0.1		0.4	
Total with compensation				**35.9**		**33.5**	

In terms of measures, the greatest CO_2 savings relative to the WOM scenario are obtained by the CO_2 levy, including its exemption mechanisms, the building codes of the cantons and the measures in the transport sector (Figure 2).

[2] The emissions from these combined-cycle gas turbine (CCGT) power plants must be compensated. The line "International compensation CCGT" in Table 2 shows the amounts of CO_2 emissions the sector is estimated to compensate abroad. Equal amounts will be compensated domestically. These reductions are counted in the emissions of the other sectors.

Figure 2: Total CO_2 savings by cluster of measures relative to the WOM scenario



These results are driven by a large set of assumptions regarding future economic developments, including technical progress. In order to test the sensitivity of the result to the various assumptions, two different "worlds" were drafted. One which is less favourable to emission mitigation (a high CO_2 emission scenario) and another one which is more favourable to emission mitigation (a low CO_2 emissions scenario). The first has higher demographic and economic growth in Switzerland, less technical progress specifically related to energy use, less effective non-price measures and lower world prices for fossil energy. The second is the opposite. The values retained for these parameters are still quite plausible. In the "unfavourable world", existing measures (those of the WEM scenario) cannot prevent Switzerland's CO_2 emissions to rise substantially above those of 1990 after 2026. Low fossil energy prices are the main cause for this result. In the most favourable world, on the contrary, CO_2 emissions decline faster than in the central WEM scenario.

In the WOM scenario, the sensitivity analysis leads to similar effects. However, the estimated effectiveness of existing measures, i.e. the difference between the WEM and the WOM scenarios, is quite sensitive to changes in assumptions. The high CO_2 emissions scenario not only leads to higher emissions in the WEM and WOM scenario relative to the central set of parameters, it also widens the gap between WEM and WOM. This is because there are a few measures that are tightened in the WEM scenario in response to higher CO_2 emissions, mainly the ETS price and the compensation mechanisms, and of course not in the WOM scenario.

1. Introduction

1.1. Goals and key questions

1.1.1. Context of this study

Under the United Nations Framework Convention on Climate Change, Switzerland is required to report an estimate of the development of greenhouse gas emissions with existing measures (WEM scenario) until 2030. It is also encouraged to report a without measures (WOM) scenario and a with additional measures (WAM) scenario. As an important contribution to these scenarios, this report provides quantitative estimates for CO_2 emissions from combustion processes under the WEM and WOM scenarios.

Since 1990, greenhouse gas emissions of Switzerland remained relatively constant apart from some year-to-year fluctuations, despite strong population and economic growth (see below). The present study assesses to which extent this stabilisation can be attributed to existing greenhouse gas abatement measures as opposed, for instance, to rising energy prices. The FOEN commissioned EPFL and INFRAS to project CO_2 emissions from combustion processes to 2030 considering implemented measures (WEM scenario), and to also provide a scenario without implementation of specific measures to reduce emissions (WOM scenario) for the full period 1990-2030.

A number of greenhouse gas abatement measures were realised since 1990 (see e.g. Betz et al. 2015 and Table 1), which contributed to the stabilization of CO_2 emissions despite an increase of population by 22%, of real GDP by 45%, of the number of motor vehicles by 53%, and of the energy reference area by 40%. The full impact of the Swiss energy and climate policies is not known, even though the impact of specific measures has been assessed in several studies (INFRAS 2011, INFRAS 2015, BfE 2010, BfE 2015a, Gebäudeprogramm 2014, Bundesrat 2016, Ecoplan EPFL und FHNW 2015, TEP Energy und Rütter Soceco 2016). Adding-up bottom-up impact assessments of specific abatement measures poorly reflects the actual reduction, since rebound effects reduce the estimated CO_2 savings, while spill-over effects in other sectors might amplify them. Therefore, this study estimates the overall emissions abatement by simulating the effects of the existing measures in a computable general equilibrium (CGE) model called GEMINI-E3, which accounts for interactions between the effects of different policy measures, direct and indirect rebound effects and spill-over effects in all economic sectors. Further, the study addresses the separation of individual measures to avoid double counting of their effects.

Outline

The report provides an overview of the methodological approach applied in this study (chap. 2), a summary of the bottom-up impact assessment for selected abatement measures including a documentation of the underlying data sources and assumptions (chap. 3) and corresponding full impact assessments obtained with the GEMINI-E3 model simulations (chap. 4). A sensitivity analysis is provided in chapter 5. The report concludes with a discussion and outlook (chap. 6).

1.1.2. Goals

The goal of this study is to estimate the net impact on CO_2 emissions from combustion process between 1990 and 2030 of all the policies and measures that were implemented since 1990 with a view to increasing energy efficiency or to reducing fossil fuel consumption or CO_2 emissions. This includes policies and measures related to transport, buildings and industry. The study provides a projection of CO_2 emissions until 2030 under the assumption of continuation of existing measures and contrasts the emissions with a scenario without policies and measures.

This study does not estimate the evolution of other greenhouse gas emissions or the impact of measures on these emissions. Nor does it simulate a scenario with additional measures that are currently discussed but not yet decided or that may become necessary in the future if it appears that the emission targets cannot be met with existing measures.

1.2. Definitions and system boundaries

In the following sections, the scenarios and the scope of the present study are defined.

Scenarios

- The scenario “with existing measures” (WEM) corresponds to observed economic activity and CO_2 emissions for the period 1990 until 2014, to a simulation of economic development and emissions until 2020 with the existing set of legislation that is relevant for CO_2 emissions (in particular the revised CO_2 Act of 2011 which defines measures until 2020), and to a simulation of economic development and emissions from 2020 until 2030 based on the continuation of the measures that will exist in 2020.
- The scenario “without measures” (WOM) depicts a hypothetical situation in which the economic and environmental effects of greenhouse gas abatement measures implemented since 1990 are excluded for both the past and the future. The counterfactual past emissions without measures are estimated by back casting under the exclusion of the impact of

existing measures. Projections to 2030 are simulated as in the WEM scenario, except that all measures that lead to CO_2 savings are removed.

Emissions covered by the model simulations

The simulations performed in the present study cover only CO_2 emissions from combustion processes (source category 1A). Emissions from all other source categories and sectors (1B, 2, 3, 4, 5, and 6) are not considered. Accordingly, in particular CO_2 emissions from industrial processes, e.g. from cement and lime production, are not part of this study. Further, emissions from all greenhouse gases other than CO_2 (CH_4, N_2O, HFCs, PFCs, SF_6, NF_3, and indirect greenhouse gases resulting from the atmospheric oxidation of NMVOCs and CO or induced by emissions of NOx and NH_3) are not considered. However, a bottom-up estimation of the abatement of non-CO_2 emissions is provided for selected measures in the appendix (Table 30). For the sake of simplicity, in the following we use the expression "CO_2 savings" for the reduction of the CO_2 emissions in source category 1A considered here.

Time period

The time period of interest is 1990 to 2030. The WEM scenario of the Swiss economy is based on statistical data from 1990 to 2014 and forecasts for 2015 to 2030. The WOM scenario is derived from the WEM scenario by subtracting the estimated effects of Swiss energy and climate policies (see chap. 3).

2. Methodological approach

2.1. Introduction

The strength of this study is to embed GHG mitigation measures into a model of the economy that allows for a full set of supply, demand and price responses. For an illustration, consider a measure that raises fossil fuel prices for the industry. It will induce the industry to save fuels and replace them by non-fossil energy. These direct effects are well captured by bottom-up impact assessments. However, the measure will also raise production costs, which leads to higher prices for the goods, the more so the more energy-intensive their production is, which will in turn encourage the business and household buyers of these goods to buy less of them and to replace them to some extent by imported goods or by less energy-intensive substitutes. This contributes also to lowering emissions. Furthermore, incomes and taxes paid by the affected firms will decrease, causing effects that will also ripple through all sectors of the economy. The replacement of fossil fuels by non-fossil energy will raise the price of the latter, causing its own chain of impacts on production costs, demands, the trade balance and incomes.

Consider another example: a measure designed to improve fuel efficiency in buildings. A rapid bottom-up analysis would multiply the share of fuel-efficient buildings obtained by the measures with their efficiency improvement and the initial fuel consumption of all buildings to estimate the impact of the measure on total fuel consumption in buildings and on resulting emissions. This calculation ignores direct rebound effects such as the possibility that inhabitants of more fuel-efficient buildings choose to indulge a higher room temperature or to keep their windows more often open. It also ignores the indirect rebound effects, i.e. the additional emissions related to the spending of the money saved on heating costs (Winkler et alii 2014).

Finally, the increase in fossil fuel costs and the measure designed to improve fuel efficiency in buildings interact. In this case, the interaction is one of reinforcement: the total impact of the two measures is likely to be greater than the sum of their individual effects.

The limitations of bottom-up impact assessments do not render them useless. First of all, the spill-over, rebound and interaction effects could be small enough to be ignored. This is often the case for narrowly focused measures. More importantly, the simulation of the effects of policies and measures in a full-fledged economic model requires information on these measures that are typically gathered in bottom-up assessments, such as the equivalent tax or subsidy value of a regulatory measure, the technical potentials for substitutions, or abatement costs. For this reason, we draw on existing bottom-up assessments or performed our own when necessary for all the CO_2 abatement measures that are ultimately implemented and simulated in GEMINI-E3. In addition, some measures cannot be directly implemented in GEMINI-E3 because the model lacks the sectoral disaggregation and the detailed technology description that would be needed to represent narrowly targeted measures. In those cases, bottom-up assessments are the only estimates available for their potential impacts. This concerns particularly the SwissEnergy Programs, with their emphasis on information and the dissemination of innovations.

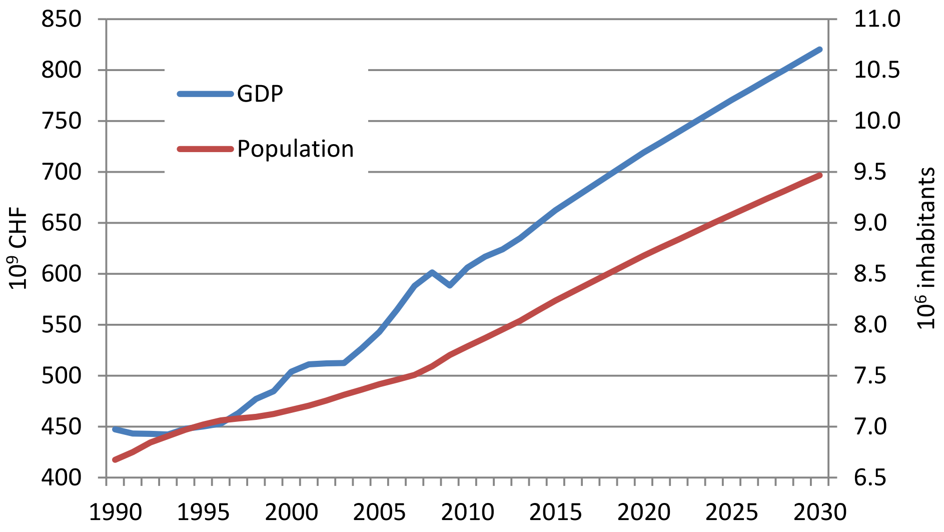
2.2. Key variables for the WEM and WOM scenarios

The WEM and WOM scenarios use a common set of demographic and macroeconomic assumptions (Table 3). Population assumptions follow the Swiss demographic scenario A-00-2015 (OFS 2015). GDP growth is forecasted by the State Secretariat for Economic Affairs SECO by multiplying the labour force (coming from the demographic scenario) with a labour productivity increase of 0.9% per year. Historical heating degree days (HDD) are from the Swiss Federal Office of Energy SFOE (BfE 2015c); the forecasted HDD are the same as in Switzerland's Sixth National Communication under the UNFCCC (Swiss Confederation 2013, table 29). Energy prices are based on the *current policies scenario* of the World Energy Outlook 2014 (IEA 2014). More specific variables will be presented in the respective sections.

Table 3: Key variables in the WEM and WOM scenarios

	1990	1995	2000	2005	2010	2013	2020	2025	2030
Population (million, 1st Jan.)	6.67	7.02	7.16	7.42	7.79	8.04	8.68	9.08	9.47
GDP (billion CHF_{2013})	447	450	504	543	606	635	717	768	818
Heating degree days	3203	3397	3081	3518	3586	3471	3244	3154	3064
Energy reference area for housing (base 100 in 1990) [3]	100	111	126	136	147	155	173	184	196
IEA crude oil price (USD_{2013}/barrel)	36	25	37	59	82	106	116	128	139
Natural gas import EU price (USD_{2013}/Mbtu)	4.1	2.8	4.2	6.7	7.9	10.6	11.5	12.4	13.2

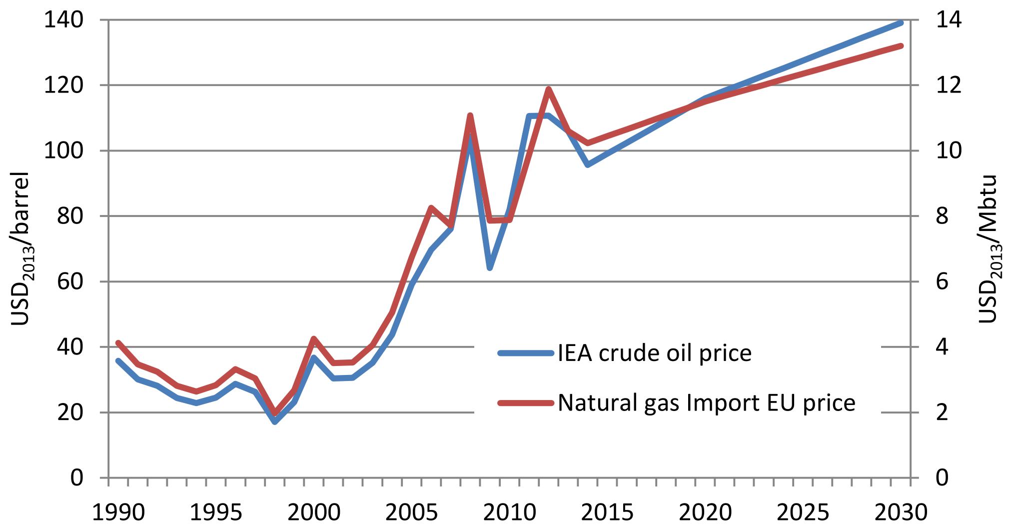
Figure 3: GDP and population in the WEM and WOM scenarios



GDP on left axis, population on right axis

[3] Proxy based on household consumption in housing.

Figure 4: Energy prices in the WEM and WOM scenarios



Crude oil price left axis, natural gas price right axis.

2.3. Energy efficiency improvement

Of central importance for CO_2 emissions from combustion processes is the evolution of energy efficiency. In order to represent the increased efficiency in the use of energy for production, GEMINI-E3, like most other computable general equilibrium (CGE) models, relies on an assumption of autonomous energy efficiency improvement (AEEI), and similarly for energy used directly by households. AEEI is commonly set at a constant rate, for instance 1.5% per year, implying that the same quantity of output, mobility, or room temperature can be achieved with 1.5% less energy every year that passes. This rate is based on observed trends in energy efficiency from which changes in energy services (e.g. energy reference area), prices, and policies have been removed. Consider for instance the energy use for room heating. The AEEI reflects the decrease in energy use for constant energy reference area, constant prices and incomes, constant weather conditions, and constant policies (regulation). Why would energy use decrease through time if everything stays constant?

- Because of technical progress: the same type of building material or component (same price) yields better insulation; the same type of furnace and heat distribution system delivers more calories into rooms with the same quantity of primary energy.
- Because of changed behaviour: people accept, for various reasons, to lower their room temperature or they select more energy efficient buildings.

- Climate change reduces the heating energy need.[4]

In fact, energy prices change through time. An increase relative to other prices induces additional efficiency improvement, which we call "market price-induced energy efficiency improvements" (MPIEEI). CGE models predict a future path of the economy without policy change but with an evolution of economic parameters (e.g. world energy prices). This is the so-called "baseline scenario". In this scenario, the energy efficiency changes under the joint effects of AEEI and MPIEEI:

$$TEEI_{baseline} = AEEI + MPIEEI \quad (1)$$

where TEEI stands for total energy efficiency improvement. If we knew AEEI and MPIEEI, we could combine this with forecasts for economic activities to predict the WOM scenario.

CGE models are used to simulate and estimate the effects of policy changes or policy shocks. They predict a future path of the economy with policy, the so-called "policy scenario". Comparing the policy scenario with the baseline scenario reveals the effect of the policy.

In most simulations using CGE models, the AEEI is held constant while the simulated policy shocks lead to substitutions between inputs and between outputs. Furthermore, the simulations assume that the underlying energy prices, i.e. world market prices, are also the same in both scenarios. As a result, the AEEI and MPEEI play virtually no role in the measurement of policy impacts, even if they play a central role in the shape of the baseline and policy scenario.

Suppose that a policy, for instance a new or increased energy tax, makes energy more expensive. CGE models will show that firms and households respond by using less energy because they replace some of it by other inputs (e.g. capital, when they insulate their buildings) and because they switch to less energy-intensive goods (e.g. more energy-efficient cars). These are the same responses that underlie the MPIEEI. They cause an additional decrease in energy use compared to production or consumption, the so-called "tax-induced energy efficiency improvement" (TIEEI).

Next to the substitution effects triggered by changes in relative prices, one can expect that some policies could foster innovation and the development and adoption of more efficient production and consumption options even with constant prices. This is typically the case of information campaigns and public support for RD&D. It could even be the case for tax and subsidies programmes, because they signal to users that energy should be conserved. This additional improvement in energy efficiency is an "endogenous energy efficiency improvement" (EEEI).

[4] On the other hand, the need for cooling energy increases, so total energy use in buildings could possibly increase. Our simulations suggest that this is not the case (Winkler et al., 2014).

Consider again the energy tax example. It renders energy use for heating more expensive relative to the baseline scenario. Building owners may respond by better insulating their buildings, and by replacing their furnace and heat distribution systems with more efficient ones, which deliver the same room temperature with less primary energy. Building occupants may lower room temperatures or move to smaller buildings. These possible TIEEI effects are normally captured in CGE models by elasticities of substitution between energy and capital inputs, and between goods. If the tax provides additional, non-price motives for energy conservation and if it is accompanied by information and persuasion measures, these additional effects should be captured by the EEEI, i.e. by an acceleration of energy efficiency improvement at constant prices.

As a result, the TEEI in the policy scenario is:

$$TEEI_{policy\ scenario} = AEEI + MPIEEI + TIEEI + EEEI \quad (2)$$

Comparing (1) and (2):

$$TEEI_{policy\ scenario} - TEEI_{baseline} = TIEEI + EEEI = PIEEI \quad (3)$$

where PIEEI stands for “policy-induced energy efficiency improvement”. The difference between energy efficiency improvement in the policy scenario and the baseline scenario is attributable to the tax-induced EEI and the endogenous EEI, both being triggered by the policy.

2.4. Energy efficiency improvement in WEM and WOM

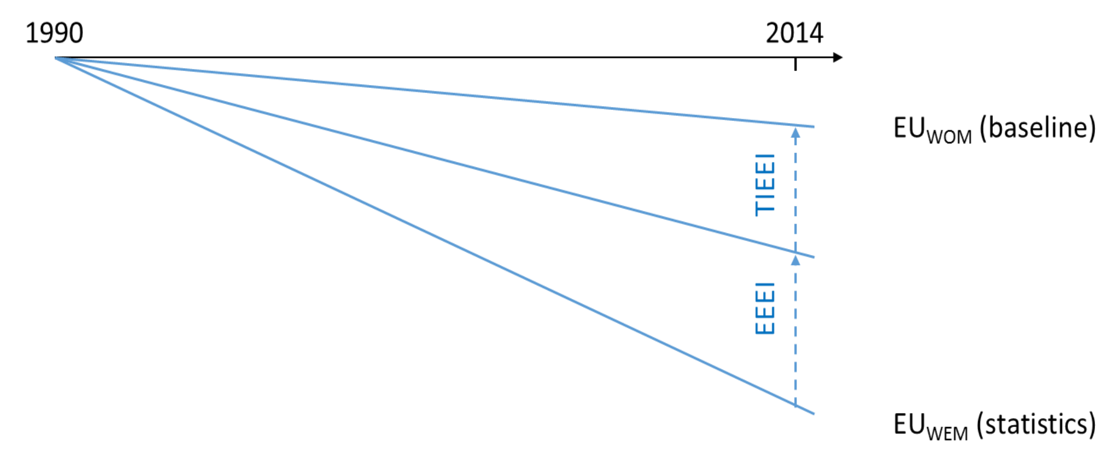
For this study, the baseline scenario is called WOM scenario and the policy scenario is called WEM scenario. For the WEM/WOM simulations, the simulation context is unusual. Rather than imposing policy shocks on a baseline to assess their effects, the baseline has the policies (WEM) and it is the development path without the policies (WOM) that must be simulated. This implies that the model is first calibrated to and extrapolated for the WEM scenario, and then the policies are "removed" to simulate the WOM scenario, both in the past and in the future.

For the historical period 1990-2014, we proceed as follows:

1. We use the statistical paths of total energy use for the different sectors (residential heating, services, industry, and transportation); these determine the TEEI for the policy scenario: $TEEI_{WEM}$.
2. We estimate the EEEI for this period in a bottom-up analysis of the non-price measures that were in place, or of measures whose price effects are not otherwise considered in the simulations with GEMINI-E3 (chap. 3).

3. We estimate the TIEEI for this period using GEMINI-E3 to simulate price-related measures that were in place over that period (chap. 4).
4. Subtracting the calculated EEEI and TIEEI from $TEEI_{WEM}$ yields $TEEI_{WOM}$. Figure 5 illustrates these adjustments in a stylized fashion. The starting point is energy use (EU_{WEM}) in a sector for constant energy reference activity (e.g. energy reference area or transportation activity), represented as a straight line declining from 1990 thanks to cumulative TEEI. Subtracting EEEI and TIEEI leads to a higher path of EU called EU_{WOM}.
5. This higher path EU_{WOM} is then used to compute CO_2 emissions in the absence of climate and energy policies (WOM scenario) for each sector, whereby changes in energy reference activity are taken into account. In GEMINI-E3, CO_2 emissions are computed from the energy consumptions in physical unit (i.e. tonne oil equivalent (toe)) by multiplying them by these average emissions factors: 4.12 tCO_2/toe of coal, 3.04 tCO_2/toe of petroleum products, and 2.39 tCO_2/toe of natural gas.

Figure 5: From WEM to WOM (illustration of the method, the curves are not to scale)

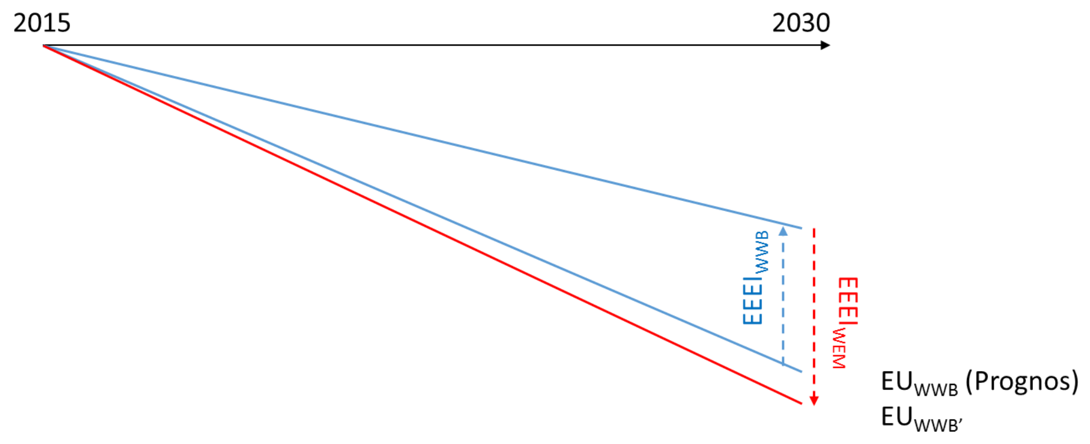


For the forecast period 2015-2030, we proceed in a first stage as follows:

1. We use the forecast paths of total energy use for the different sectors (residential heating, services, industry, transportation) estimated in the *Energy perspectives* (Prognos 2012). We use their scenario "Weiter wie bisher" (WWB), which extrapolates past trends of energy efficiency improvements and integrates energy price expectations and existing measures related to energy and climate policies that have already been defined and implemented at the time of their forecasts. Of the three scenarios they simulate, this is the one that is closest to WEM. It yields EU_{WWB} and $TEEI_{WWB}$.

2. We estimate the $EEEI_{WWB}$ implicit in the WWB scenario in a bottom-up analysis of the non-price measures that are part of the WWB scenario, or of measures whose price effects are not otherwise considered in the simulations with GEMINI-E3.
3. We estimate, in a similar bottom-up fashion, the $EEEI_{WEM}$ corresponding to the non-price measures of the WEM scenario, or of measures whose price effects are not otherwise considered in the simulations with GEMINI-E3.
4. $TEEI_{WWB} - EEEI_{WWB} + EEEI_{WEM} = TEEI_{WWB'}$ (Figure 6). The resulting path of energy use $EU_{WWB'}$ corresponds to a scenario that has the non-price measures of WEM but the price measures of WWB. Section 4.1 shows the derivation of $TEEI_{WWB'}$ for the different sectors, which allows to grasp the technical innovations forecast until 2030. These calculations have not required simulations with GEMINI-E3.

Figure 6: From WWB to WWB' (illustration of the method, the curves are not to scale)

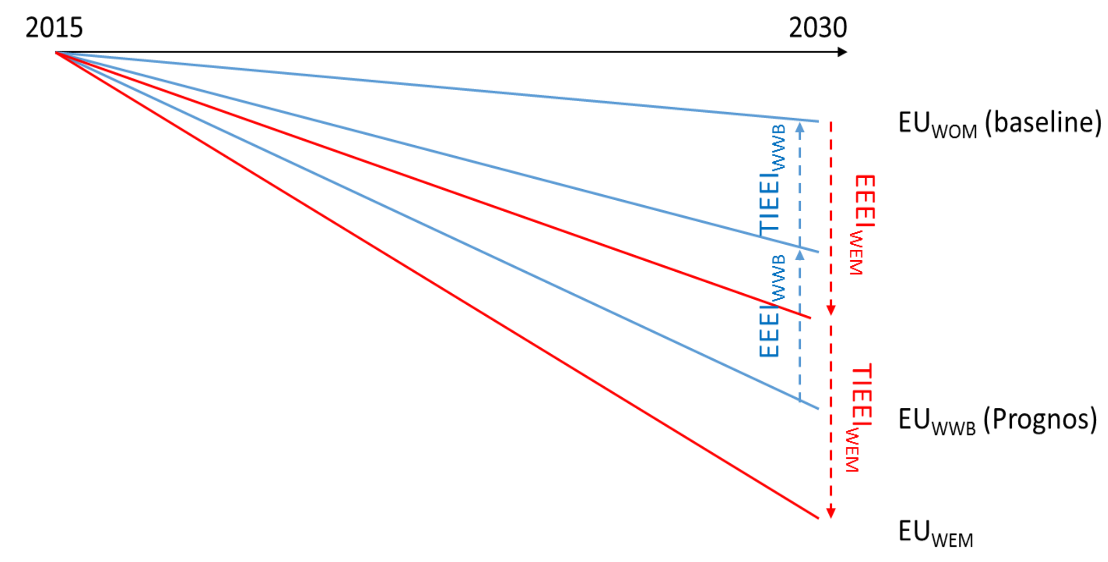


A second stage is needed, for the forecast period 2015-2030, to account for price measures in WWB and WEM. We proceed as follows:

1. Using GEMINI-E3, we estimate the $TIEEI_{WWB}$ implicit in the WWB scenario by replicating the price measures retained by Prognos.
2. $TEEI_{WWB} - EEEI_{WWB} - TIEEI_{WWB} = TEEI_{WOM}$ (Figure 7). This is then used to compute expected energy use (EU_{WOM}) and CO_2 emissions in the absence of climate and energy policies (WOM scenario).
3. Using GEMINI-E3, we estimate the $TIEEI_{WEM}$ for the price measures of the WEM scenario.
4. $TEEI_{WOM} + EEEI_{WEM} + TIEEI_{WEM} = TEEI_{WEM}$ (Figure 7). This is then used to compute expected energy use (EU_{WEM}) and CO_2 emissions with the climate and energy policies of the WEM

scenario. $EEEI_{WEM}$ + $TIEEI_{WEM}$ = $PIEEI_{WEM}$, the policy-induced EEI of the WEM scenario relative to the WOM scenario.

Figure 7: From WWB to WOM and WEM (illustration of the method, the curves are not to scale)



As an illustration, consider the national buildings refurbishment programme. It combines a set of measures encompassing subsidies for insulation and renewable energy sources, information, dissemination of best practices, some additional regulation, and some RD&D support. Some of these measures could be captured by lowering the price of capital (insulation) that can substitute energy and thus lead to energy efficiency improvement through a price effect (equivalent subsidies). Some could also be captured by an increase in elasticities of substitution, which would lead to more energy efficiency improvement when (fossil) energy prices increase. In fact, a bottom-up analysis of the national buildings refurbishment programme does not yield such parameter changes in a reliable way. What it can yield is an estimation of the energy that was saved thanks to the programme *ceteris paribus*, i.e. for constant energy prices, climate conditions and energy reference area.

We estimate the energy efficiency improvement obtained by the national buildings refurbishment programme as defined by the WWB scenario of Prognos (2012), which is in particular based on a budget of 200 million CHF per year. Next, we estimate the energy efficiency improvement obtained by the national buildings refurbishment programme as defined in the WEM scenario, in particular with a budget increasing to 300 million CHF per year. The additional EEI leads to the $EU_{WWB'}$ estimation of energy use under the revised WWB scenario.

2.5. Simulation model GEMINI-E3

GEMINI-E3 is a multi-country, multi-sector, recursive dynamic computable general equilibrium (CGE) model (Bernard and Vielle, 2008) similar to CGE models implemented and applied by other modelling teams and institutions (EPPA, OECD-Env-Linkage, etc.). GEMINI-E3 has been used extensively over the last 20 years to assess planned climate and energy strategies at global and regional levels.

The model assumes perfect flexibility in all markets, both macroeconomic markets such as the capital market and international trade (with the associated prices being the real rate of interest and the real exchange rate, which are then endogenous), and microeconomic or sector markets (goods, factors of production).

The industrial classification used in GEMINI-E3 for this study comprises 18 sectors (Table 14). The model describes six energy goods and sectors: coal, oil, natural gas, petroleum products, electricity and heat supply. Considerable effort was spent on obtaining a good description of the main energy intensive industries and on identifying in each sector the share of firms that are allowed to participate in the Swiss emissions trading scheme (ETS). Concerning the regions represented by the model, we use an aggregated version of GEMINI-E3 that describes five countries/regions: Switzerland, European Union, United States of America, BRIC (Brazil, Russia, India and China) and the rest of the world.

The current version is built on the Swiss input-output table 2008 (Nathani et alii, 2011) and the GTAP database 8 (Narayanan et alii, 2012) for the other countries. The *calibration year*, called sometimes *reference year*, is the year 2008. The equations of the model are calibrated on this reference year for which all the information relative to the variables (exogenous and endogenous) used in the model is available. A calibration procedure was also implemented on the past (1990-2014) in order to ensure that the model is able to reproduce the historical economic development with the associated energy consumptions and CO_2 emissions.

2.6. Bottom-up impact assessment for specific policy measures

Since 1990, a set of abatement measures was implemented under Swiss energy and climate policies. These measures address specific sectors, such as transport, buildings and industry. For the simulations with GEMINI-E3, similar measures are clustered (Table 1) and their impacts are estimated only at this aggregated level. For each measure, CO_2 savings and related financial data such as subsidies, investments and taxes are estimated based on existing impact assessment studies. As indicated above, we distinguish between non-price measures and price measures, depending on whether they directly modify prices or costs for consumers or firms. The costs and effects, particularly in terms of CO_2 emission reductions, of non-price measures are estimated through bottom-up impact assessment (chap. 3). The costs and effects of price measures are estimated through top-down impact assessment (chap. 4). This avoids double counting of impacts. Table 1 in the Executive Summary indicates which measures are treated as non-price or price measures. Details about the individual measures are provided in the different sections of chapter 3, when their impacts are assessed.

A key issue in the bottom-up assessment concerns the exclusion of double counting of impacts, in particular when a specific measure is part of more than one cluster. Therefore, existing assessments for specific measures need to be corrected so that only additional impacts are considered. In addition, the bottom-up assessments do not take into account spill-over, rebound and interaction effects resulting from the measures.

On the other hand, the bottom-up approach for estimating CO_2 savings allows accounting for specific characteristics of a particular measure and its various fine details. Translating such measures into an aggregate simulation model requires some simplification. Thus, for instance, the myriad specific agreements negotiated with firms exempted from the CO_2 levy are represented in the GEMINI-E3 model by a single price on CO_2 emissions for a share of the production of each sector. The price and the share of production in each sector subject to that price are calibrated in GEMINI-E3 so that their direct effects on CO_2 emissions correspond to those that were estimated with the detailed bottom-up assessment.

By calibrating the GEMINI-E3 model to the bottom-up estimates, consistency with these detailed estimates can be ensured. However, the bottom-up impact assessments depend on the availability of detailed data and bear the risk of double counting. The underlying assumptions and implications are presented in the following chapter.

3. Bottom-up impact assessment

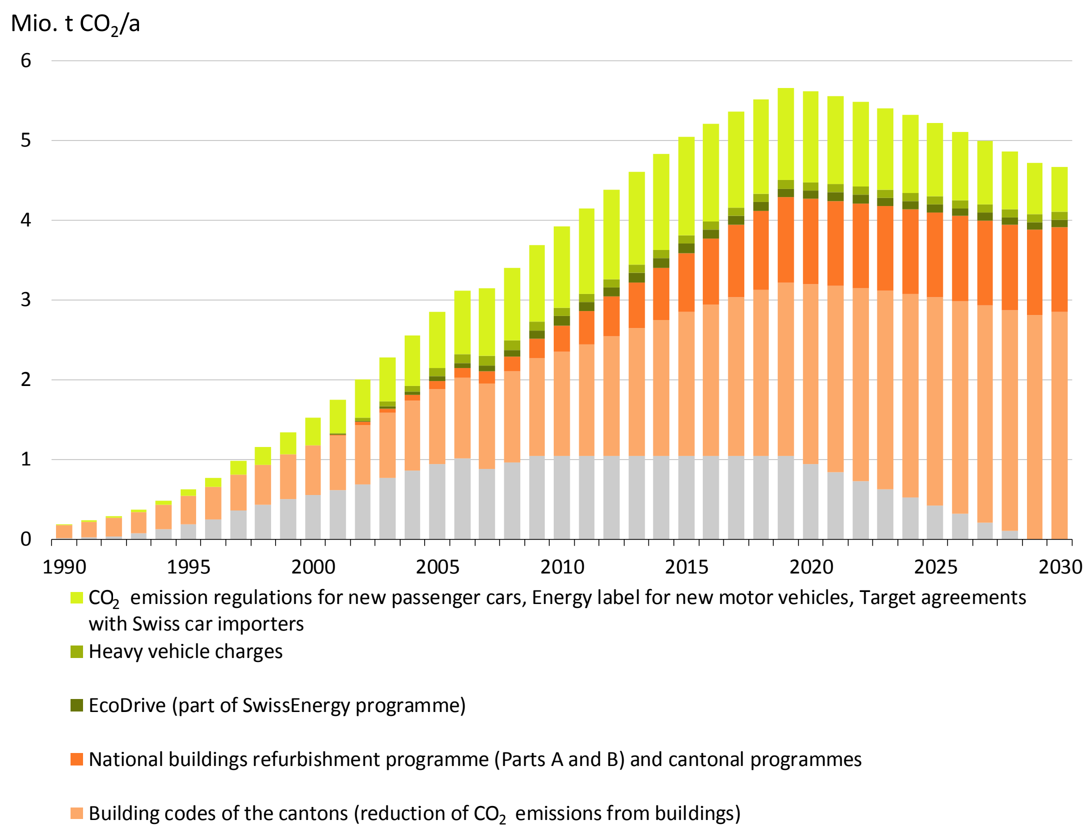
In its first part, this chapter provides an overview of total savings from each of the measures considered in the present study (sect. 3.1). Details on data sources and assumptions are summarized in sections 3.2-3.5. Furthermore, some measures are directly implemented in the GEMINI-E3 model and therefore do not require a bottom-up assessment (chap. 3). While not part of the present study, a brief documentation of the bottom-up impact assessment of selected policies and measures related to the abatement of greenhouse gases other than CO_2 is provided in the Appendix.

3.1. Overview of bottom-up estimates

The annual CO_2 savings estimated from bottom-up assessments of the non-price measures listed in Table 1 amounts to about 5.6 million tonnes per year by 2020 and decreases to about 4.7 million tonnes per year by 2030. The shares of the different measures show significant changes over time (Figure 8). In 1990, the cantonal building codes have the largest impacts. Impacts related to the SwissEnergy programme and the energy label for new motor vehicles in the transport sector are starting to have a visible impact around 1995, which further increases until 2010 due to target agreements with the Swiss car importers and since 2012 due to CO_2 emission regulations for new passenger cars. From 2010, impacts from the SwissEnergy programme remain constant and start to decrease after 2020.

Furthermore, substantial impacts are due to the national buildings refurbishment programme, since 2010, and cantonal programmes, starting around 2000. As it is not yet decided whether the current national buildings refurbishment programme will be continued after 2020, only the remaining ongoing impacts of measures that were realised before 2020 are taken into account.

Figure 8: Overview of bottom-up estimates of CO_2 savings due to non-price measures



CO_2 savings based on aggregation of bottom-up estimates for specific non-price measures, relative to the absence of these measures. Indirect CO_2 savings due to the promotion of renewable electricity generation are not shown in this figure. Since not for all measures a bottom-up estimate is required, this figure does not depict total CO_2 savings.

Uncertainties in bottom-up estimates

The estimated CO_2 savings rely on a number of assumptions and approximations, so that both their magnitude as well as their temporal evolution are affected by uncertainty. They should be considered as an educated guess of the actual emission reductions based on data available from existing literature.

Deriving a quantitative estimate of the uncertainty is quite challenging since most impact assessments for specific measures and programmes do not provide any information on related uncertainties. Thus in the study at hand, we assume an overall uncertainty of ±30% in the bottom-up estimates of CO_2 savings due to non-price measures (see sensitivity analysis in chap. 5). We expect that within this margin of uncertainty a wide range of possible outcomes can be covered.

3.2. Energy in buildings

Within the cluster *energy in buildings*, CO_2 savings and total investments due to existing building codes of the cantons and their revisions as well as CO_2 reductions attributed to the national buildings refurbishment programme (parts A and B), since 2010, and cantonal programmes since 2000 are considered. Whereas the building codes of the cantons (e.g. MuKEn, see below) mainly have an impact on general standards in the buildings sector and therefore on the use of energy (e.g. heating oil), the national buildings refurbishment programme also has an impact on the penetration of renewable energies as part of the additional cantonal funding activities (part B).

A particularity of measures improving the energy efficiency of buildings is that these improvements last for the lifetime of these buildings. Consider for instance a subsidy paid to an owner in 1990 that she uses to improve the building's envelope, which reduces fuel use and hence CO_2 emissions by 1 tonne in 1990. It will permit the same savings for decades, even if no more subsidy were paid after 1990. Suppose a new subsidy is paid in 1990 inducing another owner to improve her building's envelope, generating savings of 1.5 tonne CO_2 in 1991 and beyond. The sum of these effects (2.5 tonnes in 1991 and after) corresponds to the "annual savings" obtained by the subsidy programme, as in Figure 10. The amount of savings added to the pre-existing annual savings in 1991 (1.5 tonne) is called "annual incremental savings", as in Figure 9. We will also compute "cumulated savings", which is the sum of annual savings obtained by the subsidy programme over a certain period. There can be some erosion of the long-term savings obtained by a measure, meaning for instance that the 1 tonne of savings obtained by the subsidy and investment in 1990 slowly decreases over time because the building loses its improved energy efficiency. There can also be some erosion in the annual incremental effect obtained by a given amount of subsidy or investment, typically because the most effective efficiency improvements are implemented first.

3.2.1. Data sources and assumptions

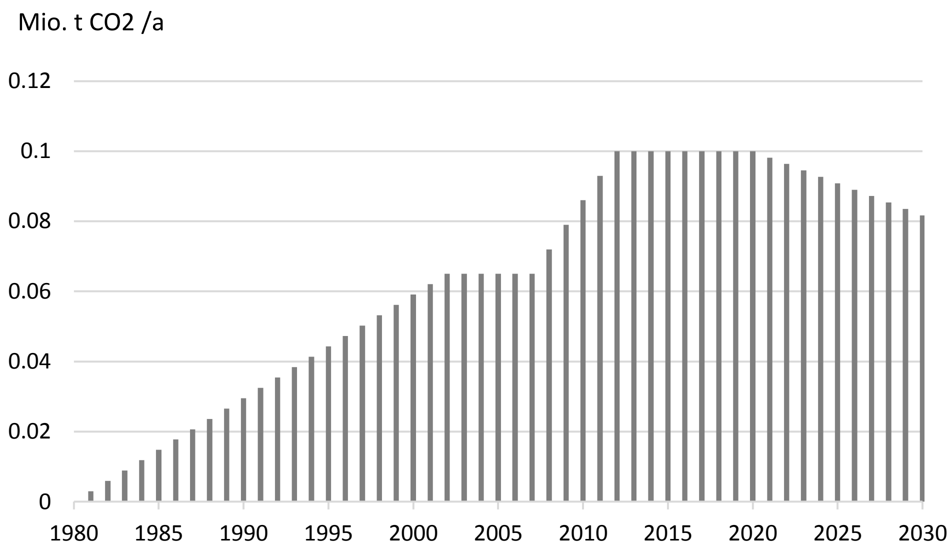
In order to provide a bottom-up estimation of the impacts of the *energy in buildings* cluster, a set of assumptions is required.

Building codes of the cantons

The building codes of the cantons relative to energy efficiency are implemented in the cantons starting in the early 80s. In 1992, the so-called MuKEn regulations (Mustervorschriften der Kantone im Energiebereich) came into force. They were harmonized among the cantons in subsequent years. Revised regulations became effective in 2008. Data on impacts in terms of CO_2 savings due to regulations are available from the latest impact assessment (BfE 2013). Data are available since 2002. It is assumed that the annual CO_2 savings increase from zero in 1980 to about 2.8 Mio. t in 2030 (see Figure 10). Regarding annual incremental savings, it is assumed that there is a linear increase between 1990 and 2002 and it is further assumed that the annual incremental savings remain constant between 2002 and 2007 because of similar progress of the regulations and the autonomous technical progress. Between 2008 and 2012, an increase is assumed due to the revised and more ambitious regulations (MuKEn 2008). For the time period 2013-2020 it is assumed that the annual incremental CO_2 savings remain constant due to a new revision of the regulations in 2014 (MuKEn 2014), which will come into force gradually between 2016 and 2020[5]. Beyond 2020, it is assumed that the annual incremental CO_2 savings decrease by 2% per year due to “erosion of the attributable impact” by technical progress (Figure 9).

[5] Since the implementation of these measures is already decided in 2016, they are accounted for as existing measures.

Figure 9: Bottom-up impact assessment of annual incremental CO_2 savings due to the building codes of the cantons, i.e. amount of savings added to the pre-existing annual savings



National buildings refurbishment programme (parts A and B) and cantonal programmes

The cluster *energy in buildings* contains impacts on CO_2 emissions from the early phase of the buildings refurbishment programme implemented at the cantonal level from 2001 to 2009 (e.g. BfE 2010) as well as the funding by the climate cent foundation 2006-2009 (Climate Cent Foundation 2011). Data before 2010 are available annually. For the period 2010-2014 the current national buildings refurbishment programme (consisting of parts A and B) started. Data on CO_2 savings are also available on an annual basis (e.g. Gebäudeprogramm 2014, EnDK 2015, BfE 2015a). It is assumed that the impacts on CO_2 emissions as well as the investments remain stable between 2015 and 2019. After 2019, no additional impact of the national buildings refurbishment programme is considered because it is not yet decided whether it will be continued.

Table 4: Data sources and assumptions for the impact assessment of the cluster *energy in buildings*
Data sources
▪ **Building codes of the cantons**: Data concerning CO_2 savings and investments are based on an impact analysis for the years 2002-2012 (e.g. BfE 2013). ▪ **National buildings refurbishment programme**: Data on CO_2 savings and investments are available for the years 2001-2009 (e.g. BfE 2010 and Climate Cent Foundation 2011) as well as annually for the current national buildings refurbishment programme parts A and B based on impact analyses (e.g. EnDK 2015, Gebäudeprogramm 2014, BfE 2015a). The impact in terms of CO_2 savings has been revised according to BfE (2015b).
Assumptions
Building codes of the cantons Ex post ▪ Data on CO_2 savings and investments are linearly interpolated between 1990 and 2002. It is assumed that CO_2 savings as well as the investments remain constant between 2002 and 2007. Between 2008 and 2012 the impact and investments increase due to revised regulations. Ex ante ▪ Between 2013 and 2020, it is assumed that the impact and the investments remain constant at the 2012 level because of revised regulations (MuKEn 2014). Beyond 2020, the impact and the investments will decrease by 2% per year. ▪ Shares of energy carriers in buildings (today) are based on the annual statistics of the national buildings refurbishment programme (Gebäudeprogramm 2014) and expert assessments (2030) following the Energy Perspectives 2050 (Prognos 2012), linear interpolation in-between. ▪ Heating oil 60/50%, natural gas 15/15%, other 25/35% Shares of economic sectors (1990-2030) ▪ Private households 66%, services 33% Double counting ▪ Double counting might occur if cantonal buildings refurbishment programmes support measures that are already prescribed by building codes of the cantons. **National buildings refurbishment programme** Ex post ▪ Data are available from 2001 onwards. Investments are based on BfE (e.g. 2010). Additional data are provided by Climate Cent Foundation (2011) for 2006-2009. Ex ante ▪ It is assumed that the impact between 2015 and 2019 remains constant at the 2014 level. After 2019, the national buildings refurbishment programme is assumed to be discontinued. Shares of energy carriers (in 2014 and 2030, with linear interpolation in-between) ▪ Heating oil 60%/50%, natural gas 15%/15%, other 25%/35% Shares of economic sectors (1990-2030) ▪ Private households 66%, services 33% Double counting ▪ In the context of both KliK and cantonal agencies supporting projects of the buildings refurbishment programmes, cantons assume that emission reductions supported by KliK also help to reach cantonal targets. In the clear distinction assumed in this study, this could lead to double counting of emission reduc-

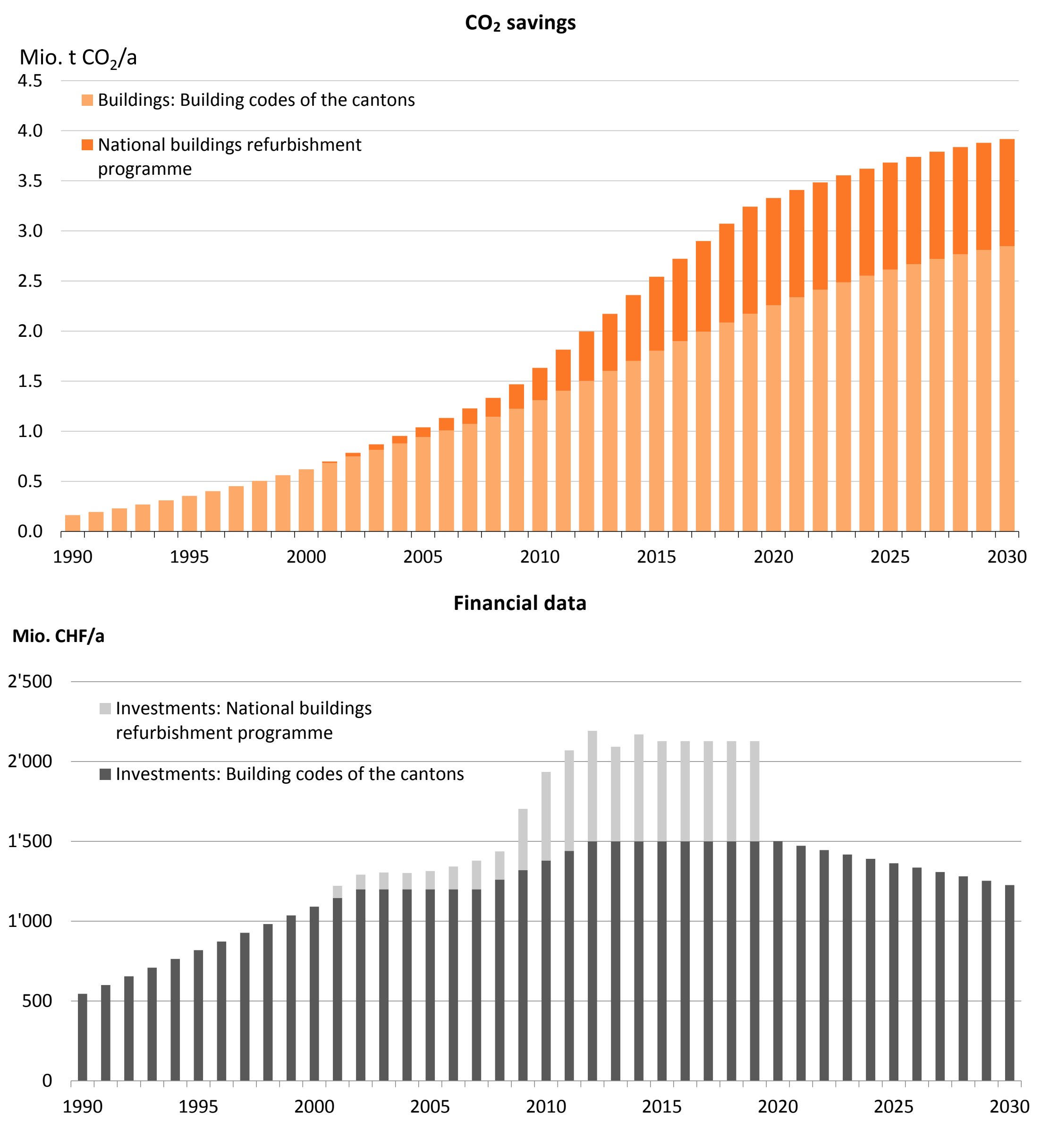
tions for (i) KliK and (ii) the national buildings refurbishment programme.

3.2.2. CO_2 savings and financial data

In total, cumulated CO_2 savings between 1990 and 2030 of approximately 78 million tonnes are expected due to the building codes of the cantons and the current national buildings refurbishment programme as well as measures at the cantonal level before 2010. The annual CO_2 savings continuously increase over time, up to roughly 4 million tonnes in 2030. The main impact is attributed to building codes of the cantons (75%).

We estimate that total cumulated investments of approximately 57 billion CHF (subsidies and additional investments by third parties) are needed over the entire period 1990-2030 to follow this path of CO_2 savings. Thereof, 87% are allocated to investments resulting as a consequence of the building codes of the cantons.

Figure 10: Bottom-up assessment of annual CO_2 savings and investments attributable to the cluster *energy in buildings*



3.3. SwissEnergy programme

The cluster *SwissEnergy programme* subsumes the impacts from two phases of the Swiss-Energy programme ("Energie 2000": 1991-2000, "EnergieSchweiz": 2001-2010). The Swiss-Energy programme includes several measures addressing private households, the services sector as well as industry, measures aimed at reducing fossil fuel consumption by increasing efficiency as well as by substitution with renewable energy sources.

3.3.1. Data sources and assumptions

Detailed estimates of the CO_2 savings are available from annual impact assessments of the SwissEnergy programme (INFRAS 2011), which combine aggregate and disaggregate data. The aggregate data are public statistics for Switzerland (e.g. sales of heat pumps) multiplied by estimated shares of the contribution of SwissEnergy. The disaggregate data are estimated savings from individual projects based on an indicator (e.g. number of projects) and an estimation of corresponding emission reductions. The measures are reported for four different sectors: (i) public sector and buildings, (ii) services and industry, (iii) mobility, and (iv) renewable energy use. Measures related to mobility are not accounted for in the study at hand, since transport related measures are accounted for in the transport cluster.

Future projections require several assumptions regarding the continuation of these measures. Even though the SwissEnergy programme will continue until 2020, it is assumed that there is no further increase of the impacts since the scope of the programme was shifted towards soft measures, such as dissemination of information and raising awareness. Additionally, in order to avoid double counting of the impact that is already accounted for in a different cluster of measures, the data have to be adjusted based on several assumptions as documented in the following table.

Table 5: Data sources and assumptions for the impact assessment of the cluster *SwissEnergy programme*
Data sources
▪ Impacts in terms of CO_2 savings and investments were assessed annually between 1990 and 2010.
Assumptions
Ex post ▪ After 2007, 75% of the total savings from voluntary measures are accounted for under nonETS price measures. In order to avoid double counting, these CO_2 savings are not included in the SwissEnergy programme after 2007. Ex ante ▪ Between 2010 and 2020 the impact is assumed to remain constant. ▪ It is assumed that between 2020 and 2030 there is a phasing out of the impact from the SwissEnergy programme. The impact therefore decreases linearly until 2030. Shares of energy carriers (1990-2030) ▪ Oil 70 %, gas 30 % Shares of economic sectors (1990-2030) ▪ Industry 10 %, private households 45 %, services 45 % Double counting ▪ The impacts in the industry and services sectors (as resulting from the energy model or the benchmark model) were reduced by 20% to account for the fact that some of these measures would have been realised also without any financial incentive (e.g. due to autonomous technical progress or energy price

changes). Regarding renewable energy sources, the impact was reduced by40% for the same reason.

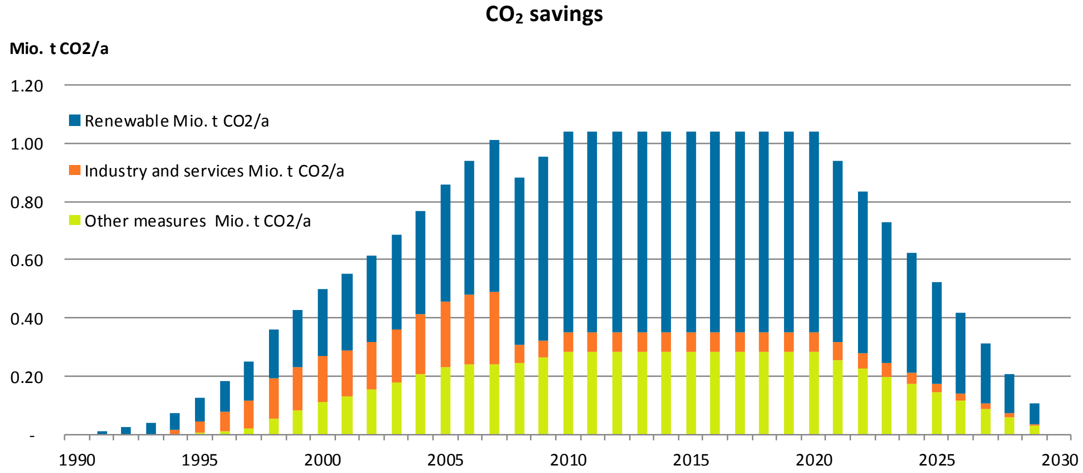
- The SwissEnergy programme also includes measures in the transport sector. In order to avoid double counting with measures in the transport cluster, the impacts of these measures are not considered here.

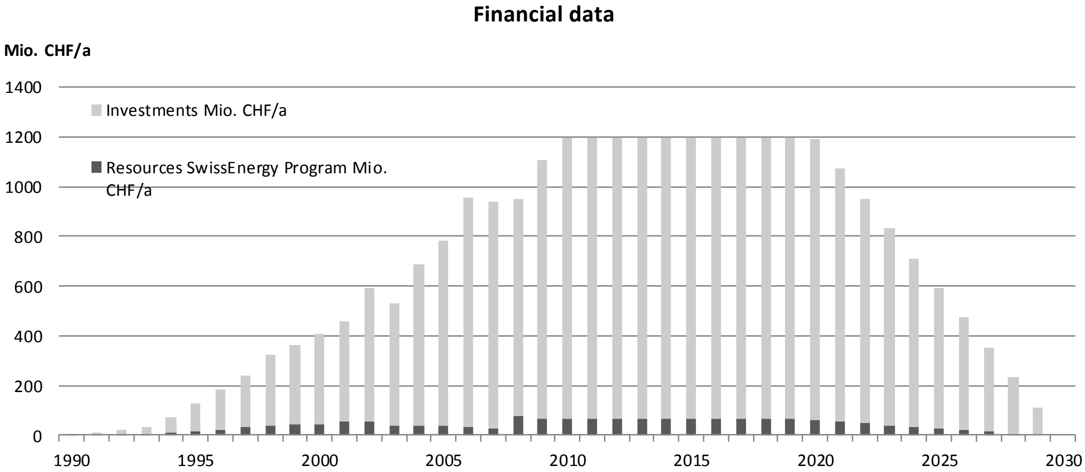
3.3.2. CO_2 savings and financial data

Based on the assumptions presented above, CO_2 savings of about 1 Mio. t CO_2 per year between 2005 and 2020 are estimated (Figure 11). The largest contribution – about two thirds – stems from measures aiming at replacing fossil fuels by renewable energy sources through the promotion of heat pumps and wood-fired heating systems. Due to the phasing out of the programme, the emission savings decrease after 2020.

The industry and services sectors make only a minor contribution, since voluntary agreements (Benchmarkmodell, Energiemodell) are accounted for by a nonETS carbon price that is directly implemented in GEMINI-E3 (cluster *CO_2 prices*, sect. 4.3.1) and does therefore not require a bottom-up estimation. Various additional measures under the SwissEnergy programme (e.g. SwissEnergy programme for municipalities, energho – competence centre for energy efficiency in buildings, energy in infrastructure) account for the remaining 30% of the total impact.

Figure 11: Bottom-up assessment of annual CO_2 savings and investments attributable to the SwissEnergy programme





Time series of historical and projected total impact in terms of CO_2 savings from various measures in the cluster *SwissEnergy programme* 1990-2030 (upper part). Other measures comprise SwissEnergy for communities, energy in infrastructure and energy efficiency in buildings (energho). Related financial data are shown in the lower part. After 2007, 75% of the total savings from voluntary measures are accounted for under nonETS price measures. In order to avoid double counting, these CO_2 savings are not included in the cluster *SwissEnergy programme* after 2007. This results in a significant decrease of emission savings attributed to the cluster *SwissEnergy programme* between 2007 and 2008.

3.4. Transport

The cluster *transport* groups four measures:

- EcoDrive (as part of the SwissEnergy programme but accounted for in this cluster)
- The heavy vehicle charges (LSVA)

- A set of measures such as the energy label for new motor vehicles (Energieetikette) leading to fuel efficiency improvement
- The voluntary agreement between the Swiss government and car importers association (AutoSchweiz) to increase the fuel efficiency of new cars
- The CO_2 emission regulations for new passenger cars.

All of these measures result in decreasing fossil fuel consumption. EcoDrive decreases the fuel consumption of cars and trucks by teaching drivers fuel-saving driving modes. The heavy vehicle charges incentivize firms to reduce truck rides and to buy more fuel-efficient trucks. The other measures also induce vehicle sellers to promote, and households and firms to buy more fuel-efficient vehicles.

3.4.1. Data sources and assumptions

The following assumptions have been made in order to obtain impact pathways for each measure:

EcoDrive

Information on CO_2 savings is available from annual impact assessments of the SwissEnergy programme (INFRAS 2011) for the period 2001-2010. It is assumed that there is no funding through the programme after 2011 but third party investments remain stable at 2 million CHF per year for future projections with constant CO_2 saving efficiencies per CHF at 2010 level.

Heavy vehicle charges (LSVA)

Estimates of CO_2 savings due to the heavy vehicle charges are based on Ecoplan/INFRAS (2012). We attribute only about a third of these CO_2 savings to the heavy vehicle charges and the remainder to increasing carrying capacities (from 28 t to 40 t per truck), which are implicitly taken into account under the sub-cluster *increasing efficiency* below. It is assumed that the charges stay constant at their 2012 level and therefore the CO_2 savings as well.

Increasing efficiency (CO_2 emission regulations for new passenger cars, energy label for new motor vehicles, target agreements with Swiss car importers)

The sub-cluster *increasing efficiency* contains several measures related to efficiency increase in the transport sector such as the *energy label for new motor vehicles* (Energieetikette), *CO_2 emission regulations for new passenger cars,* and *target agreements with Swiss car importers*. The data were modelled by INFRAS (2015) based on assumptions of the business as usual scenario of Prognos (2012). The CO_2 Act of 2011 sets a limit for CO_2 emissions for new cars at 130 g CO_2/km in 2015. No limits apply beyond this date but it may be assumed that the same limit is maintained. In the EU, the ceiling will be lowered gradually to 95 g CO_2/km in 2020. This should encourage the production of more fuel-efficient cars for the European market, cars that will also penetrate the Swiss market but at a slower pace as car buyers in Switzerland will not be penalized for buying cars emitting between 95 and 130 g/km. It is therefore assumed that the limit of 95 g CO_2/km is reached in Switzerland with a 10 year delay. Thus, we assume in the WEM scenario an efficiency of 130 g CO_2/km in 2015 and a linear decrease to 95 g CO_2/km in 2030. For the WOM scenario, we assume that the past increase in efficiency for new passenger cars would have been only half that of the WEM scenario. For the future, we assume a reduction of only 15%, since after 2015 the efficiency increase is mainly driven by stricter regulation in the EU, which affects both the WEM and WOM scenarios. As a result, annual CO_2 savings decrease after 2015 (Figure 13).

Table 6: Data sources and assumptions for the impact assessment of the cluster *transport*
Data sources
▪ **EcoDrive:** Annual data of CO_2 savings and investments are available between 1990 and 2010 based on the SwissEnergy programme impact assessment reports (e.g. INFRAS 2011). ▪ **Heavy vehicle charges (LSVA):** Data on annual CO_2 savings are based on Ecoplan/INFRAS (2012). Annual data on the levy are taken from EZV (2015). ▪ **CO_2 emission regulations for new passenger cars, energy label for new motor vehicles, target agreements with Swiss car importers:** Annual data on increasing efficiencies of the Swiss car and truck fleet are based on INFRAS (2015). Investments are based on expert estimates.

Table 6: Data sources and assumptions for the impact assessment of the cluster *transport*

Assumptions

EcoDrive

Ex post
- From 2007 to 2010, impacts from the climate cent foundation are also accounted for.

Ex ante
- After 2010, the subsidies of the SwissEnergy programme are discontinued while third party investments remain stable at 2 million CHF per year with stable CO_2 saving efficiencies per CHF.

Shares of energy carriers (1990–2030)
- Diesel 50 %, gasoline 50 %

Shares of economic sectors
- It is assumed that gasoline is mainly consumed by households and diesel by firms. The allocation of diesel consumption by sectors is based on refined petroleum consumption for road transportation purposes computed by the GEMINI-E3 model. The shares are illustrated in Figure 12 for the calibration year 2008.

Double counting
- The transport cluster also comprises measures of the cluster *SwissEnergy programme*. In order to avoid double counting, related impacts are only considered under this transport cluster.

Heavy vehicle charges (LSVA)

Ex post
- Only one third of the impact estimated in Ecoplan/INFRAS (2012) is attributed to the heavy vehicle charges.

Ex ante
- It is assumed that the levy remains constant at its 2014 level for the period 2015-2030.

Shares of energy carriers (1990-2030)
- Diesel 100%

Shares of economic sectors (1990-2030)
- It is assumed that diesel is consumed by firms. The allocation of diesel consumption by sectors is based on refined petroleum consumption for road transportation purpose computed by GEMINI-E3. The shares are illustrated in Figure 12 for the calibration year 2008.

Double counting
- The heavy vehicle charges are not simulated in GEMINI-E3.

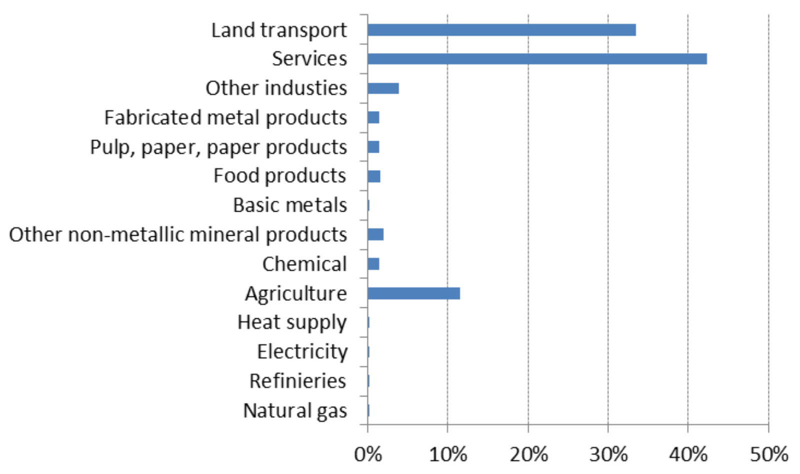
CO_2 emission regulations for new passenger cars, energy label for new motor vehicles, target agreements with Swiss car importers

Ex post
- Energy consumption by road traffic is based on a bottom-up model approach, taking into account the composition of the Swiss vehicle fleet (INFRAS 2013). It differentiates vehicle classes (e.g. passenger cars, busses, HCV, LDV), fuel types (gasoline, diesel, electric vehicles) as well as emission standards (Euro 0 – Euro 6). Energy consumption and related emissions are derived from the composition of the fleet, distances travelled according to road type, specific fuel consumption as well as fuel types (e.g. share of biofuels). Rail transport is also taken into account in the impact assessment using INFRAS (2015).

Ex ante
- Data on future evolution of fleet composition, share of fuel types and emission standards are based on

Table 6: Data sources and assumptions for the impact assessment of the cluster *transport*
the business as usual (WWB) scenario developed by Prognos (2012). The underlying model was adapted for the project based on more recent data on fuel sales.
Shares of energy carriers (1990/2030, linear interpolation in-between) ▪ Diesel 22/49%, gasoline 74/44%, electricity 4/7%
Shares of economic sectors (1990-2030) ▪ It is assumed that gasoline is mainly consumed by households and diesel by firms. The allocation of diesel consumption by sectors is based on refined petroleum consumption for road transportation purpose computed by GEMINI-E3. The shares are illustrated in Figure 12 for the calibration year 2008.
Double counting ▪ The transport cluster also comprises measures of the SwissEnergy programme. In order to avoid double counting with the cluster *SwissEnergy programme* (e.g. energy label), related impacts are only considered under this transport cluster.

Figure 12: Shares in % of refined petroleum consumption for road transportation by sectors in 2008

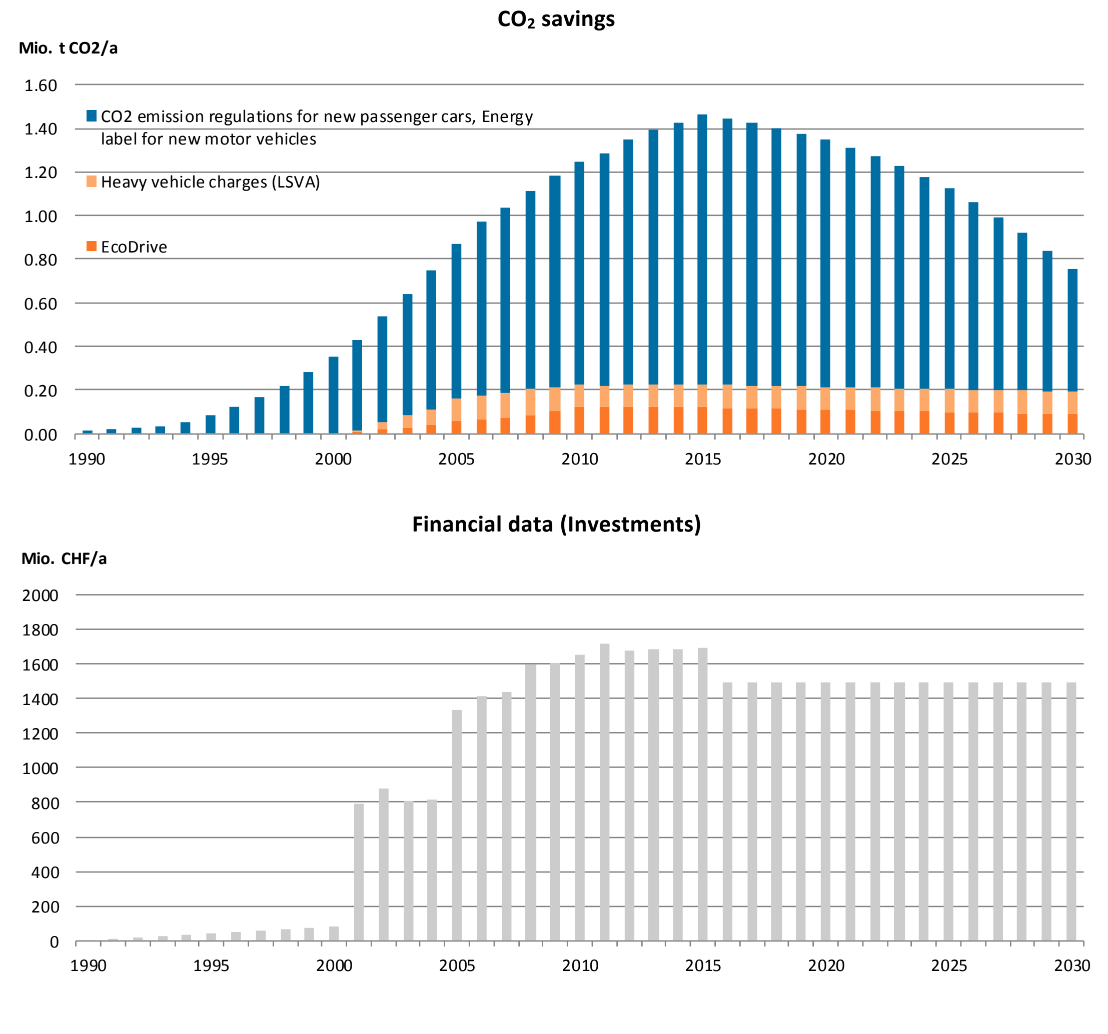


3.4.2. CO_2 savings and financial data

Following the bottom-up assessment, CO_2 savings from measures related to transport amount to about 1.4 million tonnes per year in 2015. The largest contributions stem from efficiency measures (approximately 80%) reducing fossil fuel consumption of the entire car and truck fleet.

Other measures contribute only minor amounts. EcoDrive (as part of the SwissEnergy programme) contributes 13% and the heavy vehicle charges 6% respectively to the total CO_2 savings in the transport cluster. In 2015, financial investments and the heavy vehicle charges within the cluster *transport* amount to about 1500 Mio. CHF annually.

Figure 13: Bottom-up assessment of annual CO_2 savings and investments attributable to the cluster *transport*



Time series of total impact in terms of CO_2 savings from various measures attributed to the cluster *transport* since 1990 as well as future projection (upper part). Related financial data are shown in the lower part.

3.5. Renewable electricity production

3.5.1. Data sources and assumptions

Domestic electricity production in Switzerland comprises mainly hydropower plants and nuclear power plants. Thus, currently, electricity production contributes very little to total CO_2 emissions. Under our assumptions regarding the phasing-out of existing nuclear power plants (cf. sect. 4.4.2), we expect fossil fuel-based electricity production to increase, in particular in combined-cycle gas turbine (CCGT) plants. By promoting electricity production from renewable energy, the future increase in electricity demand can partly be covered and the fossil fuel-based electricity production is reduced as compared to a scenario without promotion of renewable energies. An increase in electricity production from renewable sources has therefore an indirect impact on CO_2 emissions.

The most important measure regarding promotion of technologies for electricity generation from renewable sources is the feed-in tariff (*kostendeckende Einspeisevergütung* KEV) for renewable electricity production. For eligible technologies, the feed-in tariff covers the difference between the cost of production and the market price for electricity supplied to the grid. The feed-in tariff is implemented in GEMINI-E3 based on the assumptions presented in the following sections.

Table 7: Data sources and assumptions for the impact assessment of the renewable electricity production cluster
Data sources
▪ Annual reports of the KEV foundation provide annual data on the amount of subsidised electricity production as well as on related financial data (KEV 2010-2015) ▪ Annual electricity production for 2014 is provided by the Swiss federal office of energy (BfE 2015)
Assumptions
Ex ante ▪ It is assumed, that the amount of subsidised electricity remains constant after 2016, since only existing measures are taken into account.

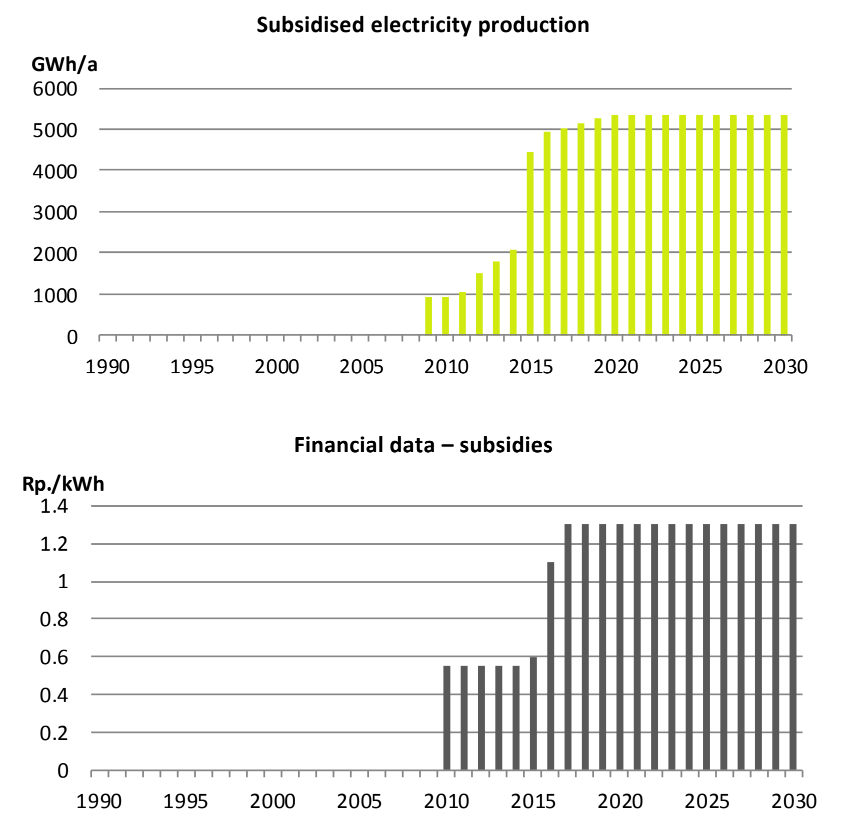
3.5.2. Renewable electricity production and financial data

The feed-in tariff was implemented in 2009 for promoting electricity generation from renewable energy sources. It covers the difference between the cost of production and the market price. The feed-in tariff covers small-scale generation of electricity such as hydropower plants (<10MW), photovoltaics (>10kW), wind energy, geothermal energy, biomass and biological waste. Small photovoltaic plants are eligible for a one-time investment subsidy.

The amount of subsidised electricity production continuously increased since 2009. Since in the WEM scenario only existing measures are considered, it is assumed that the amount remains constant in the future.

The feed-in tariff is funded by a network surcharge per consumed kilowatt-hour that is paid by all electricity consumers. Between 2009 and 2013, it amounted to 0.55 ct/kWh. It is rising since 2014 (2014: 0.6 ct/kWh, 2015: 1.1 ct/kWh, 2016: 1.3 ct/kWh). Large electricity consumers can apply for a refund of the fee if they commit to a target agreement on energy efficiency. In addition, they are required to invest 20% of the refund into energy efficiency measures.

Figure 14: Bottom-up assessment of electricity production and subsidies attributable to the cluster *renewable electricity production*



4. Top-down impact assessment

The bottom-up estimations of the previous chapter provide the CO_2 savings that can be attributed to non-price measures. Thus, they account for part of the wedge between the WEM and WOM scenarios of CO_2 emissions. This chapter shows how the WEM scenario itself is calculated (sect. 4.1), a calculation for which energy efficiency improvements play a central role. The WOM scenario is derived from the WEM scenario by factoring in the CO_2 savings and investments computed by the bottom-up assessment for non-price measures as well as the simulated effects of the price measures. This is done with the help of the macroeconomic simulation model GEMINI-E3, briefly presented in section 4.2. The price measures and how they are implemented in the model are described in section 4.3. The results of the respective simulations are presented in section 4.3.3.

4.1. Estimated energy efficiency improvements in the WEM scenario

This section shows how the total energy efficiency improvement (TEEI) is calculated for the most important energy uses in the WEM scenario. As indicated in section 2.4, the point of reference for the future, i.e. for the period 2015-2030, is the WWB scenario of the *Energy perspectives* (Prognos 2012). As a first stage of simulation, we correct the paths of energy consumption for the differences in non-prices policies. In the second stage, described in sections 4.3 and 4.3.3, we use simulations with GEMINI-E3 to make corrections for the differences in policies between the WWB and the WEM scenario that affect prices.

As a result, we first show below the TEEI for a scenario that is similar to WWB except that the non-prices policies are those of WEM. The correction performed is represented in Figure 6 in section 2.4. Comparison with Figure 7 shows how this corrected WWB (or WWB') scenario differs from the WOM and WEM scenarios.

4.1.1. Efficiency improvement in households' residential energy use

The historical and expected energy use in the WWB scenario (EU_{WWB}, Table 8) are drawn from Table 7-10 of the *Energy perspectives* (Prognos 2012). The historical data are corrected for fluctuations in weather conditions. 2000 was characterized by a relatively warm winter, with 3081 heating degree days (HDD). In contrast, 2010 was a relatively cold year with 3585 HDD. For the forecast period, Prognos (2012) and Switzerland's Sixth National Communication under the UNFCCC (Swiss Confederation 2013, table 29) assume a gradually warmer climate. In the latter, HDD decrease to 3244 in 2020 and 3064 in 2030. The energy used for heating per energy reference area decreases through time under the combined effects of a warmer climate, better insulated buildings, more effective conversion of primary to useful energy, and possible changes in user behaviour. Some of this $TEEI_{WWB}$ can be considered as AEEI because it is independent of price and policy changes. The rest is triggered by rising market prices for oil (MPIEEI) and the energy and climate policy measures assumed in the WWB scenario (PIEEI). In particular, the CO_2 levy is gradually raised from 36 CHF/t CO_2 in 2010 to 72 CHF/t CO_2 in 2016 in the WWB, and then stays at that level. The national buildings refurbishment programme is endowed with 200 Million CHF per year. The standards for the energy efficiency of new buildings are adapted to the assumed AEEI. These assumptions do not correspond to the WEM scenario. Hence, their estimated effects must be extracted from $TEEI_{WWB}$ in order to return to the $TEEI_{WOM}$ of the baseline (WOM), before the efficiency effects of the actual policies are factored back into the energy consumption pathway, finally yielding $TEEI_{WEM}$ and EU_{WEM}.

At this stage, the only correction we make relative to EU_{WWB} is for the fact that the WEM scenario has more funds in the national buildings refurbishment programme than anticipated in the WWB scenario – 300 million CHF instead of 200 million. This leads to faster TEEI in the corrected WWB' scenario than in the original WWB scenario: 3.2%/year on average between 2010 and 2020 compared to 3.1%/year. This looks like a small correction, because it is only the difference between $EEEI_{WWB'}$ and $EEEI_{WWB}$, but since $EEEI_{WWB}$ will be used to compute EU_{WOM} and $EEEI_{WWB'}$ will be used to compute EU_{WEM}, it is the full magnitude of EEEI that will drive a wedge between WOM and WEM (Figure 7).

Table 8: Energy efficiency improvement – Residential energy consumption

	2000	2010	2020	2030
Energy consumption for heating (kWh/m^2, Prognos 2012, WWB, Table 7-10, p. 250)	129.9	106.4	78.1	58.3
Energy consumption for heating corrected for additional funds for the national buildings refurbishment programme (kWh/m^2, WWB')	129.9	106.4	77.5	57.8
		2000-2010	2010-2020	2020-2030
Total energy efficiency improvement ($TEEI_{WWB'}$) per year		2.0%	3.2%	3.0%
	2000	**2015**	**2020**	**2030**
Energy consumption for heating (kWh/m^2, WWB)	129.9	92.3	78.1	58.3
Energy consumption for heating corrected for additional funds for the national buildings refurbishment programme (kWh/m^2, WWB')	129.9	92.0	77.5	57.8
		2000-2015	2015-2020	2020-2030
Total energy efficiency improvement ($TEEI_{WWB'}$) per year		2.3%	3.5%	3.0%

WWB' = WWB with national buildings refurbishment programme as in WEM

The second part of Table 8 is based on the first, with the year 2015 interpolated between 2010 and 2020. Indeed, we will distinguish whenever possible between historical data until 2014 or 2015 and forecasts beyond. In this case, it is not possible to do better than this interpolation.

The next stage involves subtracting the effects of the CO_2 levy as modelled in the Prognos WWB scenario from the path of energy consumption for heating in Table 8 and adding in the effects of the actual and predicted CO_2 levy according to the WEM scenario. This is shown in section 4.3 with simulations carried out with GEMINI-E3.

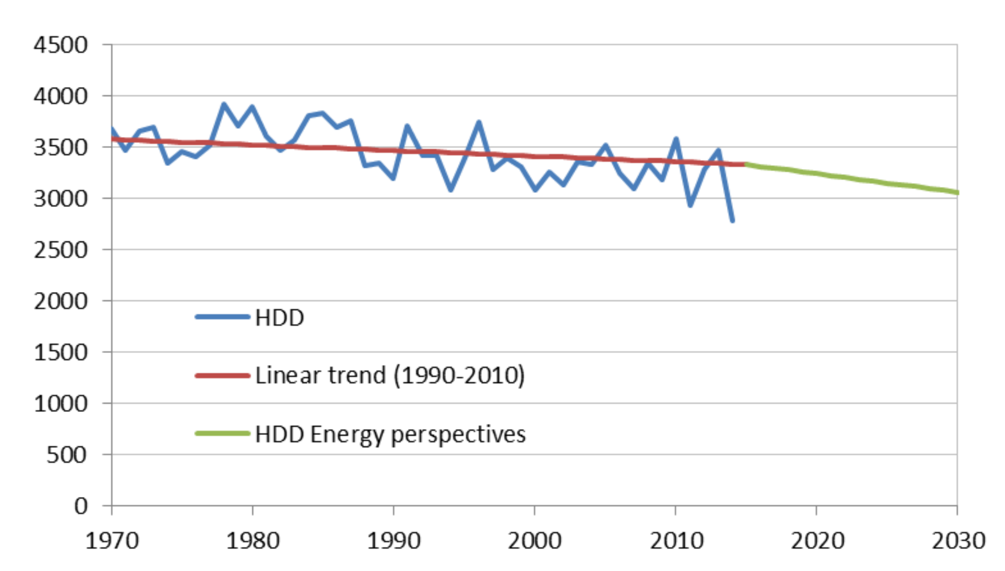
4.1.2. Efficiency improvement in energy consumption by the services sector

Energy efficiency improvement in the services sector is estimated from the ratio of its energy consumption to the total energy reference area of buildings used by this sector, using tables 5-32 (column WWB) and 3-4 of Prognos (2012).

The data for heating energy consumption in 2000 and 2010 in table 5-32 are actual data, affected by weather conditions. Between these two years, the energy used for heating increased by 4.2% while the energy reference area increased by 8.7%. This shows only part of the heating energy efficiency improvement, as 2010 was substantially colder than 2000. The increase in HDD caused energy use to decrease less than if the weather had been the same.

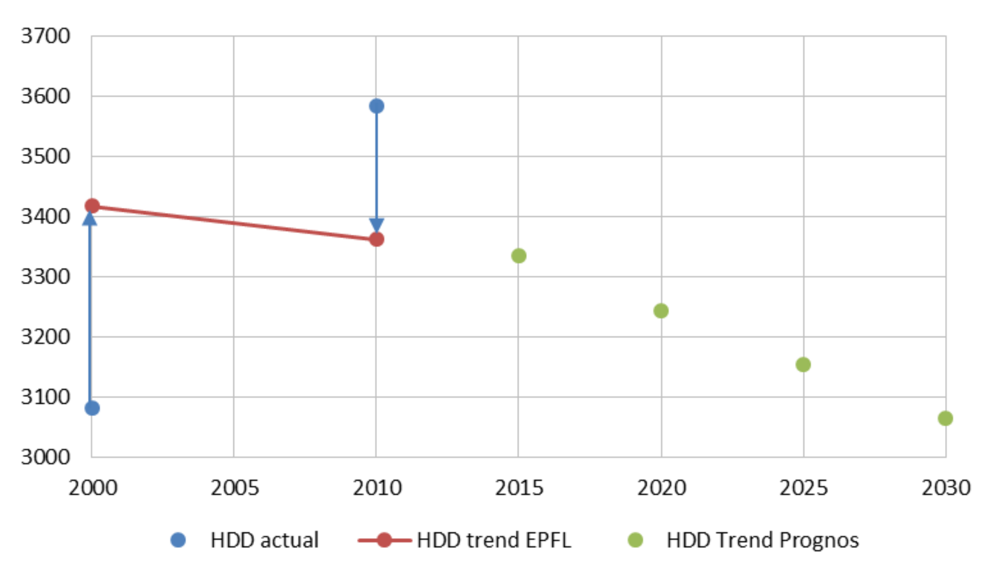
In order to make the energy use data for all years from 2000 until 2030 comparable, we need to estimate the "normal" HDD on a trend line that is compatible with the one used in Prognos (2012) after 2010. This trend line is estimated by fitting it to the actual HDD for the period 1990-2010[6] (Figure 15). Figure 16 illustrates the correction of heating energy use in 2000 and 2010 by projection on this trend line. A gradually warmer climate is assumed for the future, based on the projections of Switzerland's Sixth National Communication under the UN-FCCC (Swiss Confederation 2013, table 29).[7]

Figure 15: Trend HDD, adjusted to actual data for 1990-2010 and extrapolated based on Swiss Confederation (2013, table 29)



[6] The trend line fitted to the data of 1990-2010 reaches a value in 2015 very close to the value retained by Swiss Confederation (2013, table 29). We extrapolate it back to 1970.
[7] This is explained on p. 40 of Prognos (2012).

Figure 16: Correction of heating energy use for HDD



Heating energy use is not proportional to HDD. We have an estimate for a 50% rebound effect (Winkler et al., 2014). This implies that energy use increases only by half of the increase of HDD, *ceteris paribus*.[8] On this basis, we correct energy use by only half of the difference in HDD between actual and trend values. A further correction is made for the fact that the national buildings refurbishment programme has more funds available in the WEM scenario than in the WWB scenario. This correction is similar to the one made for residential energy consumption. It yields the WWB' scenario.

[8] Rebound effects are generally defined for a warmer weather, which would allow for a substantial decrease in heating energy use but users 'rebound', i.e. they take advantage of lower heating costs to increase their room temperature, to air their rooms more frequently, etc. As a result, heating energy uses decreases by a smaller proportion than the HDD. The mirror effect is assumed here for cooler weather: users mitigate the increase in heating costs by reducing room temperature, airing more efficiently, etc. As a result, heating energy use increases by less than the proportional increase in HDD. Ecoplan (2012) uses a ratio of 65% between change in energy use and change in HDD (p.7).

Table 9: Energy efficiency improvement – Energy consumption by the services sector

	2000	**2010**	**2020**	**2030**
Energy reference area (million m², Prognos 2012, Table 3-4, p. 60)	139.7	151.8	161.88	171.6
Heating energy consumption (PJ, Prognos 2012, WWB, Table 5-32, p. 150)	79.2	82.5	71.0	64.6
Heating energy consumption corrected for additional funds for the national buildings refurbishment programme (PJ, WWB')	79.2	82.5	70.3	63.9
Heating degree days (Swiss Confederation 2013, Table 29, p. 154)	3081	3585	3244	3064
Trend heating degree days	3417	3362	3244	3064
Heating energy consumption on trend HDD (PJ, WWB')	83.5	79.9	70.3	63.9
Other energy consumption (PJ, Prognos 2012, WWB, Table 5-32, p. 150)	61.7	69.9	80.5	87.1
Total energy consumption on trend HDD (PJ, WWB')	145.2	149.8	150.8	151.0
Energy consumption per m² (GJ, WWB')	1.04	0.99	0.93	0.88
		2000-2010	2010-2020	2020-2030
Total energy efficiency improvement ($TEEI_{WWB'}$) per year		0.5%	0.6%	0.6%
	2000	**2015**	**2020**	**2030**
Energy consumption per m² (GJ, WWB')	1.04	0.96	0.93	0.88
		2000-2015	2015-2020	2020-2030
Total energy efficiency improvement ($TEEI_{WWB'}$) per year		0.5%	0.6%	0.6%

WWB' = WWB with national buildings refurbishment programme as in WEM

4.1.3. Efficiency improvement in energy consumption by industry

Energy efficiency improvement for industry is estimated from the ratio of its energy consumption to its total value added, using table 7-35 (WWB) of Prognos (2012).

Table 10: Energy efficiency improvement – Energy consumption in industry

	2000	2010	2020	2030
Energy consumption per gross value added (PJ per billion CHF, Prognos 2012, WWB, Table 7-35, p. 294)	1.38	1.24	1.13	0.97
		2000-2010	2010-2020	2020-2030
Total energy efficiency improvement ($TEEI_{WWB}$) per year		1.1%	0.9%	1.5%
	2000	**2015**	**2020**	**2030**
Energy consumption per gross value added (PJ per billion CHF, WWB)	1.38	1.19	1.13	0.97
		2000-2015	2015-2020	2020-2030
Total energy efficiency improvement ($TEEI_{WWB}$) per year		1.0%	1.0%	1.5%

Following Prognos, the TEEI is strongest over 2020-2030 in all three groups of little, moderately and strongly energy intensive sectors. When one looks at specific sectors, it appears that this acceleration of TEEI is particularly pronounced in two dominating sectors: chemistry and electric engineering. Therefore, this irregularity in TEEI rather results from the developments in specific sectors than to the changing importance of sectors (cf. also fig. 3-6 on p. 57 and fig. 5-40 on p. 162 of Prognos, 2010). The EEI in each sector is the result of technological developments and product reallocations estimated by Prognos in bottom-up analyses. For the most important sector – chemistry – their report only indicates that the pharmaceutical segment is the main driver (p. 411, Prognos 2012).

4.1.4. Efficiency improvement in energy consumption by railway transport

GEMINI-E3 has one aggregated transport sector, which groups person and freight transportation by all modes. It uses gasoline, diesel and electricity. In order to compute the energy efficiency improvements for these energy forms, we assume that all gasoline and diesel is consumed by cars and all electricity by trains. In fact, railways account for 72% of total electricity consumption by the land transport sector in 2008, based on the Swiss input-output table 2008 (Nathani et alii, 2011).

The energy consumption by railways is given in Table 7-41 of Prognos (2012) for the WWB scenario. Energy efficiency is computed from the ratio of this total energy consumption to the total "output" of railways. This output is an aggregate of passenger and freight transport by rail computed from the data in Table 3-5 of Prognos (2012), obtained by multiplying the two types of output by their implicit price and adding them. The implicit prices are derived from the 2008 values of revenues from transport and freight transportation. In 2008, the average price of passenger transport is equal to 24 cts/km and the average price of freight is 12 cts/t×km. In the absence of other data, we assume that the ratio of these prices is constant from 2000 until 2030.

Table 11: Energy efficiency improvement – Electricity consumption by railways

	2000	2010	2020	2030
Energy consumption railway passenger (PJ, Prognos 2012, WWB, Table 7-41, p. 310)	7.1	8.7	9.6	10.3
Energy consumption railway freight (PJ, Prognos 2012, WWB, Table 7-41, p. 310)	2.8	3.2	4.2	4.5
Output at constant 2008 prices (Mio CHF_{2008})	4753	6215	8065	9339
Energy consumption relative to activity (joule per CHF_{2008})	2083	1915	1711	1585
		2000-2010	2010-2020	2020-2030
Total energy efficiency improvement ($TEEI_{WWB}$) per year		0.8%	1.1%	0.8%
	2000	**2015**	**2020**	**2030**
Energy consumption railways (PJ, WWB)	9.9	12.9	13.8	14.8
Output at constant 2008 prices (Mio CHF_{2008})	4753	7140	8065	9339
Energy consumption relative to activity (joule per CHF_{2008})	2083	1800	1711	1585
		2000-2015	2015-2020	2020-2030
Total energy efficiency improvement ($TEEI_{WWB}$) per year		1.0%	1.0%	0.8%

The irregular path in the TEEI is solely due to the decrease of total energy efficiency of railway freight between 2000 and 2010 in the INFRAS data used by Prognos (2012),[9] so that 2010 is a year of relatively low energy efficiency, which is corrected in the following decade.

4.1.5. Efficiency improvement in energy consumption by road transport

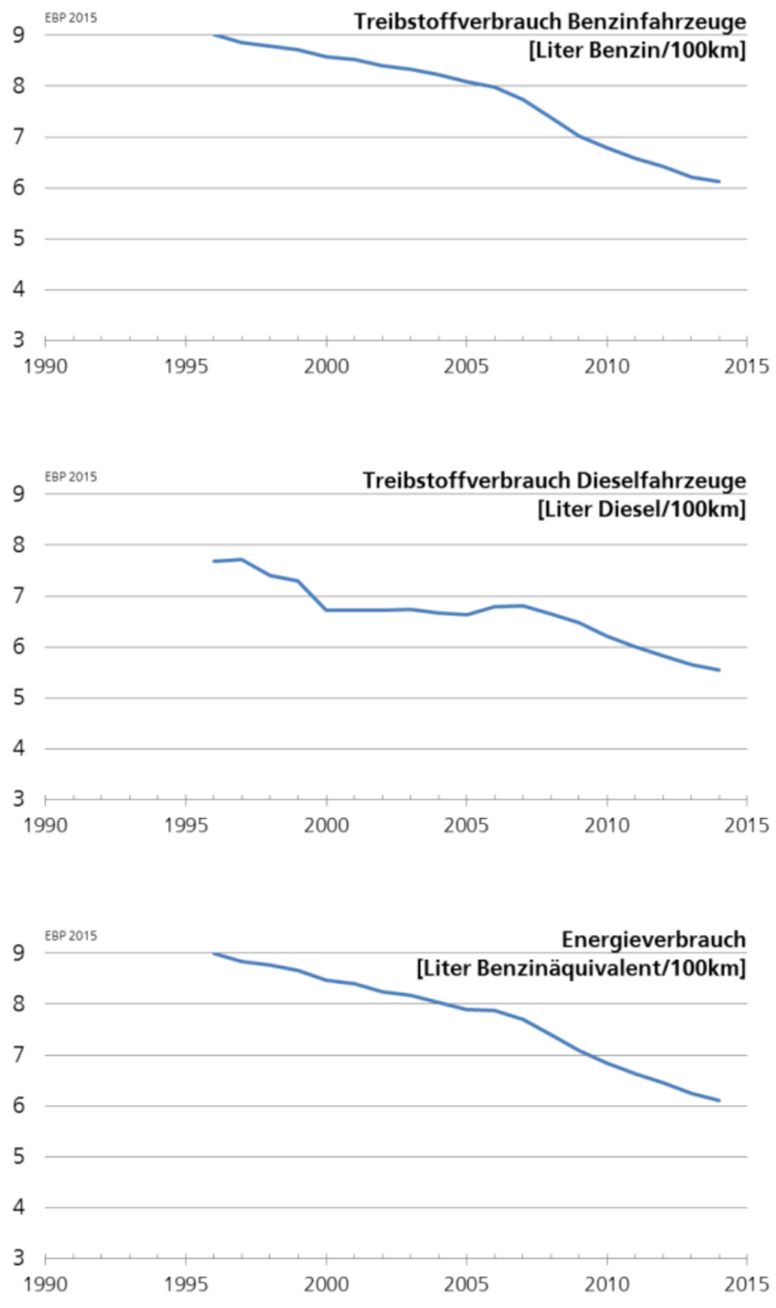
The EEI estimated for cars will serve in the model to represent the rate at which the transportation sector reduces its consumption of gasoline and diesel through time for the same transportation services.

Between 1996 and 2014, data on the evolution of specific emissions in g CO_2/km are available (Figure 17). Even though constraining regulation was implemented only in 2012, the specific emissions have been decreasing from the beginning of measurement. This could be due to the Ordinance on the reduction of the specific fuel consumption of cars of 18 December 1995, which was replaced by appendix 3.6 of the Energy Ordinance of 7 December 1998. Even though

[9] The specific energy consumption of railway freight increases from 0.28 MJ/t×km in 2000 to 0.32 MJ/t×km in 2010, before it decreases to 0.29 MJ/t×km in 2020 and 0.26 MJ/t×km in 2030.

the Ordinance was not constraining, it included an option for regulation if a target path of fuel efficiency improvement was not met. The actual path missed the targets every year, yet no regulation was implemented. Instead, the Ordinance was replaced in 2002 by the voluntary agreement with Swiss car importers, which set a new path for fuel efficiency, not to be followed either. Nevertheless, the fuel efficiency of new cars kept increasing slowly, leading even more slowly to improved fuel efficiency of the fleet and, ultimately, to a stabilization of CO_2 emissions by cars, and even a decline after 2010.

Figure 17: Specific fuel consumption of new cars (EB+P, 2015, p. 4)

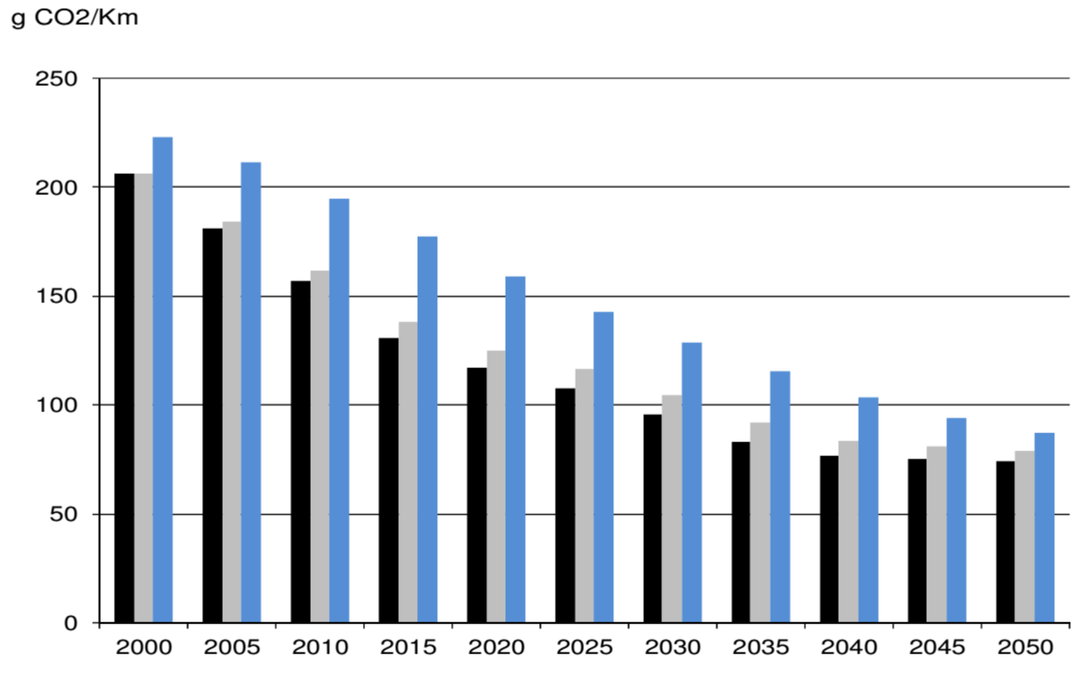


The fuel consumption per 100 km of new cars decreased from 9.00 litres of gasoline equivalent in 1996 to 8.47 litres in 2000, 6.85 litres in 2010 and 6.11 litres in 2014 (EB+P, 2015, p. A1-28). This implies a TEEI of 1.5%/year between 1996 and 2000, 2.1%/year between 2000 and 2010 and 2.9%/year between 2010 and 2014. Of course, these numbers apply only to new cars.

They reflect changes in preferences, incomes, fuel prices and regulation, not only technology, to the extent that these factors alter the types of car purchased.

For the WEM scenario, we need numbers on fuel efficiency from 1990. Fuel consumption increased by 9.8% between 1990 and 2000. According to our estimations of road transportation services in GEMINI-E3, they increased by about 13% over that period, which implies a TEEI of 0.3% per year (WEM scenario). This number compared to the TEEI for new cars suggests that it is really for new cars after 1995 that fuel efficiency was improved and this affected the fuel efficiency of the whole fleet with substantial delay. For the time after 2000, we can use the estimates in Prognos (2012, fig. 7-29 reproduced below as Figure 18) for the CO_2 emissions of new and all cars. The resulting TEEI are shown in Table 12.

Figure 18: CO_2 emissions per car for new cars and all cars in WWB scenario (reproduced from Prognos, 2012, fig. 7-29)



The first bar represents the average CO_2 emissions per km of all new cars based on manufacturers' declarations. The second bar corrects the first number to account for more realistic driving conditions. The third bar represents the average CO_2 emissions per km of all cars, incorporating new cars according to their actual emissions.

Table 12: Energy efficiency improvement – Road transport				
	2000	2015	2020	2030
Average CO_2 emissions of all cars (grams per km, Prognos 2012, WWB, Fig. 7-29, p. 305)	223	177	158	127
		2000-2015	2015-2020	2020-2030
Total energy efficiency improvement ($TEEI_{WWB}$) per year, whole fleet		1.5%	2.2%	2.2%

The WWB scenario in Prognos (2012) assumes that new cars have to satisfy an emissions limit of 130 g/km (based on manufacturers' declaration) in 2015 and that there is no further tightening of this limit beyond 2015, but that some measures are taken to make this average decrease gradually to 95 g/km in 2030 (Prognos 2012, p.304). Our analysis of the current legal conditions in Switzerland (sect. 3.4) suggests that this is still the most appropriate assumption for the WEM scenario. Since energy and climate policy in the transportation sector (cars) rest entirely on non-price measures, we do not need GEMINI-E3 simulations to derive the WOM from the WEM scenario[10].

4.1.6. Energy efficiency improvements in the WWB' scenario

Table 13 reports the *ex-post* and predicted energy efficiency improvements replicated in the WWB' scenario. For road transport, the energy efficiency improvement is evaluated for the whole fleet using Figure 7-29 (private cars) and 7-31 (LGV) of Prognos 2012, where also values for the whole fleet are documented. For trucks only 0.5%/year are assumed (see page 306).

Table 13: Total energy efficiency improvement (TEEI) per year in the WWB' scenario				
	1990-2000	2000-2014	2015-2020	2020-2030
Residential	1.5%	2.3%	3.5%	3.0%
Services	0.6%	0.5%	0.6%	0.6%
Industry	0.4%	1.0%	1.0%	1.5%
Electricity in transport (railways)	0.4%	1.0%	1.0%	0.8%
Gasoline and diesel in transport (cars)	0.3%	1.5%	2.2%	2.2%

4.2. GEMINI-E3 simulation model

The industrial classification used in GEMINI-E3 for this study comprises 18 sectors (Table 14). The model describes six energy goods and sectors: coal, oil, natural gas, petroleum products,

[10] The "climate cent" – which actually amounted to 1.5 ct/litre and was levied by oil importers between 1 October 2005 and 31 December 2012 to pay for compensation measures – was so small relative to gasoline and diesel prices (about 1%) that it is not deemed to have significantly affected motor fuel use.

electricity and heat supply. Considerable effort was spent for obtaining a good description of the main energy intensive industries and for identifying in each sector the share of firms that are allowed to participate in the Swiss emissions trading scheme (ETS). Concerning the regions represented by the model, we use an aggregated version of GEMINI-E3 that describes five countries/regions: Switzerland, European Union, United States of America, BRIC (Brazil, Russia, India and China) and the rest of the world.

The current version is built on the Swiss input-output table 2008 (Nathani et alii, 2011) and the GTAP database 8 (Narayanan et alii, 2012) for the other countries. The *calibration year* called sometimes *reference year* is the year 2008. The equations of the model are calibrated on this reference year, for which all the information relative to the variables (exogenous and endogenous) used in the model is available. A calibration procedure was also implemented on the past (1990-2014) in order to ensure that the model is able to reproduce the historical economic development with the associated energy consumptions and CO_2 emissions.

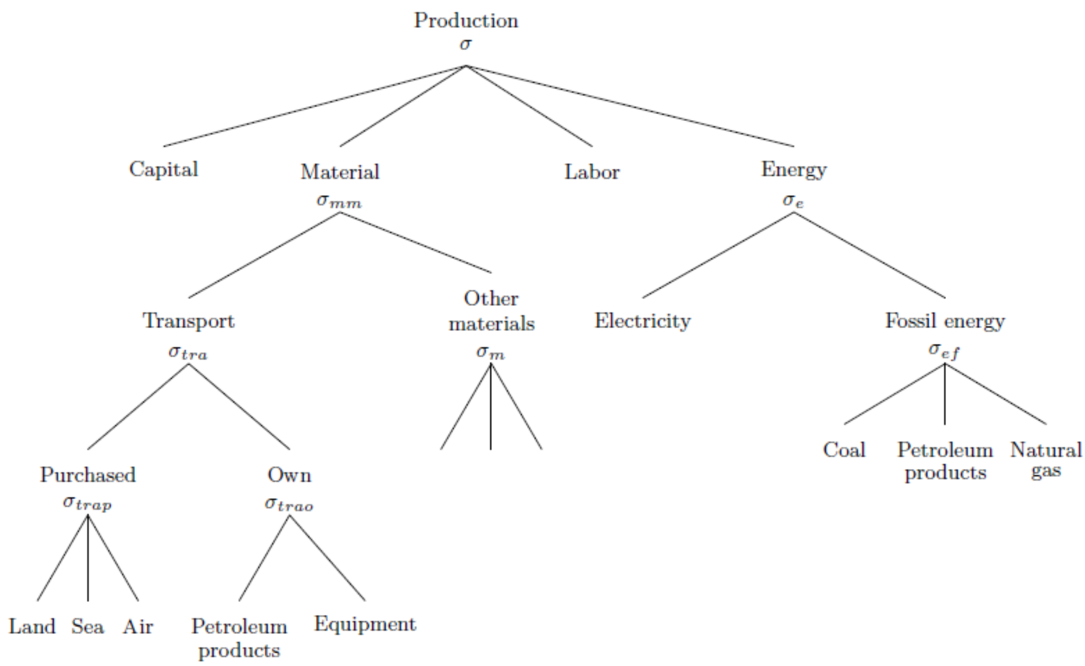
Table 14: Industrial and regional classifications

Sectors/goods		Countries/regions	
01	Coal	CHE	Switzerland
02	Crude oil	EUR	European Union
03	Gas	USA	United States of America
04	Petroleum products	BRIC	Brazil-Russia-India-China
05	Electricity	ROW	Rest of the world
06	Services of public heat supply		
07	Agriculture, forestry and fishing		
08	Chemical, rubber and plastic products		
09	Other non-metallic mineral products		
10	Basic metals		
11	Food products, beverage and tobacco products		
12	Pulp, paper, paper products, wood and wood products		
13	Fabricated metal products, except machinery and equipment		
14	Other industries		
15	Services		
16	Land transport		
17	Sea transport		
18	Air transport		

Energy demand

Domestic energy demand is equal to the sum of energy consumed by firms as a production factor and energy consumed by households as a final good. The production structure of the industrial sectors is shown in Figure 19.

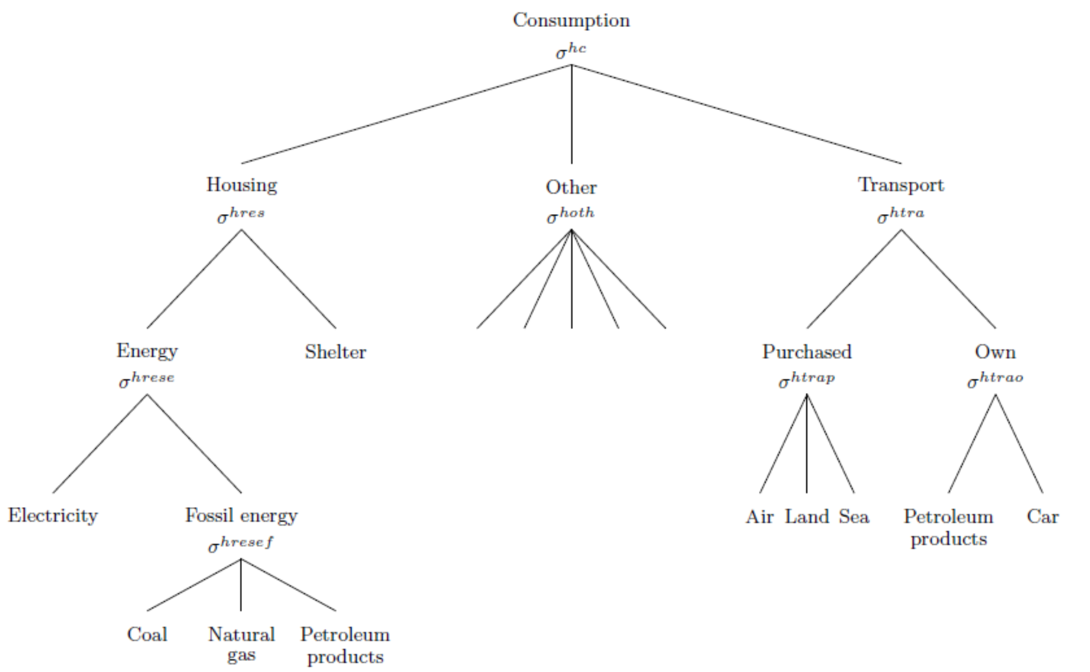
Figure 19: Nested constant elasticity of substitution (CES) production structure



Consumption choices are represented as resulting from the optimization choices of a single representative household. This household uses every year its disposable income to purchase the bundle of goods that gives it greatest satisfaction (Figure 20). Its choices will be affected by the relative prices of these goods. For instance, suppose transportation prices increase. That raises the relative price of transport compared to housing and other goods, so the household will buy less transport and more of these alternative goods. The intensity of this substitution depends on the amplitude of change of the relative prices and on the household's willingness or capacity to replace one good by another. This last determinant is measured by elasticities of substitution. In simulations, one starts from a statistically observed bundle of consumer goods and then lets changes in relative prices provoke deviations from this bundle through substitutions between alternative goods. In addition to composing its bundle of consumer goods, the representative household is modelled as a kind of producer, in that it "makes" some of the goods it consumes itself. It combines different modes of transportation (its own vehicle and public transport by land, sea or air) to create the transport services (or mobility) it enjoys. Similarly, the representative household combines capital (shelter) and energy (for heating and appliances) to create the housing services it consumes. These combinations are modelled in a similar fashion as for the production sectors, with elasticities of substitution being the main parameters. Energy enters the household's choices indirectly, in the production of transport and housing services. When fossil fuels become more expensive, e.g. due to the CO_2 levy, the households replaces some fossil fuel by electricity (mostly heat pumps) and some energy by spending more for its shelter (insulation). Even though these substitutions mitigate the impact of higher fossil prices, housing still becomes more expensive, inducing the households to substitute it partly by other goods.

Private transport, one of the modes of transportation, is produced by the household by combining its vehicle with energy (gasoline or diesel). To consume more private transportation, it must use more cars and more petroleum products (remember there is one representative household standing for the full population, so the number of cars is really the ratio of cars to households). If the price of petroleum products increases relative to that of cars, the household will spend a little bit more on cars to choose models that are more fuel-efficient. In addition, private transportation becomes relatively more expensive, inducing the households to replace some of it by public (purchased) transportation and other goods. Thus, the number of cars decreases. Similarly, the household will be able to consume more housing services by buying more shelter capital and more building related energy. In that case, the household can even choose how it obtains that energy, by combining purchases of electricity and fossil fuels.

Figure 20: Nested constant elasticity of substitution (CES) consumption structure



4.3. Implementation of price measures

The CO_2 savings from the non-price policy measures (energy in buildings, SwissEnergy programme and transport) have been estimated bottom-up (chap. 3). They are introduced into the GEMINI-E3 model. For each measure, the impacts on the Swiss energy mix (oil, gas, wood, and electricity in *toe*) are defined, together with the sectors in which these changes in energy consumption are obtained. These *ex-ante* changes in the energy mix are introduced into the model through a modification of the rates of energy efficiency improvement. The model also takes into account the costs of these CO_2 savings expressed in the bottom-up assessment in the form of additional investments. The changes in capital consumption are also introduced into the model through changes in the technical progress associated with capital expenditures.

Several measures can be implemented directly in the GEMINI-E3 model without intermediate bottom-up estimation. They include CO_2 prices such as the CO_2 levy and the price of emission certificates in the Swiss emissions trading scheme (ETS).

4.3.1. CO_2 levy and ETS price

Since 2008, a CO_2 levy is imposed on heating and process fuels. Over time, it was raised depending on the achievement of a reduction target (Figure 22). In 2014 and 2015, the CO_2 levy was equal to 60 CHF/t CO_2. It was raised to 84 CHF/t CO_2 at the beginning of 2016. Future increases are determined by applying the adjustment rule to the emissions path simulated for the WEM scenario (sect. 4.4.1).

The Swiss ETS market was created in 2008. Participating firms are exempted from the CO_2 levy. Since 2013, participation in the Swiss ETS is mandatory for greenhouse gas intensive firms. The cap is reduced by 1.74% annually. For the WEM scenario, the resulting ETS price for the period 2013-2020 is a result of model simulations (sect. 4.4.1). Beyond 2020, the ETS price is assumed to remain constant. For the WOM scenario, the ETS is not considered.

Some firms can be exempted from the CO_2 levy if they commit to an emission reduction target (*nonETS* regime). The abatement they commit to is implemented in the simulation model through a shadow price on emissions (*PriceNonETS*), sufficient to induce them to fulfil their commitment as though they had to pay it. This shadow price is assumed equal to the Swiss CO_2 levy, which amounts to assuming that the firms commit to the emission reductions they would undertake if they were subject to the CO_2 levy.

In each sector, there could be firms subject to any of these regimes or even entirely exempted (e.g. electricity generation). As the simulation model aggregates firms at the sectoral level, an average CO_2 price is estimated for each sector by multiplying the share of emissions in that sector covered by a specific regime with the respective carbon price:

$$CO_2\,price = (1 - \alpha_i - \beta_i - \mu_i)\; CO_2levy + \alpha_i\, PriceETS + \beta_l\, PriceNonETS + \mu_l\, 0 \qquad (1)$$

α_i, β_i, μ_l being the shares of emissions that are covered by the ETS, the nonETS shadow price or exempted respectively.

Implementation of these measures in GEMINI-E3 is thus based on input data on the shares of emissions and corresponding prices. Regarding future projections, several assumptions about the continuation of these measures are necessary. It is assumed, that all of these measures are continued after 2020 in a similar form. The carbon prices (CO_2 levy, Swiss ETS price and shadow price in the *nonETS* sectors) are maintained at their levels of the year 2020 for the period 2021 to 2030. Since the planned linking of the Swiss and the European ETS is not completed yet, the current Swiss ETS is extended until 2030. The shares of the four possible regimes in the different industrial sectors are assumed constant.

4.3.2. CO_2 compensation for transport fuels

Compensation requirements

The CO_2 emissions that result from the use of transport fuels must be compensated in the following proportions (CO_2 Ordinance of 30.11.2012, art. 89):

2013 and before: 0%

2014-2015: 2%

2016-2017: 5%

2018-2019: 8%

2020: 10%

For the WEM scenario, we shall assume that the 10% compensation is maintained from 2021 to 2030. This compensation requirement applies to gasoline, diesel, natural gas and kerosene. There are a few exceptions, mainly fuels used in public transportation and agriculture, but we will ignore this for the sake of simplicity.

Table 15 indicates the quantities of transport fuels, resulting CO_2 emissions and ensuing compensation requirements for 2014-2030 as predicted by the macroeconomic model under our assumptions about demographic and economic growth, fuel prices and fuel efficiency.

Table 15: Expected transport fuel consumption, CO_2 emissions and offsets (Mt CO_2)

	2014	2015	2016	2017	2018	2019	2020
CO_2 emissions transport (WEM)	15.94	15.58	15.62	15.61	15.57	15.54	15.51
Percentage of compensation	2%	2%	5%	5%	8%	8%	10%
Compensated CO_2 emissions	0.32	0.31	0.78	0.78	1.25	1.24	1.55

2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
15.32	15.24	15.15	15.07	14.98	14.95	14.91	14.84	14.77	14.70
10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
1.53	1.52	1.52	1.51	1.50	1.50	1.49	1.48	1.48	1.47

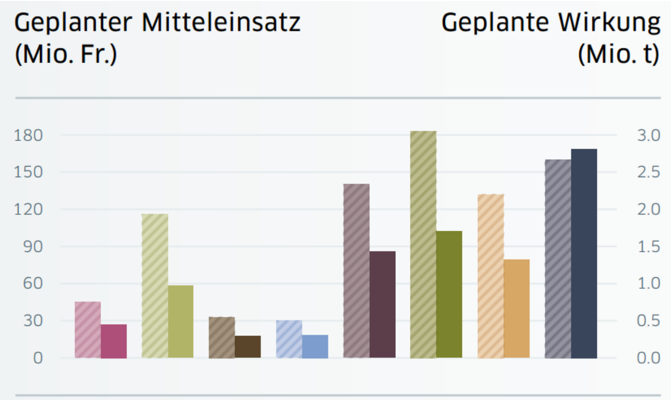
Total compensation requirements amount to 6.23 Mt CO_2 for 2014-2020 and 14.99 Mt CO_2 for 2021-2030, which must be compensated within Switzerland. The admissible options are detailed in BAFU (2015). Offsets can be in the form of all greenhouse gases of the inventory, not only CO_2.

KliK Foundation

The Swiss Petroleum Association, the association of mineral oil importers, created a foundation to fulfil this compensation obligation, the Foundation for Climate Protection and Carbon Offset KliK. It estimates that it will have to offset 6.5 million tonnes CO_2 over 2013-2020, with a peak of 1.5 million tonnes in 2020, which will cost it up to 1 billion CHF or between 1 and 2 cents per litre of motor fuel (KliK Short Profile[11]). The CO_2 Act sets a cap of 5 cents per litre (art. 26).

Despite its estimation of needed offset of 6.5 million tonnes CO_2, KliK displays plans to offset 9.28 million tonnes in the same document (Figure 21).

Figure 21: Planned offsets (KliK Short Profile, German version)



Geplanter Mitteleinsatz (Mio. Fr.)		Geplante Wirkung (Mio. t)
45	Programme Verkehr	0.45
116	Programme Unternehmen	0.97
33	Programme Gebäude	0.29
30	Programme Landwirtschaft	0.31
140	Projekte neu	1.43
183	Projekte Klimarappen	1.70
132	Mehrleistungen	1.32
160	Emissionsrechte	2.81
839	Total	9.28

The simulation of the compensation measures for motor fuels will be based on this Figure 21 but with updated emission reductions potentials as described on the webpages of KliK, in particular on the pages of the different platforms on 24.02.2016. Below, it is shown how this is done for each offset option in decreasing order of importance.

[11] http://www.klik.ch/resources/KliK_Leporello_41.pdf.

Emission rights

In the first phase of the CO_2 Act, from 2008 to 2012, firms could be exempted from the CO_2 tax in exchange for pledges to reduce their emissions. They were granted emission rights for their allowed emissions, which they had to forfeit in proportion of their actual emissions. Overall, they did not use all these rights. The remaining rights were converted into certificates in 2014 and KliK bought them at a price of 50 CHF/t CO_2.

These reductions are already part of the differential between WOM and WEM in 2012. In other words, statistical emissions in 2012 reflect these additional efforts made by firms. It is just assumed that they will stay effective until 2020. As a result, this part of offsets does not contribute to further reducing CO_2 emissions beyond 2012.

In our simulations, these offsets are represented as permanent increases in energy efficiency for the firms that were exempted from the CO_2 tax in the first phase of the CO_2 Act. They do not lead to additional reductions in CO_2 emissions but they reduce the total compensation requirement for the period 2013-2030 by 2.81 Mt CO_2.

Climate Cent projects

In the first phase of the CO_2 Act, from 2008 to 2012, the climate cent foundation funded emission mitigation projects in Switzerland. KliK purchases these emission reductions deemed to remain constant at the same level until 2020 at a price comprised between 60 and 135 CHF/t CO_2. KliK counts these (past) compensations as equivalent to 1.70 Mt CO_2 for the period 2013-2020 (Figure 21). In fact, the FOEN accepted on 27.11.2014 that 0.265 Mt CO_2 can be counted for 2013, but the lasting effect is only 0.06 Mt CO_2 per year. Therefore, we add seven years of these lasting effects for the period 2014-2020 and count them for 2021-2030 too, *pro rata temporis*.

In our simulations, these offsets are represented as increases in energy efficiency in the first phase of the CO_2 Act. They do not lead to additional reductions in CO_2 emissions but they reduce the total compensation requirement for the period 2013-2030 by 1.3 Mt CO_2[12].

Additional efforts

In the second phase of the CO_2 Act, firms can again be exempted from the CO_2 tax in exchange for a commitment to reduce their emissions. When they exceed this commitment by more than 5%, they get attestations for the additional emission reductions (the 5% not included), which they can sell to KliK. KliK offers to buy them at a price of 100 CHF/t CO_2.

---

[12] $0.265 + 17 \times 0.059$ Mt CO_2.

In the absence of better information, we assume that this offset option will deliver all of the reduction amount published in Figure 21 in the form of CO_2 emissions from combustion processes, which amounts to 1.32 Mt CO_2 cumulated over 2013-2020 and, with their lasting effects, to 2.93 Mt CO_2 cumulated over 2021-2030. In our simulations, we will represent this as a subsidy for additional abatement by firms. We detail in the next subsection how we specifically do this.

Platforms – programmes and new projects

The four KliK platforms each group several programmes that make it possible to handle smaller greenhouse gas abatement projects with reasonable administrative costs. In addition, they host "new projects", which are projects created after 2013 that will each lead to cumulative emission reductions until 2020 of at least 1,000 tonnes of CO_{2eq}. Each project must be negotiated with KliK, which only announces that district heating projects will be supported at the rate of 100 CHF/t CO_2 avoided.

The programmes and projects need not reduce CO_2 emissions from combustion processes; they can reduce any greenhouse gas.

Platform for businesses

The platform for businesses has a programme for carbon sinks in wood (0.81 Mt CO_2 cumulated over 2013-2020)[13] and several programmes and new projects for reducing non-CO_2 greenhouse gas emissions (0.224 Mt CO_{2eq}). None of these would lead to reductions in CO_2 emissions from combustion processes (IPCC category code 1A). Given that our simulations are limited to these emissions, we must consider that they make no contribution. They merely reduce the compensation requirement, by 1.034 Mt CO_2 cumulated over 2013-2020. For the period 2021-2030, we assume that the carbon sinks programme is extended with the same amount per year and that the other programmes and new projects have lasting effects. This implies 1.51 Mt CO_{2eq} cumulated over 2021-2030.[14]

Platform for transportation

This platform has a programme and a new project for biofuels and fuel from waste oil, for a total of 0.863 Mt CO_2 for 2013-2020. In addition, it has smaller programmes for electric vehi-

[13] Estimates published on KliK website, platform for agriculture, sum of different programmes; data collected on 19.02.2016.

[14] This is the sum of 10 years of carbon sinks in wood (0.81/8×10) and 2.22 times the total reductions obtained from the other programmes and projects (0.224×2.22). As shown in Table 18, if emission reductions accumulate constantly over the eight years of 2013-2020 and then stay at the level of 2020 for the ten years of 2021-2030, then total reductions over 2021-2030 are equal to 2.22 times the total reductions of 2013-2020.

cles and transfer of freight transportation onto trains estimated to save 0.056 Mt CO_2. The latter can be expected to have lasting effects. We assume that the biofuels and waste oil programmes and projects are continued at the same level for 2021-2030. Total effects are 0.91 Mt CO_2 for 2013-2020 and 1.20 Mt CO_2 for 2021-2030.[15] These amounts can be subtracted from the CO_2 emissions of motor fuels in the WEM scenario. They must also be subtracted from the compensation requirements.

Platform for agriculture

This platform encourages the reduction of non-CO_2 greenhouse gas emissions in agriculture. Given that our simulations are limited to CO_2 emissions from combustion processes, we must consider that they make no contribution. They merely reduce the compensation requirement, by 0.456 Mt CO_2 cumulated over 2013-2020 and, with their lasting effects, 1.01 Mt CO_2 cumulated over 2021-2030.[16]

Platform for buildings

One programme and many new projects on this platform promote distance heating and the use of waste heat. The estimated saving is 0.37 Mt CO_2 for 2013-2020. Other programmes promote efficient heating, for 0.36 Mt CO_2. These effects should be lasting, so that 1.63 Mt CO_2 can be saved over 2021-2030. We shall model this in the form of an additional CO_2 price as detailed below.

Summary of compensations

The tables below summarize the estimations made above about the compensations that do not lead to additional reductions in CO_2 emissions from combustion processes and those that do.

[15] This is the sum of 10 years of fuel replacement programmes and projects (0.863/8×10) and 2.22 times the total reductions obtained from the other programmes and projects (0.056×2.22).
[16] 0.456×2.22.

Table 16: KliK compensations that do not lead to additional reductions in CO_2 emissions from combustion processes			
	2013-2020	**2021-2030**	**2021-2030rev**
Emissions rights phase I	2.81	0.00	0.00
Climate Cent Foundation	0.68	0.59	0.59
Platform for businesses	1.03	1.51	2.75
Platform for agriculture	0.46	1.01	1.84
Total	4.98	3.11	5.18
Total 2013-2030		8.09	10.16

Table 17: KliK compensations that lead to additional reductions in CO_2 emissions from combustion processes			
Expected compensations	**2013-2020**	**2021-2030**	**2021-2030rev**
Additional efforts	1.32	2.93	2.93
Platform for transportation	0.92	1.20	2.19
Platform for buildings	0.74	1.63	2.97
Total	2.97	5.77	8.09
Total 2013-2030		8.74	11.07

The sum of compensations in the two tables above – 16.84 Mt CO_2 – is not sufficient for the required amount of compensations estimated in Table 15, namely 21.22 Mt CO_2 for the whole period 2013-2030. There is a bit too much compensation over 2013-2020 (7.95 Mt CO_2 compared to required 6.23 Mt CO_2) and too little over 2021-2030. We assume that the excess compensation of 2013-2020 can be carried forward, in accounting terms, to 2021-2030. That still leaves a deficit of 4.39 Mt CO_2. The contribution of the emissions rights of phase I and the climate cent foundation cannot be increased. It would be very costly to seek more additional efforts. Therefore, we assume that the four platforms are amplified pro rata. This is shown in the last column of Table 16 and Table 17.

Procedure for representing the offsets funded by KliK in GEMINI-E3

Distribution of offsets through time

The cumulated offsets of measures with lasting effects must be spread through time if we wish to replicate them in our simulations. We shall proceed as follows. We assume that measures funded by KliK start producing their effects in 2013[17] and that the emission reductions carry through until 2030. This means that efficiency solutions put in place deliver the same effects every year for up to 18 years (from 2013 until 2030). As a result, the emission reductions in 2014 are the sum of those obtained in 2013 and the additional reductions obtained through the new measures of 2014. In 2020, the emission reductions effects of measures implemented during 8 years, from 2013 until 2020, will develop their effects. We shall assume that this cumulated effect can count as a 10% offset of the CO_2 emissions from motor fuels in 2020. Since we assume that the offset rate remains unchanged, that implies that no additional reductions are needed beyond 2020 (except to replace non-permanent reduction effects).

Table 18 illustrates with illustrative dimensionless numbers the accumulation of emission reductions through time if the measures are introduced linearly between 2013 and 2020. It shows, in particular, that the cumulated emission reductions over 2021-2030 are equal to 2.22 times the cumulated emission reductions over 2013-2020.

[17] The Federal office for the environment validated offsets by KliK in the amount of 265,482 t CO_{2eq} for 2013.

Table 18: Distribution of lasting effects through time with no new measures after 2020 (dimensionless numbers)

	Additional reductions per year	Cumulated effects per year	Cumulated emission re-ductions	
2013	1	1		
2014	1	2		
2015	1	3		
2016	1	4		
2017	1	5		
2018	1	6		
2019	1	7		
2020	1	8	36	2013-2020
2021	0	8		
2022	0	8		
2023	0	8		
2024	0	8		
2025	0	8		
2026	0	8		
2027	0	8		
2028	0	8		
2029	0	8		
2030	0	8	80	2021-2030
			116	2013-2030

More programmes and new projects are needed over 2021-2030 to meet the compensation requirement. Table 19 shows how this can be obtained for the platform for buildings.

Table 19: Distribution of offsets for platform for buildings (Mt CO_2)				
	Additional reductions per year	Cumulated effects, per year	Cumulated emission reductions	
2013	0.0204	0.02		
2014	0.0204	0.04		
2015	0.0204	0.06		
2016	0.0204	0.08		
2017	0.0204	0.10		
2018	0.0204	0.12		
2019	0.0204	0.14		
2020	0.0204	0.16	**0.74**	2013-2020
2021	0.0243	0.19		
2022	0.0243	0.21		
2023	0.0243	0.24		
2024	0.0243	0.26		
2025	0.0243	0.28		
2026	0.0243	0.31		
2027	0.0243	0.33		
2028	0.0243	0.36		
2029	0.0243	0.38		
2030	0.0243	0.41	**2.97**	
			3.71	2013-2030

In our simulations, we will set instruments that allow achieving the additional reductions of Table 19. They need not be exactly the same in every year, but the cumulated emission reductions should match the expected effects of the compensations funded by KliK.

Offsets in industrial sectors

Firms reduce their emissions either because they want to avoid paying the CO_2 levy or because they have committed to implement all abatement measures that are profitable for energy prices augmented by the CO_2 levy in order to be exempted from paying the levy. In economic terms, the only difference between the two alternatives is that firms recover the CO_2 levy in the second case. Apart from this difference, firms face the same carbon price (the CO_2 levy) under both alternatives.

In order to obtain additional emission reductions by firms, a higher carbon price is needed. KliK encourages these additional reductions by paying for them. If it paid a price equal to the CO_2 levy, it would not obtain any additional reductions because firms have already implemented all reductions that are profitable for that price. In 2014, when the CO_2 levy was 60

CHF/t CO_2, KliK offered to buy additional reductions at 100 CHF/t CO_2. This encouraged firms to implement abatement measures that cost more than 60 but less than 100 CHF/t CO_2.

With the CO_2 levy, the incentive to abate is the saving of 60 CHF/t CO_2. Firms subject to the levy that accept KliK's offer save these 60 CHF on every additional tonne they abate. KliK could offer only 40 CHF for each attestation it buys from these firms. Firms exempted from the levy require the full 100 CHF for additional abatement.

As the CO_2 levy is raised, KliK will have to offer a higher price for attestations. In GEMINI-E3, we first simulate the CO_2 emissions by industry for 2013-2030 with the CO_2 levy and no purchase of attestations by KliK. Next, we compute the price KliK has to pay to induce firms to make the additional abatement, relative to the first simulation, that is planned in conformity with compensation requirements.

Offsets in buildings

The procedure for the buildings sector is similar. We simulate CO_2 emissions in the absence of KliK and then we assume that KliK buys additional reductions at a price exceeding necessarily the CO_2 levy.

Impact on motor fuel prices

The CO_2 price the KliK foundation will have to pay according to our simulations in order to generate enough CO_2 emission reductions from combustion processes represents only a part of the total costs of its many compensation measures and programmes. After all, these reductions correspond only to about 38% of all compensations. As a result, it is not possible to use the estimated cost of these measures to calculate the levy on motor fuels needed to fund the full set of compensation measures. KliK estimates that between 1 and 2 cents per litre will be sufficient. The CO_2 Act sets a ceiling of 5 cents per litre. Given these numbers, the possible incentive effect of the supplement on motor fuel consumption can safely be ignored.

4.3.3. CO_2 compensation for combined-cycle gas turbine plants

Combined-cycle gas turbine (CCGT) plants are introduced in the model when needed to balance the electricity market. According to the CO_2 Act, they are required to compensate their emissions, with a minimum share of 50% domestic compensation. The rest can be compensated by using international emission reduction units. The price of foreign certificates (linked to international compensation) is fixed at 10 CHF/t CO_2.

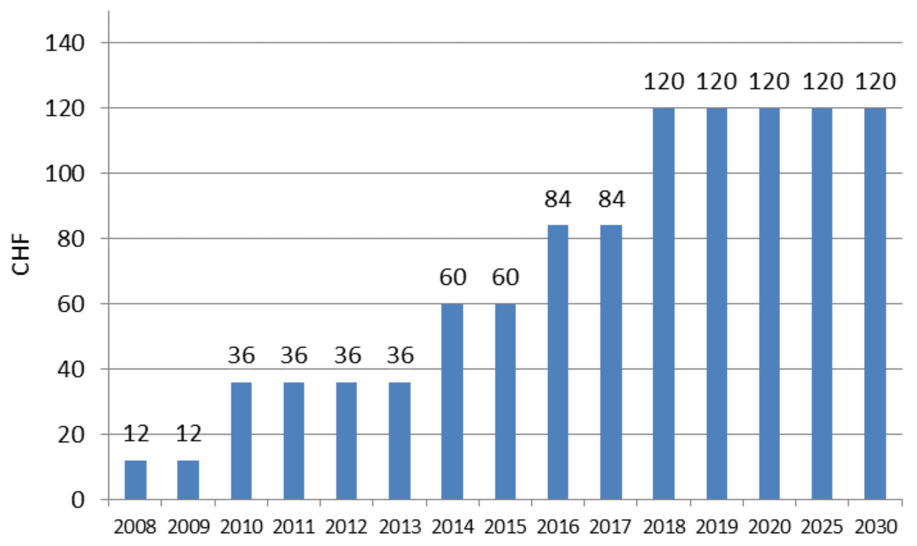
CCGT plants are not part of the Swiss ETS since the new entrant reserve of emission certificates is too small to cover their emissions. The domestic compensations have to be obtained from the other sectors. The procedure is that same as described above for transport fuels under *Offsets in industrial sectors* and *Offsets in buildings*.

4.4. Model results

4.4.1. Endogenous CO_2 prices

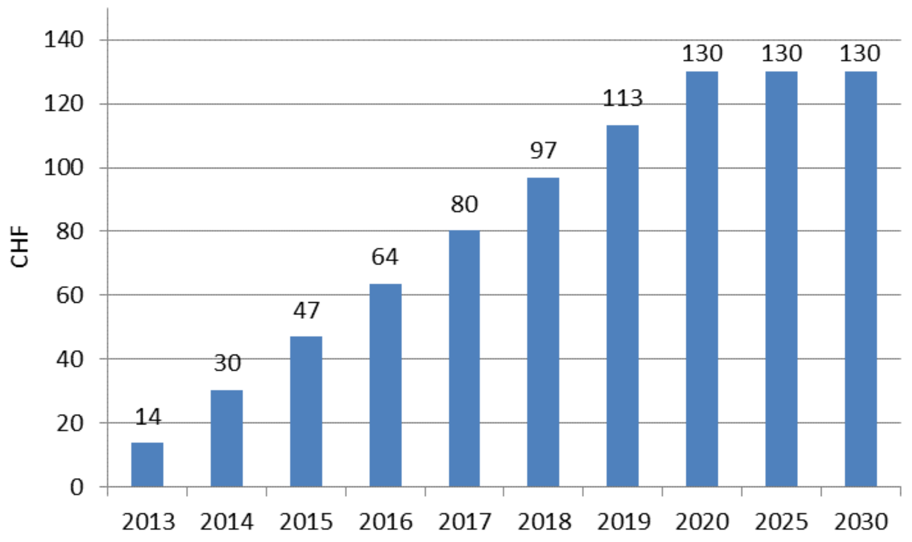
According to the calculation of the model, the CO_2 levy will be raised from 84 to 120 CHF/t CO_2 in 2018, because the CO_2 emissions on fossil combustible fuels are expected to reach 76.4% of the 1990 emissions levels in the year 2016. Figure 22 shows the evolution of the CO_2 levy in the WEM scenario (model result).

Figure 22: CO_2 levy in CHF/t CO_2 (current prices) in the WEM scenario (model result)



The ETS cap is reduced by 1.74% annually. This means a decrease by 12% between 2013 and 2020. With this decrease in ETS supply and the growth in production by the firms subject to that cap, the model finds that an ETS price of 130 CHF/t CO_2 is needed in 2020 to clear the market. We assume a linear increase between the 14 CHF/t CO_2 of 2013 and this estimated price (Figure 23).

Figure 23: ETS price in CHF/t CO_2 (current prices) in the WEM scenario



4.4.2. Electricity generation

The WEM and WOM scenarios assume that nuclear electricity generation is gradually phased out in Switzerland. Specifically, the five existing nuclear power plants will stop production when they reach the end of their service life and they will not be replaced by new ones. The operator of the Mühleberg power plant already decided to shut it down in 2019. For the other nuclear power plants, we assume a lifetime of 60 years. This means that the Beznau I power plant will be shut down in 2029. In the WEM scenario, the promotion of renewable electricity generation and the compensation requirement for CO_2 emissions limit the deployment of fossil power plants. In 2020, Swiss electricity generation reaches 71.4 TWh, of which only 0.9 TWh are produced with fossil energy (88% by CCGT plants). In 2030, total electricity generation equals 73 TWh with 2.2 TWh from CCGT plants.

In the WOM scenario, electricity consumption reaches 72.1 TWh in 2020 and 74.9 TWh in 2030. This is the result of low electricity prices when there is no feed-in-tariff and no carbon taxation for the natural gas used in CCGT plants. The increased demand is mainly met with such plants, which produce 9.9 TWh in 2030. New renewables (excluding hydro) account for 3.0 TWh instead of 7.9 TWh in the WEM scenario.

Figure 24: Electricity generation in the WEM scenario

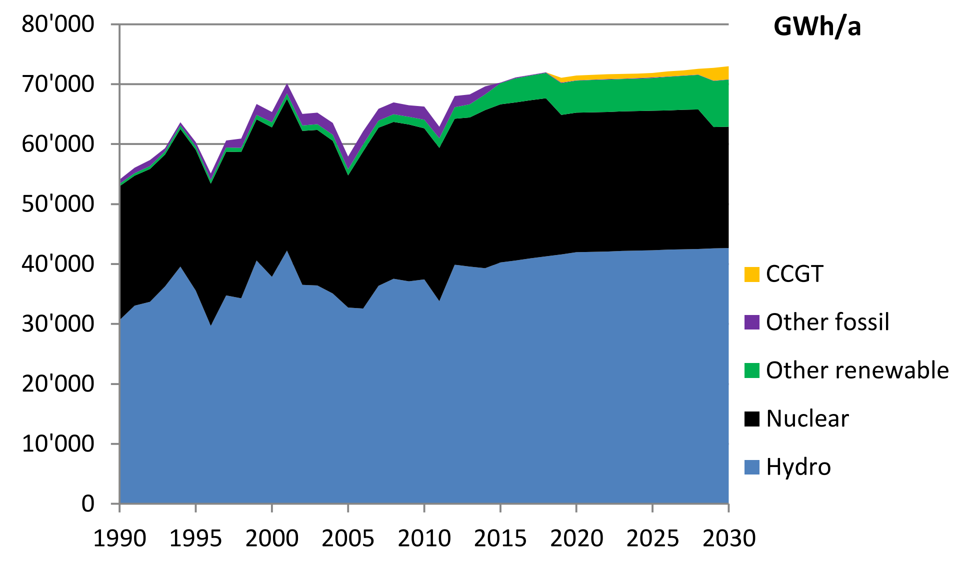
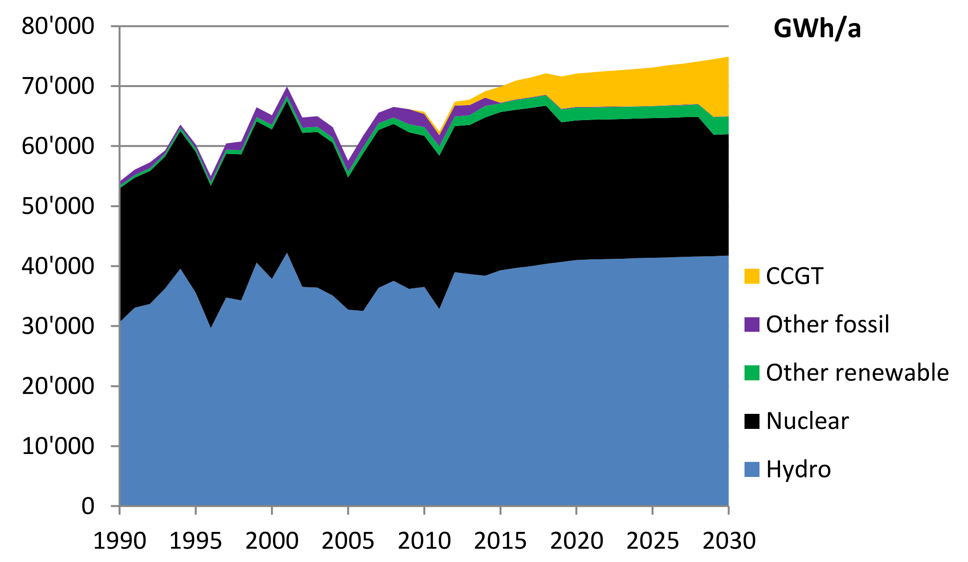


Figure 25: Electricity generation in the WOM scenario



4.4.3. Emissions under the WEM and WOM scenarios

The two emissions scenarios computed by GEMINI-E3 are described in Figure 26, in Table 20 and in Table 21. In the WEM scenario, the CO_2 emissions (from energy combustion) reach 36.0 million tonnes in 2020. Subtracting the 50% of emissions from electricity generation using natural gas that will be compensated through international compensation, total CO_2 emissions will equal 35.9 million tonnes, which represents a 12.2% reduction with respect to 1990 levels. In

2030, total CO_2 emissions will reach 33.5 million tonnes (including the international compensation), which amounts to a reduction by 18.1% relative to 1990 levels. Without policy measures aiming at reducing GHG emissions, Switzerland's CO_2 emissions would reach 45.0 million tonnes in 2020 and 43.3 million tonnes in 2030.

Figure 26: CO_2 emissions in the WEM and WOM scenarios 1990-2030

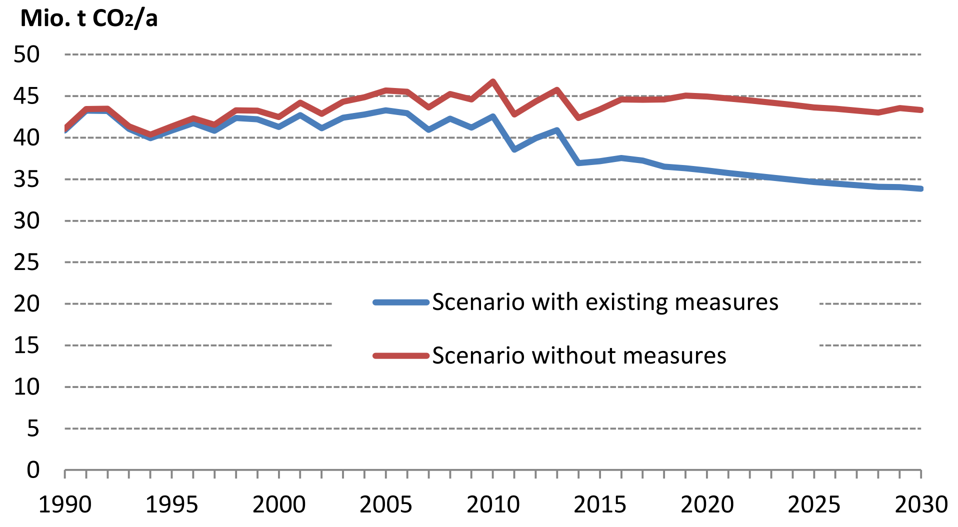


Table 20: CO_2 emissions from energy combustion in WEM scenario (Mt)

Sector	1990	1995	2000	2005	2010	2015	2020	2030
Energy (1A1)	2.5	2.6	3.1	3.8	3.8	3.2	3.5	4.0
Industries (1A2)	6.4	6.2	5.9	6.0	5.8	5.2	4.6	4.1
Transport (1A3)	14.4	14.0	15.7	15.7	16.2	15.6	15.5	14.7
Other sectors (1A4)	17.4	17.9	16.4	17.7	16.6	13.1	12.4	11.0
Services (1A4a)	*5.2*	*5.6*	*5.3*	*5.6*	*5.2*	*4.1*	*4.1*	*4.1*
Households (1A4b)	*11.6*	*11.8*	*10.6*	*11.6*	*11.0*	*8.5*	*7.8*	*6.4*
Others (1A4c)	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*
Military (1A5)	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Total domestic (1A)	**40.9**	**40.9**	**41.3**	**43.3**	**42.6**	**37.2**	**36.0**	**33.8**
International compensation CCGT							0.1	0.4
Total with compensation	**40.9**	**40.9**	**41.3**	**43.3**	**42.6**	**37.2**	**35.9**	**33.5**

Table 21: CO_2 emissions from energy combustion in WOM scenario (Mt)								
Sector	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2030**
Energy (1A1)	2.5	2.6	3.1	3.8	4.0	4.1	5.2	6.6
Industries (1A2)	6.4	6.2	5.9	6.0	6.1	5.8	5.9	5.3
Transport (1A3)	14.4	14.1	15.9	16.6	17.4	17.0	16.9	15.8
Other sectors (1A4+1A5)	17.5	18.3	17.3	19.2	19.1	16.4	16.9	15.5
Services (1A4a)	*5.3*	*5.7*	*5.6*	*6.1*	*6.1*	*5.2*	*6.0*	*6.1*
Households (1A4b)	*11.7*	*12.1*	*11.2*	*12.6*	*12.5*	*10.6*	*10.4*	*8.9*
Others (1A4c)	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.6*	*0.6*	*0.5*
Military (1A5)	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Total domestic (1A)	**41.0**	**41.4**	**42.5**	**45.7**	**46.8**	**43.4**	**45.0**	**43.3**

4.4.4. Evolution of emissions by sector in the WEM scenario and contributions to CO_2 savings

Table 22 shows the evolution of CO_2 emissions by sector between 1990 and 2020 with the contribution of each sector to the Swiss abatement target.

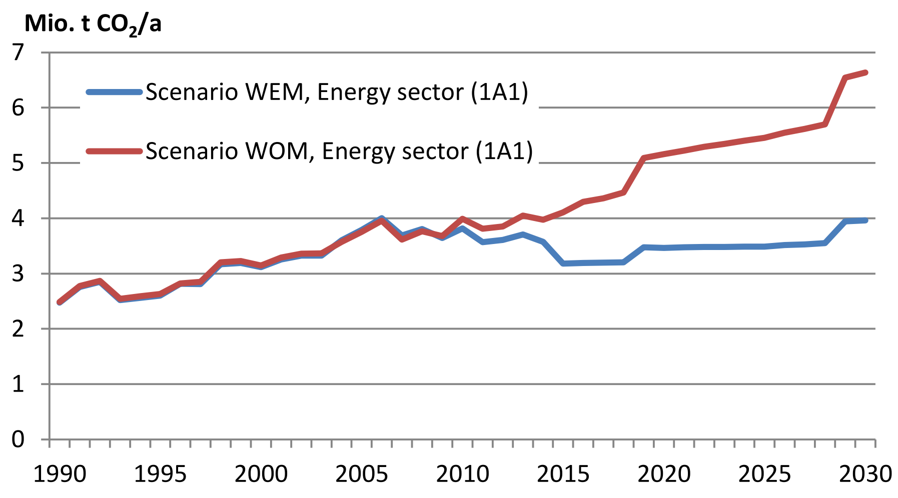
Table 22: Emissions under the WEM scenario in 2020 with respect to 1990 levels (in Mt CO_2)			
Sector	**1990**	**WEM 2020**	**Percentage change**
Energy (1A1)	2.5	3.5	40%
Industries (1A2)	6.4	4.6	-29%
Transport (1A3)	14.4	15.5	8%
Other sectors (1A4+1A5)	17.4	12.4	-29%
Services (1A4a)	5.2	4.1	-21%
Households (1A4b)	11.6	7.8	-33%
Others (1A4c)	0.5	0.5	-5%
Military (1A5)	0.2	0.1	-52%
Total domestic (1A)	**40.9**	**36.0**	**-12%**

Figure 27 to Figure 31 show the evolution of CO_2 emissions by sector in the WEM and WOM scenarios. Two sectors – the energy sector and the transport sector – emit more CO_2 in 2020 than in 1990. The CO_2 emissions decrease in all other sectors with respect to their 1990 levels.

Energy

Under the WEM scenario, the energy sector (energy conversion, in particular electricity generation) will emit 40% more CO_2 in 2020 than in 1990, and even 60% more in 2030 (Figure 27). This is mainly due to new CCGT plants, which replace the first decommissioned nuclear power plants in 2019 and 2029, leading to stepwise increases of CO_2 emissions. The increase is limited to 35% in 2020 relative to 1990 when the foreign compensation for CO_2 emitted by CCGT plants is subtracted.

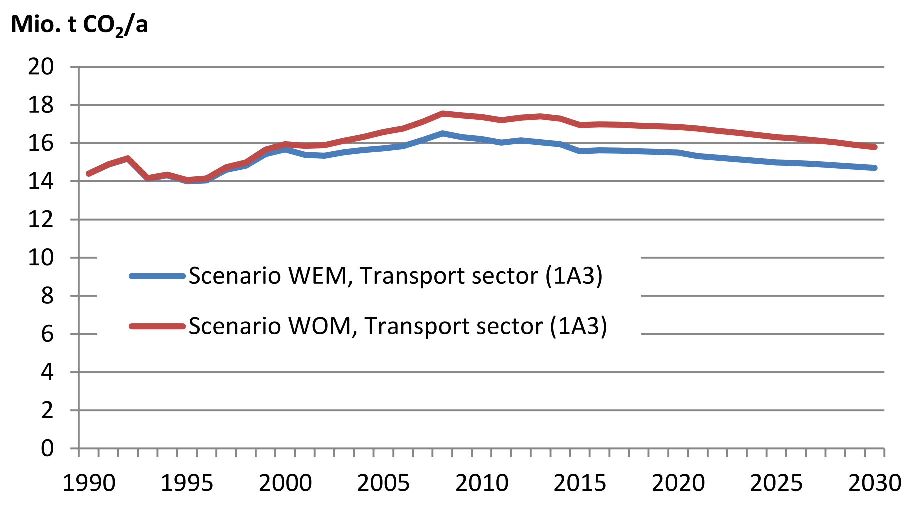
Figure 27: CO_2 emissions in the energy sector (energy conversion, in particular electricity generation, without compensation)



Transport

The second sector that experiences emission increases with respect to its 1990 level is the transport sector. In 2020, its CO_2 emissions exceed the 1990 level by 8%, but they are on a declining path since 2008 (Figure 28). In 2030, they are 2% above the 1990 levels. These numbers are before subtraction of the CO_2 compensations procured by the KliK foundation, which equal 10% of emissions in 2020 and 2030. Indeed, they are counted in the sectors whose emissions actually decrease for these compensations. If they were subtracted from the CO_2 emissions of the transport sector, these emissions would fall below 1990 levels, by 3% in 2020 and 8% in 2030.

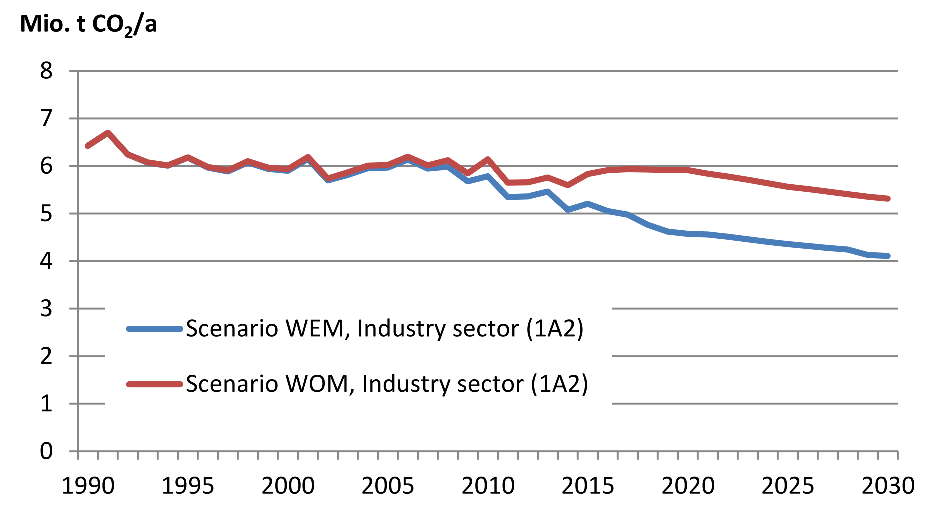
Figure 28: CO_2 emissions in the transport sector (before compensation)



Industry

In the industry sector, there is a clear declining trend of CO_2 emissions over the whole period. This decrease becomes more pronounced after 2010 following the introduction of the carbon prices (CO_2 levy and ETS price). This reduction includes savings related to the CO_2 compensation mechanism of the transport and the electricity generation sectors. CO_2 emissions from industry are projected to be 29% below the 1990 level in 2020 in the WEM scenario, and even 36% below in 2030.

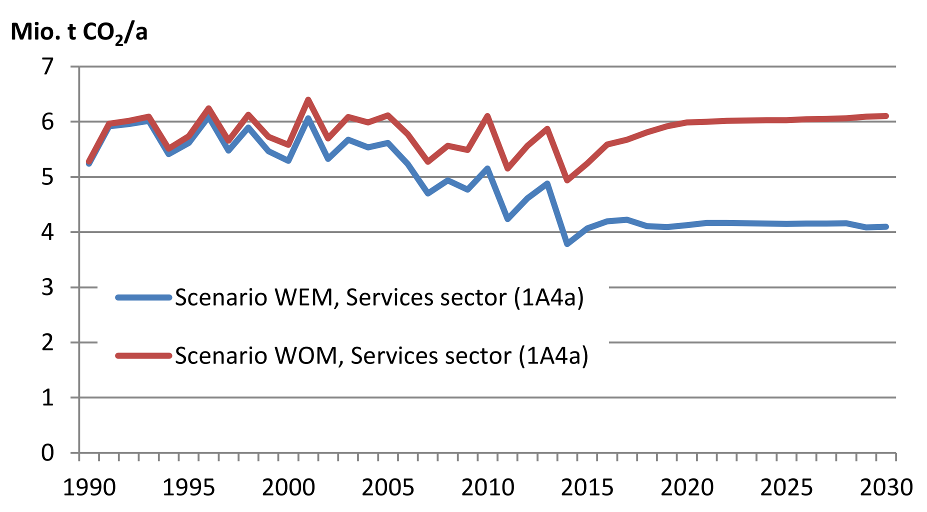
Figure 29: CO_2 emissions in the industry sector



Services

In the services sector, CO_2 emissions are 21% below their 1990 level in 2020. This is mainly obtained by measures dedicated to the buildings stock of this sector: the building codes of the cantons, the national buildings refurbishment programme, and the SwissEnergy programme. In 2030, the CO_2 emissions of this sector are projected to amount to 4.1 Mt CO_2 in the WEM scenario, 22% below 1990 emissions.

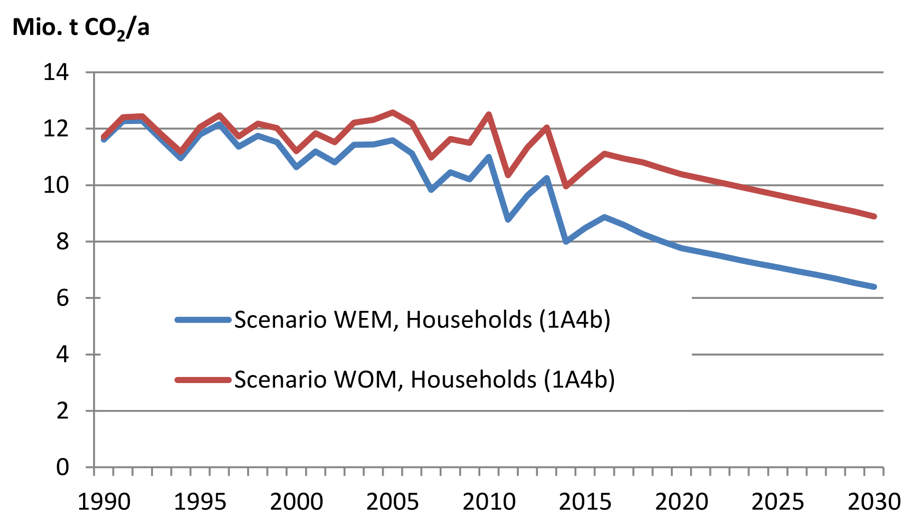
Figure 30: CO_2 emissions in the services sector



Households

The CO_2 emissions of households significantly decrease over the period 1990-2020. In 2020, they are 33% below 1990 levels in the WEM scenario. As for the services sector, these reductions are mainly driven by the implementation of measures related to the use of energy in buildings, reinforced by the CO_2 levy on heating fuels. After 2020, CO_2 emissions decrease mainly due to expected autonomous energy efficiency improvement.

Figure 31: CO_2 emissions by households



These predictions can be compared, with some care, with those of Prognos (2012, scenario WWB, table 7-2), although the scope of emissions attributed to households is not exactly the same. Prognos estimated that CO_2 emissions would decrease from 2000 to 2020 by 22% and from 2000 to 2030 by 40%. We predict corresponding emissions savings of 26% and 40%, i.e. not much more, despite a higher CO_2 levy and more funds for the national buildings refurbishment program. This is mainly due to stronger economic growth in our simulations.

4.4.5. Evolution of emissions by sector in the WOM scenario

Without greenhouse gas abatement measures (WOM scenario), CO_2 emissions would have been higher by 10% in 2010, 25% in 2020, and 28% in 2030 with respect to the WEM scenario. In other words, all the measures defined in Table 1 led to a reduction of CO_2 emissions by 9% in 2010, 20% in 2020, and 22% in 2030 relative to the WOM scenario (Table 24). The measures yield CO_2 savings in all sectors. The transport sector is the only major sector where the savings are smaller than 10% in 2020 and 2030.

Table 23: Reductions of CO_2 emissions from energy combustion in the WEM scenario relative to the WOM scenario (Mt CO_2), international compensation amounting to 0.2 $MtCO_2$ in 2020 and 0.4 $MtCO_2$ in 2030 is not considered here

Sector	2010	2020	2030
Energy (1A1)	0.2	1.7	2.7
Industries (1A2)	0.4	1.3	1.2
Transport (1A3)	1.2	1.3	1.1
Other sectors (1A4+1A5)	2.5	4.6	4.5
Services (1A4a)	*1.0*	*1.9*	*2.0*
Households (1A4b)	*1.5*	*2.6*	*2.5*
Others (1A4c)	*0.0*	*0.1*	*0.0*
Military (1A5)	0.0	0.0	0.0
Total domestic (1A)	**4.2**	**8.9**	**9.5**

Table 24: Reductions of CO_2 emissions from energy combustion in the WEM scenario relative to the WOM scenario (%), international compensation is not considered here

Sector	2010	2020	2030
Energy (1A1)	-4%	-33%	-40%
Industries (1A2)	-6%	-23%	-23%
Transport (1A3)	-7%	-8%	-7%
Other sectors (1A4+1A5)	-13%	-27%	-29%
Services (1A4a)	*-16%*	*-31%*	*-33%*
Households (1A4b)	*-12%*	*-25%*	*-28%*
Others (1A4c)	*-9%*	*-11%*	*-6%*
Military (1A5)	0%	0%	0%
Total domestic (1A)	**-9%**	**-20%**	**-22%**

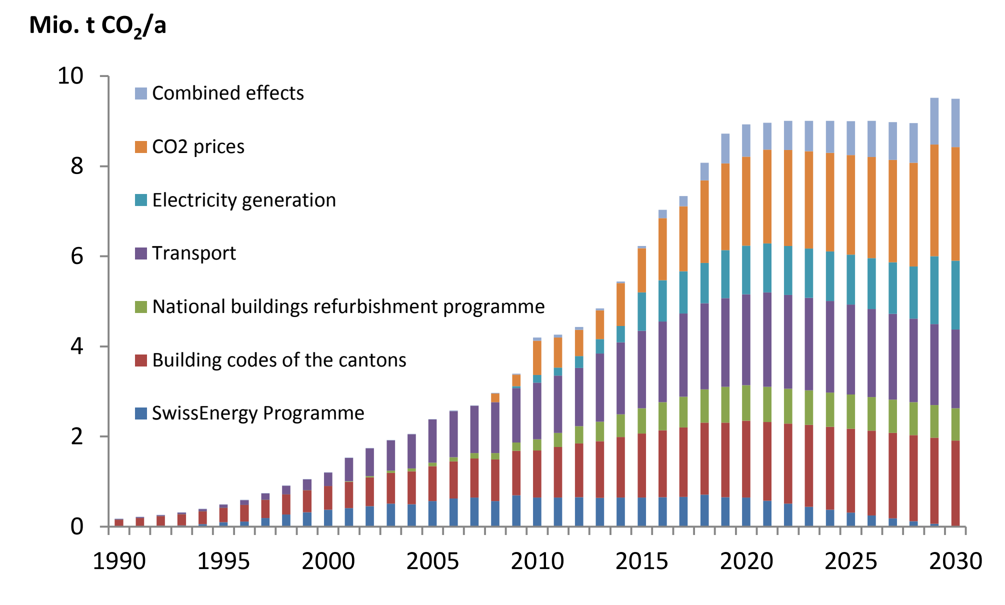
Over the whole period 1990-2030, the CO_2 emissions in the WOM scenario increase in three sectors (Table 21). In the energy sector, the increase of electricity demand and the shutdown of two nuclear power plants require investments mostly in CCGT plants with large CO_2 releases (Figure 27). The growth of demand for services combined with limited energy efficiency improvement in this sector induces a significant increase of its CO_2 emissions (Figure 30). The difference between the WEM and WOM scenarios increases between 2016 and 2020, when the CO_2 levy is raised to 120 CHF/t CO_2 in the WEM scenario. A similar effect can be observed in the industry and household (residential) sector (Figure 29 and Figure 31), but with smaller magnitude. The emissions of these two sectors slowly decrease in the long term after a peak around 2020, even in the absence of measures, thanks to autonomous energy efficiency improvement. The CO_2 emissions of transport peak earlier, in 2010 (Figure 28).

4.4.6. Decomposition of CO_2 abatements by measures

Figure 32 shows the contribution of each measure to total CO_2 savings relative to the WOM scenario. These contributions have been estimated by removing sequentially each measure in the WEM scenario. For example, we have simulated the WEM scenario without taking into account the CO_2 prices (CO_2 levy and ETS price). The difference between the CO_2 emissions of this scenario and those of the WEM scenario is an estimation of the contribution of the carbon prices to total CO_2 savings.

We include in the transport cluster not only the impacts related to *EcoDrive*, heavy vehicle charge and other measures inducing general energy efficiency improvements, but also the partial compensation of CO_2 emissions from transport fuel use. The same assumption is made for the electricity generation cluster, which includes not only the feed-in tariff but also the domestic CO_2 compensation from gas use in CCGT plants. As can be seen by comparing Figure 32 with Table 23, the sum of each individual measure gives an amount of CO_2 abatement smaller than the difference in emissions between the WOM and the WEM scenario. This difference represents the combined effects of the different measures that lead to additional CO_2 savings. For example, the combination of a CO_2 levy on heating fuels and subsidies to building refurbishment reinforce the impacts on CO_2 saving of each measure. Nevertheless, these combined effects remain limited and represent at most 12% of the total CO_2 saving.

Figure 32: Total CO_2 savings by cluster of measures relative to WOM scenario (Top-Down)



4.4.7. Comparison of bottom-up and top-down impact assessments

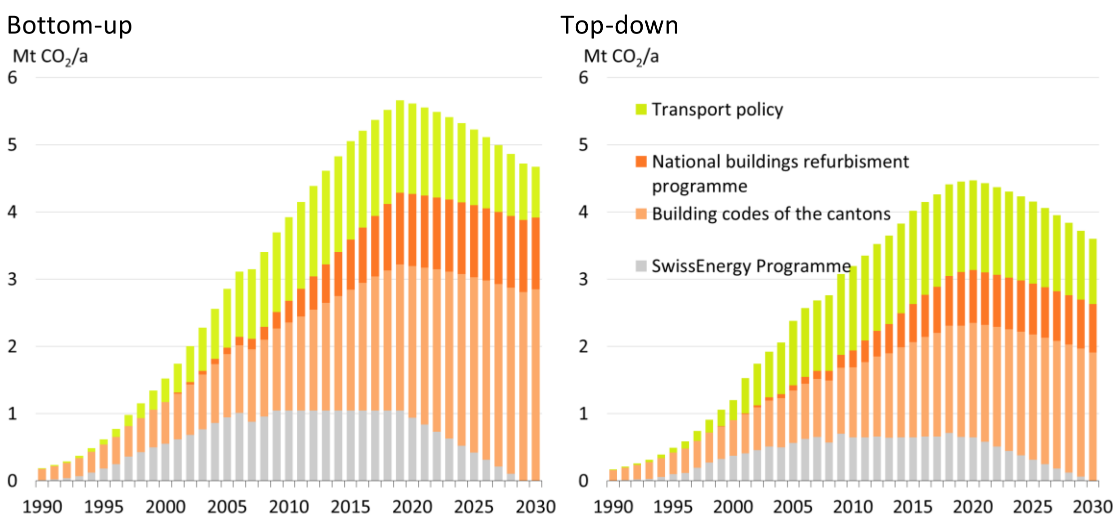
Comparing the bottom-up and top-down estimates of the specific policy measures is not an easy task. Indeed, the non-price and price measures interact. Furthermore, the decomposition performed in the previous section is only an estimation of the impact of the policy and the comparison with the bottom-up assessment must be done cautiously.

However, it is possible to examine the differences between the bottom-up and the top-down assessments. The top-down evaluation of the SwissEnergy programme, building codes of the canton and national buildings refurbishment programme are always lower than the bottom-up estimates.

The difference stems from a rebound effect. Rebound effects are well documented in the economic literature (Dimitropoulos 2007), explaining that when the cost of energy services falls (which is the case when we suppose that less energy is required to satisfy the same level of comfort) there is a tendency to increase the level of comfort (e.g. to increase room temperatures) by using more energy. This response reduces total energy savings. By regressing energy use for space heating on heating degree days (HDD), Duerinck et alii (2008) found an elasticity between the heating energy demand and HDD of 0.55 on average for selected European Union member states. This corresponds to a rebound effect of 45%. For Switzerland, using a similar econometric approach, Winkler et alii (2014) found a rebound effect equal to 50%. However, these studies focused on the "direct" rebound effect. Allan et al (2007) noted that CGE models also account for the "indirect" and "economy-wide" effects that pass through changes in outputs, income and relative prices. Indirect effects, also called “secondary effects” (Greening et alii 2000), result from an increase in demand for other goods including other energy goods driven mainly by an income effect. “Economy-wide effects” are the result of price and quantity changes within the economy, which affect not only the energy industry, but all other sectors as well. In an open economy, these effects also reflect changes in competitiveness. Greening et alii (2000) remarked that only a general equilibrium analysis can predict the ultimate results of these changes.

These rebound effects are constant over the whole period, at 18% for the building codes of the canton, 24% for the national buildings refurbishment programme and 33% for the SwissEnergy programme. These differences in average rebound effects can be explained by several factors. First, each measure has different effects on economic sectors (services, industry and households). Additionally, these sectors are unequally responsive to changes in energy prices. For example, the building codes of the cantons concern mainly the energy consumption in buildings, in contrast with the SwissEnergy programme, in which some measures are related to energy consumption by industry. Secondly, the rebound effect computed by GEMINI-E3 is also driven by the costs of the policy measure that are different from the bottom-up assessments. For each measure, this cost is evaluated in the bottom-up assessment by investment expenses that are added to the energy cost in GEMINI-E3. The higher this additional investment cost is, the smaller is the rebound effect. For a measure that generates small energy savings compared to the additional costs, this could result in a negative rebound effect. We find an intermediate situation for the transport cluster, where the top-down evaluation agrees with the bottom-up assessment over the period. Indeed, the measures in the transport sector (listed in Table 6) are quite costly in comparison with the other measures detailed in the bottom-up assessment.

Figure 33: Comparison of top-down and bottom-up impact assessment



In this figure, the transport cluster does not include the CO_2 compensation for fuel imports.

5. Sensitivity analysis

5.1. Goals

There is, of course, substantial uncertainty in the future path of the Swiss economy, which will affect its CO_2 emissions. The WEM scenario simulated above uses the best available forecasts, but the economy could grow faster or slower, world energy prices could be lower or higher, etc. With stronger economic growth and lower world energy prices, CO_2 emissions would certainly be higher than estimated for the WEM scenario in the previous chapter. This would affect the comparison with the 1990 level, which is critical for the attainment of the targets set for 2020 in the CO_2 Act and for 2030 in the INDC for the COP21. On the other hand, it would affect the WOM scenario in a similar fashion, so one would expect the comparison between the WEM and WOM scenarios, i.e. the evaluation of the effectiveness of energy and climate policies, to be less sensitive to this type of parameter uncertainty.

There is, of course, also significant uncertainty in our bottom-up estimates of the effects of these measures, as well as in the parameters of the top-down simulation model. Again, we did our best to minimize these uncertainties. Indeed, there should not be systematic biases that would lead to substantial errors in the assessments. Normally, such simulations are accompanied by sensitivity analyses, in which all the main assumptions of the models and scenarios are altered over a range of plausible values to see to what extent they modify the main results of the analysis. We present a brief sensitivity analysis in this chapter. Combining bottom-up estimations of the effects of non-price policies with the simulation of price policies cannot be automated. Back casting different paths requires recalibration of the model. Therefore, the sensitivity analyses is restricted to comparing "sensitivity scenarios", i.e. the consequences for model results of replacing the central set of values for the core parameters by new sets of values that would together either facilitate or complicate target achievement.

5.2. Methodology and uncertain parameters

We consider the following parameters that contribute substantially to the uncertainty in the model simulations:

- GDP growth,
- Fossil energy prices (oil and gas),
- Technical progress,
- Bottom-up estimates.

Uncertainty on GDP growth combines two aspects: the uncertainty on population growth, and the uncertainty on productivity growth. The Federal Statistics Office (FSO) provides three main scenarios in its demographic forecasts, called A, B, C, where the active population is respectively equal to 5208, 5604, 4829 thousand persons in 2030 (FSO 2015). However, we can expect a negative relationship between the growth of active population and the growth rate of productivity. Figure 34 shows this relationship for the period 1992 to 2014 (the outlier at the bottom of the Figure 34 corresponds to 2009, the year after the financial crisis).

Figure 34: Relationship between active population growth rate and productivity growth rate

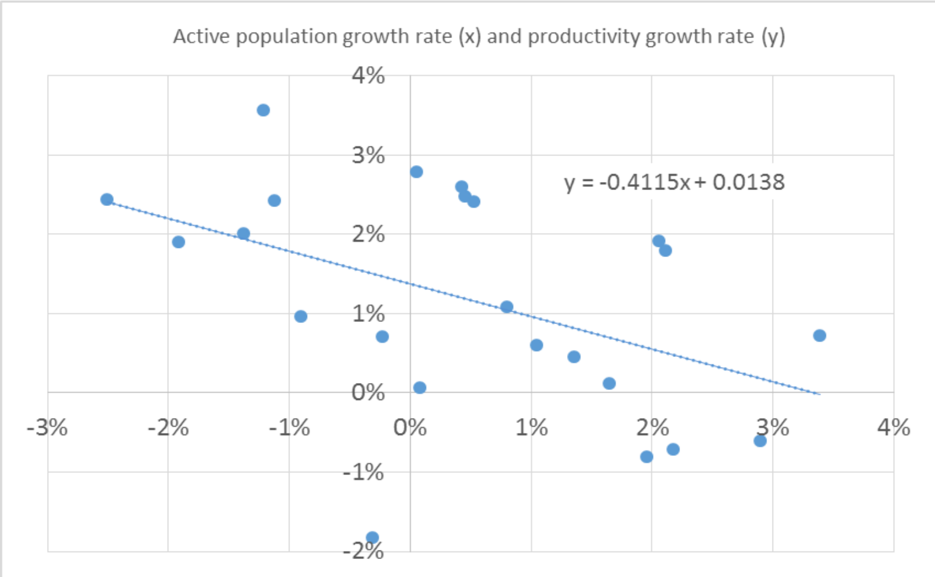


Table 25 reports, for the three population scenarios, the estimated growth rate of productivity based on our estimation of the relationship between the growth rate of the active population and the growth rate of productivity.

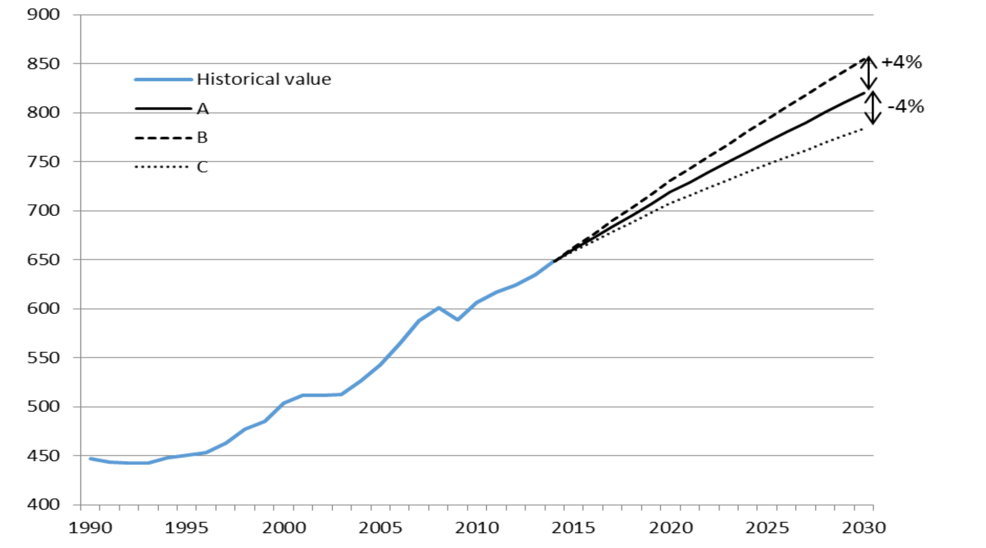
Table 25: Estimation of productivity growth rate

	Scenario C	Scenario A	Scenario B
Active population growth rate (2014-2030) (FSO demographic scenarios)	0.09%	0.57%	1.01%
Productivity growth rate (based on fitted relationship)	1.34%	1.15%	0.96%
Revised productivity growth rate	1.1%	0.9%	0.7%

Our reference scenario for GDP is based on the assumption of the State Secretariat for Economic Affairs (SECO) regarding the future growth rate of productivity. SECO predicts that this parameter will be equal in the future to 0.9%, which is slightly less than our estimation of 1.15%. Indeed, SECO assumes a slow-down of productivity improvement for the next decades. To be consistent with this assumption, we revise all our estimated productivity growth rates downwards by the same amount, to match SECO's assumption for scenario A (see the last row of Table 25).

The three GDP scenarios that combine FSO's population scenarios and our estimated productivity growth rates are shown in Figure 35. In 2030, the high and low scenarios differ by ±4% from the reference scenario.

Figure 35: Swiss GDP in billion CHF (2013 prices)



The uncertainties about energy price can be handled by using the scenarios proposed by the International Energy Agency in its World Energy Outlook (WEO). The scenarios for crude oil prices are shown in Figure 36. For our sensitivity analysis, we use the highest and lowest scenarios proposed in WEO2014 (IEA 2014) and WEO2015 (IEA 2015).

Figure 36: IEA crude oil import prices ($2013/barrel)

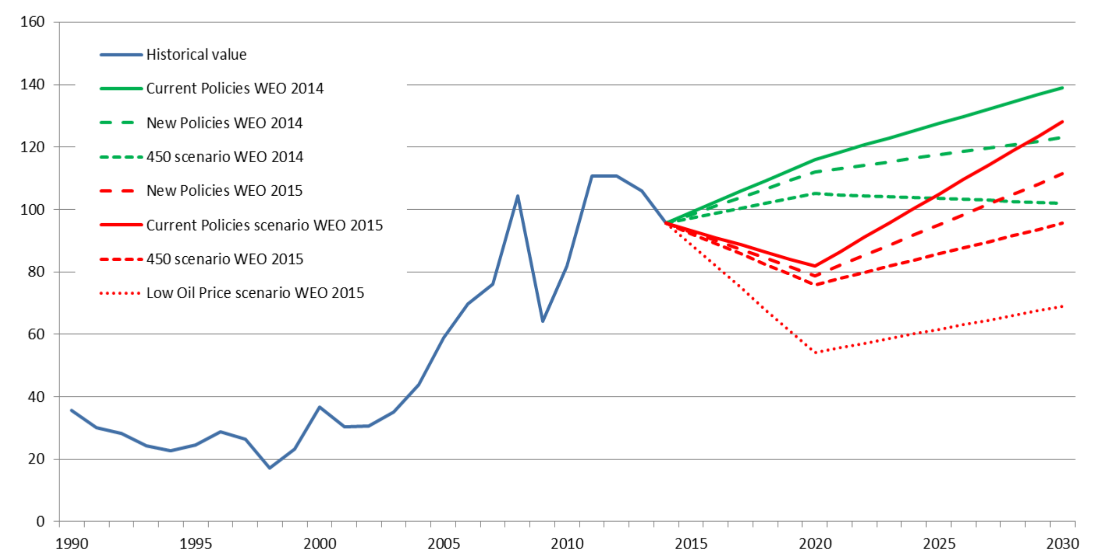


Table 26 provides an evaluation of the related uncertainties for each parameter that could be derived from existing information (demographic scenarios for GDP) or expert evaluation.

Table 26: Parameters of sensitivity analysis

Parameter	Low estimates	Median estimates	High estimates
GDP in 2030 (billion CHF 2013)	784 (-4% wrt medium estimate)	818	855 (+4% wrt medium estimate)
Oil price in 2030 ($2013/barrel)	69 $	100 $	139 $
Natural gas import EU price in 2030 (USD_{2013}/MBTU)	8.8 $	10 $	13.2 $
Technical progress in WEM	-25% medium estimate	medium estimate	+25% medium estimate
Bottom-up estimates	-30% medium estimate	medium estimate	+30% medium estimate

Our **reference scenario** assumes a GDP of 818 billion CHF and an oil price equal to 139$ in 2030[18]. We propose to define two sensitivity scenarios combining low and high values of the different parameters in such a way that they either make CO_2 emission reductions more difficult (the **high CO_2 emissions scenario**) or less difficult (the **low CO_2 emissions scenario**).

The high CO_2 emissions scenario assumes the strongest GDP growth associated with low fossil energy prices (oil price = 69 USD_{2013} in 2030), and a low rate of technical progress specifically related to energy use[19] for the WEM and bottom-up estimations. The stronger growth of population and GDP will lead to stronger growth in energy demand, while low fossil energy prices provide less incentives to invest in energy efficiency or replacement by renewables. Slower technical progress in energy efficiency also leads to higher emissions. The low CO_2 emissions scenario assumes opposite conditions: The weakest GDP growth associated with high energy prices (oil price = 139 USD_{2013}), and a high rate of technical progress for the WEM and bottom-up estimates.

For the sensitivity analysis, we simulate two additional pairs of WEM and WOM scenarios, one for each of these sensitivity scenarios. Table 27 summarizes the assumptions used in the three scenarios.

[18] This high oil price was the central value for the current policies scenario in the World Energy Outlook of 2014 (IEA 2014), the forecast that was available when we performed our first simulations.
[19] For the rest, productivity growth is strongest in this scenario.

Table 27: Main assumptions of the three sensitivity scenarios			
	Low CO_2 emissions scenario	Reference scenario	High CO_2 emissions scenario
GDP in 2030 (billions CHF 2013)	784	818	855
Oil price in 2030 ($2013/barrel)	139	139	69
Natural gas import EU price in 2030 (USD_{2013}/MBTU)	13.2	13.2	8.8
Technical progress in WEM	+25% medium estimate	Medium estimate	−25% medium estimate
Bottom-up estimate	+30% medium estimate	Medium estimate	−30% medium estimate

5.3. Results of the sensitivity analysis

5.3.1. Emissions in the WEM scenarios

Figure 37 and Table 28 show the main results of the sensitivity analysis for the WEM scenario. In 2020, according to our sensitivity scenarios, Swiss CO_2 emissions could range from 34.8 to 40.4 million tonnes of CO_2. This is a range of −3% to +12% compared to the reference scenario. In 2030, the emissions range between 30.6 to 41.7, i.e. between −9% and +23% relative to the reference scenario. In the worst case (i.e. the high CO_2 emissions scenario), the CO_2 emissions decrease by 1.2% with respect to 1990 levels, in the most favourable scenario these emissions are 14.9% below 1990 levels.

Table 28: Key results of the sensitivity analysis			
	Low CO_2 emissions scenario	Reference scenario	High CO_2 emissions scenario
WEM scenario			
Emissions in 2020 (Mt CO_2)	34.8	36.0	40.4
Emissions in 2030 (Mt CO_2)	30.6	33.8	41.7
CO_2 Levy in 2020 (CHF)	120	120	120
ETS price in 2020 (CHF)	95	130	265
WOM scenario			
Emissions in 2020 (Mt CO_2)	44.9	45.0	53.7
Emissions in 2030 (Mt CO_2)	40.2	43.3	53.5

The low CO_2 emissions scenario is characterized by an acceleration of the CO_2 emissions decrease computed in the reference scenario. Even in this most favourable sensitivity scenario the CO_2 levy must be raised to its maximum (120 CHF) allowed by the CO_2 Act. Indeed, this scenario makes no great difference for CO_2 emissions in 2016, which are relevant for revising the CO_2 levy according to the CO_2 Act (sect. 4.4.1). In contrast, the ETS price decreases by 27% in 2020 with respect to the value used in the reference scenario and is equal to 95 CHF in 2020.

Indeed, a stronger decrease in CO_2 emissions allows limiting the increase of the ETS price for energy intensive industries.

In the low CO_2 emissions scenario, these emissions are 9% below the level of the reference WEM scenario in 2030. This can be explained by two factors:

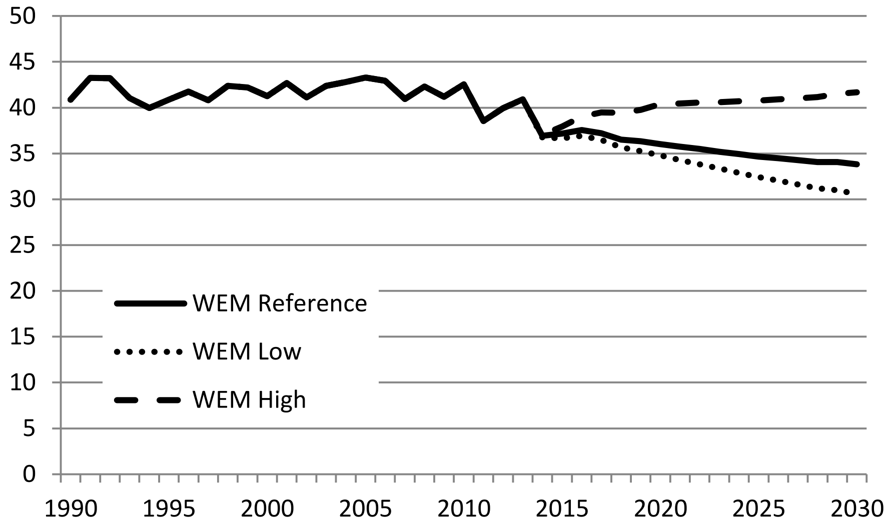
1. A decrease of energy demand with respect to the reference scenario due to more moderate economic growth,
2. Higher energy efficiency, which is assumed in the design of this sensitivity scenario.

The more moderate GDP growth leads to a decrease of CO_2 emissions equal to 5%, all other things being equal. Therefore, the contribution of the energy efficiency improvement can be approximated to the remaining 4 percentage points.

In the high CO_2 emissions scenario, another driver needs to be integrated in the analysis, namely the fall in the price of fossil energy. Indeed, this sensitivity scenario makes a different assumption on future energy prices, while the low CO_2 emissions scenario assumes the same prices as the reference scenario. This explains why the high CO_2 emissions scenario deviates more from the reference scenario than the low CO_2 emissions scenario. CO_2 emissions are 23.1% higher in the high CO_2 emissions scenarios in 2030 than in the reference scenario. The contribution of stronger GDP growth can be approximated at 5 percentage points, a symmetric variation to the one computed in the low CO_2 emissions scenario. More moderate energy efficiency improvement is credited with 4 percentage points. The remaining 14 percentage points represent the contribution of the fall of energy prices.

The high CO_2 emissions scenario leads to a clear break in the past trend of CO_2 emission of the last 25 years (see Figure 37). A new era where low international energy prices boost the consumption of oil and natural gas and where the deployment of renewables is consequently slowed, especially in electricity generation. The CO_2 levy cannot counteract this because it cannot be raised beyond its legal ceiling of 120 CHF. Only the ETS price can react and it must jump to 265 CHF for the year 2020 to achieve the committed decrease of emissions.

Figure 37: Sensitivity analysis of CO_2 emissions in the WEM scenario



Based on these scenarios, it is possible to estimate the contribution of the three factors – GDP, energy efficiency, energy prices – through a first-order approximation for 2030. Table 29 summarizes these estimations. These parameters can be used to perform a back-of-the-envelope analysis of a new set of assumptions without reprocessing all the steps. For example, if we assume that GDP would be 2% higher relative to the reference scenario and that the energy efficiency improvement is 10% lower with energy prices 20% higher, this would result in a decrease of CO_2 emissions by around 1.7%, i.e. 2*1.14-0.16*(-10)-0.28*20. This is of course only a rough first indicative approximation.

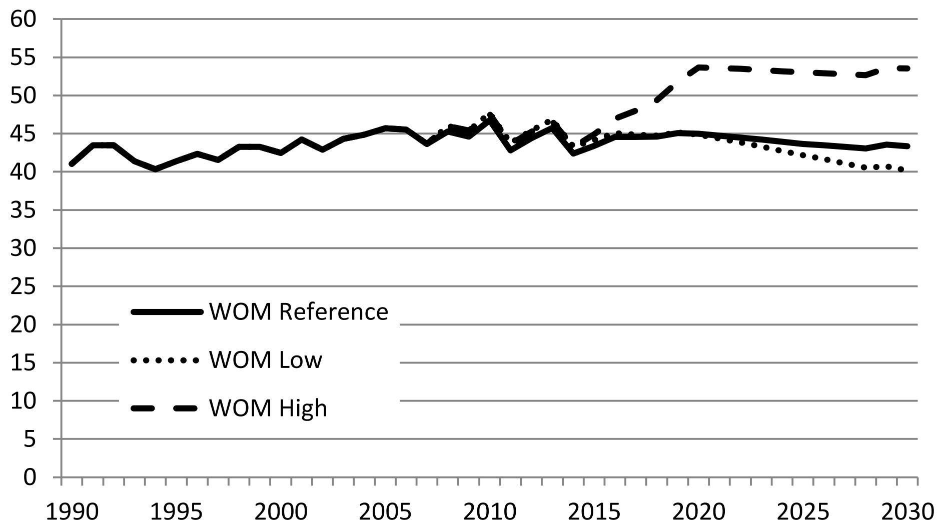
Table 29: Contribution of uncertain parameters to CO_2 emissions deviation with respect to the reference scenario

1% of additional GDP	1% of additional energy efficiency improvement	1% of increase of international oil price
↗ ≈ 1.14%	↘ ≈ -0.16%	↘ ≈ -0.28%

5.3.2. Emissions in the WOM scenarios

Figure 38 reports the results of the sensitivity analysis of the CO_2 emissions in the WOM scenarios. Of course, the dynamics of the three scenarios follow those of the WEM scenarios. However, as the uncertainty analysis assumes different levels of effectiveness for the non-price measures from 1990, the differences concern not only the forecasted period but also the historical years. Nevertheless, as can be seen in Figure 38, these differences are small for the historical period.

Figure 38: Sensitivity analysis of the CO_2 emissions in the WOM scenario



Interesting is the difference between the WEM and the WOM emissions in the two additional scenarios. In the high CO_2 emissions scenario, these emissions are 13.3 million tonnes higher in the WOM scenario than in the WEM scenario in 2020. This difference can be compared with the one computed in the reference scenario (8.9 million tonnes). However, the difference is higher even though the high CO_2 emissions scenario assumes a lower CO_2 saving potential from the non-price measures by 30% relative to the reference scenario. This counterintuitive result can be explained as follows. Firstly, the low oil price boosts oil demand in the transport sector, whose emissions have to be compensated according to the CO_2 Ordinance in the WEM scenario (see sect. 4.3.2). When this compensation is removed in the WOM scenario, CO_2 emissions increase much more than in the reference scenario. The same effect can be observed for the compensation of the emissions released by CCGT plants. Secondly, comparing WEM and WOM, the increase of the emissions from industry is also larger simply because the ETS price is two times higher than in the reference scenario.

The same dynamics are relevant in the low CO_2 emissions scenario. However, the effects are smaller, and they cannot offset the higher CO_2 saving potential that is assumed in this sensitivity scenario, at least in 2020. That is no longer the case in 2030, where the differences between the WEM and the WOM emissions are close in the two scenarios (reference and low CO_2 emissions scenarios).

6. Discussion and outlook

Switzerland will reduce its CO_2 emissions from combustion despite continued economic and demographic growth. Autonomous technical progress is sufficient, in the WOM scenario, to stabilize emissions, i.e. to offset economic and demographic growth (Figure 26), unless world energy prices stay at their current low level or growth is stronger. With our central assumptions, the decline in emissions is obtained by the energy and climate policies listed in Table 1, among which the carbon price (CO_2 levy and its exemption regimes), the building codes and the compensation for motor fuels are the most important (Figure 32). As a result of these existing policies, emissions from energy combustion are estimated to decrease by 12.2% in 2020 relative to 1990. They are projected to be 18.1% below 1990 levels in 2030.

The study has shown how complex the set of these instruments is, particularly when compared with the initial project of a general carbon tax. The special regimes for firms exempted from the CO_2 levy and the compensation mechanisms for motor fuels are extremely hard to assess, not to speak of the administration costs not estimated in this study. This study addressed this complexity by combining bottom-up micro-assessments with top-down macroeconomic simulations. This framework has proven very powerful, in particular in showing interactions between instruments and considering behavioural responses.

A difficulty of this study has been to attribute measures to sectors, particularly emission compensations, in particular those of the Klik Foundation for imported motor fuels and those for the new CCGT plants. When the achievements of the corresponding sectors – transport and energy – are considered, these compensations ought to be deducted from their emissions. However, when actual emissions are estimated, as in this report, the compensations appear as reductions in the emissions of the sectors where they take place.

Furthermore, the scenarios presented in this study assume distinct contributions from (i) the national buildings refurbishment programme, (ii) KliK and (iii) the transport sector and therefore assume separate targets for each of these instruments. It should be noted that in current discussions on federal and cantonal energy and mitigation policies this distinction is not clearly made. For instance, while both KliK and cantonal agencies support projects in the buildings sector, cantons assume that emission reductions supported by KliK also help to reach cantonal targets. In the clear distinction assumed in this study, this could lead to double counting of emission reductions for (i) KliK and (ii) the national buildings refurbishment programme. This could lead to a situation where the progress in the building sectors in cantons is overestimated. Any overlap would lead to a reduction in the expected savings thereby reducing the difference between the WEM and WOM scenario. Here, clarification of the accounting rules and information of key federal and cantonal actors as well as the private sector might be necessary.

A final lesson from this study is the importance of technical progress, in particular energy efficiency improvement. Energy efficiency improvement has a large impact on the evolution of energy consumption and CO_2 emissions. At the same time, the economic modelling of technical progress is much less established than that of production, consumption or trade decisions. This study relied very much on the detailed forecasts made in the framework of the Energy perspectives. A more sophisticated modelling framework would explicitly consider the interactions between technical progress (innovation and diffusion of innovation), economic conditions (e.g. energy prices) and policy measures. In this study, these interactions were only considered in a simplified way.

Abbreviations

AEEI: Autonomous energy efficiency improvement

CCGT: Combined-cycle gas turbines

CES: Constant elasticity of substitution

CGE: Computable general equilibrium

CO_2: Carbon dioxide

EEEI: Endogenous energy efficiency improvement

ETS: Emissions trading scheme

FSO: Federal Statistical Office

GHG: Greenhouse gas

HDD: Heating degree day

LSVA: Leistungsabhängige Schwerverkehrsabgabe (Heavy duty vehicle charge)

MuKEn: Mustervorschriften der Kantone im Energiebereich

MPIEEI: Market price-induced energy efficiency improvements

NMVOC: Non methane volatile organic compound

ODS: Ozone depleting substance

OPAC: Ordinance on air pollution control

PIEEI: Policy-induced energy efficiency improvement

SECO: State Secretariat for Economic Affairs

TEEI: Total energy efficiency improvement

TIEEI: Tax induced energy efficiency improvement

toe: Tonne of oil equivalent

VBSA: Verband der Betreiber Schweizerischer Abfallverwertungsanlagen

VOC: Volatile organic compound

WEM: With existing measures

WEO: World energy outlook

WOM: Without measures

WWB: Weiter wie bisher (business as usual)

References

Allan G, Hanley N, McGregor P, Swales K, Turner K 2007: The impact of increased efficiency in the industrial use of energy: A computable general equilibrium analysis for the United Kingdom. Energy Economics, 29(4):779–798.

Bundesamt für Umwelt BAFU 2015: Projekte und Programme zur Emissionsverminderung im Inland, Bern (UV-1315-D).

Betz R, Leu T, Schleiniger R 2015: Disentangling the Effects of Swiss Energy and Climate Policies, Workpackage 3: Energy Policy, Markets and Regulation SCCER CREST, zhaw, April 2015

BfE 2010: Globalbeiträge an die Kantone nach Art. 15 EnG. Wirkungsanalyse kantonaler Förderprogramme Ergebnisse der Erhebung 2009. INFRAS im Auftrag des Bundesamts für Energie, 2010.

BfE 2013: Wirkung Kantonaler Energiegesetze. Analyse der Auswirkungen gemäss Art. 20 EnG, Aktualisierung für das Jahr 2012. INFRAS im Auftrag des Bundesamts für Energie, 2013.

BfE 2015: Schweizerische Elektrizitätsstatistik 2014, Bundesamt für Energie, Bern.

BfE 2015a: Globalbeiträge an die Kantone nach Art. 15 EnG. Wirkungsanalyse kantonaler Förderprogramme Ergebnisse der Erhebung 2014. INFRAS im Auftrag des Bundesamts für Energie, 2015.

BfE 2015b: Energie- und CO_2-Wirkung des Gebäudeprogramms 2010–2014. Zusatzanalyse für die Berichterstattung an das Parlament. INFRAS im Auftrag des Bundesamts für Energie, 2015 (noch unveröffentlicht).

BfE 2015c: Schweizerische Gesamtenergiestatistik 2014, 2015.

Bernard A, Vielle M 2008: GEMINI-E3, a General Equilibrium Model of International National Interactions between Economy, Energy and the Environment. Computational Management Science, 5(3):173-206, May.

Bundesrat 2016: Wirksamkeit der Finanzhilfen zur Verminderung der CO_2-Emissionen bei Gebäuden gemäss Artikel 34 CO_2-Gesetz, Bericht des Bundesrates an die Bundesversammlung, März.

Carbotech 2013: Emissionsperspektiven F-Gase: HFKW, PFKW und SF_6.

Climate Cent Foundation 2011: Schlussbericht Gebäudeprogramm 2006-2009.

Dimitropoulos J 2007: Energy productivity improvements and the rebound effect: An overview of the state of knowledge. Energy Policy 35(12):6354–6363.

Duerinck J, Renders N, Schoeters K 2008: Assessment and improvement of methodologies used for greenhouse gas projection. Vlaamse Instelling voor Technologisch Onderzoek

Ecoplan 2012: CO_2-Emissionen 2008 bis 2012. Kurzfrist-Perspektiven der energiebedingten CO_2-Emissionen der Schweiz, Report to FOEN, 31 October.

Ecoplan/EPFL/FHNW 2015: Wirkungsabschätzung CO_2-Abgabe – Modellrechnungen, im Auftrag des Bundesamts für Umwelt (BAFU), Bern und Lausanne, Dezember.

Ecoplan/INFRAS 2012: Strassengüterverkehr in der Schweiz: Entwicklung im alten und neuen Verkehrsregime -Aktualisierung für die Jahre 2005 bis 2010, im Auftrag des Bundesamts für Raumentwicklung (ARE), Altdorf / Zürich, March 2012

EnDK 2015: Zwischenbericht 2010-2014 Das Gebäudeprogramm, Teile A und B, Konferenz-Kantonaler Energiedirektoren, Juli 2015

Ernst Basler+Partner 2015: Energieverbrauch und Energieeffizienz der neuen Personenwagen 2014. 19. Berichterstattung im Rahmen der Energieverordnung, Report to FOE, 11 June.

EZV 2015: Information über die Einnahmen aus der LSVA für die Jahre 2011 – 2014. Eidgenössische Zollverwaltung - EZV, 2015.

EZV 2015a: Information über die Einnahmen aus der VOC-Lenkungsabgabe für die Jahre 2000-2014. Eidgenössische Zollverwaltung – Oberzolldirektion, 2015.

FOEN 2015: Switzerland's National Greenhouse Gas Inventory 1990-2013. Federal Office for the Environment, Bern.

FOEN 2015a: Switzerland's Informative Inventory Report 2015 – Submission under the UNCECE Convention on Long-range Transboundary Air Pollution. Federal Office for the Environment, Bern.

Gebäudeprogramm 2014: Jahresstatistik 2014 des Gebäudeprogramms – Gesamtschweizerische Analyse.

Greening LA, Greene DL, Difiglio C 2000: Energy efficiency and consumption - the rebound effect – a survey. Energy Policy 28(67):389–401

IEA 2014: World Energy Outlook 2014, International Energy Agency.

IEA 2015: World Energy Outlook 2015, International Energy Agency.

IASA 2015: The Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS)-Model. http://gains.iiasa.ac.at/models/

INFRAS 2015: Impact analysis of measures related to efficiency increase in the transport sector 1990 to 2030. Internal analysis by Mario Keller based on previous results for Prognos (2015).

INFRAS 2013: Abschätzung der künftigen Entwicklung von Treibstoffabsatz und Mineralölsteuereinnahmen – Grundlagenbericht, Bern, Februar 2013

INFRAS 2011: Wirkungsanalysen EnergieSchweiz 2010, Wirkungen der freiwilligen Massnahmen und der Förderaktivitäten von EnergieSchweiz auf Energie, Emissionen und Beschäftigung, im Auftrag des Bundesamtes für Energie, Bern.

IPCC 2006: Guideliens for national greenhouse gas inventories.

KEV 2010: Annual report 2009, Stiftung Kostendeckende Einspeisevergütung KEV, Frick

KEV 2011: Annual report 2010, Stiftung Kostendeckende Einspeisevergütung KEV, Frick

KEV 2012: Annual report 2011, Stiftung Kostendeckende Einspeisevergütung KEV, Frick

KEV 2013: Annual report 2012, Stiftung Kostendeckende Einspeisevergütung KEV, Frick

KEV 2014: Annual report 2013, Stiftung Kostendeckende Einspeisevergütung KEV, Frick

KEV 2015: Annual report 2014, Stiftung Kostendeckende Einspeisevergütung KEV, Frick

KliK 2015: Factsheets on transport related CO_2 saving projects. KliK foundation, 2015. http://www.klik.ch/de/Plattformen/Plattform-Verkehr.157.html

MuKEn 2008: Mustervorschriften der Kantone im Energiebereich Version 2008.

MuKEn 2014: Mustervorschriften der Kantone im Energiebereich Version 2014. http://www.endk.ch/de/dokumentation/MuKEN

Narayanan B, Aguiar A, McDougall R, editors 2012: Global Trade, Assistance, and Production: The GTAP 8 Data Base. Center for Global Trade Analysis, Purdue University.

Nathani C, Sutter D, van Nieuwkoop R, Peter M, Kraner S, Holzhey M, Rütter H, Zandonella R 2011: Energy related disaggregation of the Swiss Input-Output Table. SFOE, EWG Publication, Bern, 2011.

OFS 2015: Les scénarios de l'évolution de la population de la Suisse 2015–2045, Office fédéral de la statistique, Juin 2015.

Prognos 2012: Die Energieperspektiven für die Schweiz bis 2050 – Energienachfrage und Elektrizitätsangebot in der Schweiz 2000-2050. Prognos AG im Auftrag des Bundesamtes für Energie, Basel. http://www.bfe.admin.ch/themen/00526/00527/index.html?lang=de&dossier_id=05024 [20.01.2015]

Swiss Confederation 2013: Switzerland's Sixth National Communication and First Biennial Report under the UNFCCC, edited by Federal Office for the Environment, Bern.

TEP Energy GmbH und Rütter Soceco AG 2016: Wirkungsabschätzung CO_2-Abgabe – Direktbefragungen, im Auftrag des Bundesamts für Umwelt (BAFU), Zürich und Rüschlikon, April.

UBA 2010: Fluorierte Treibhausgase vermeiden – Wege zum Ausstieg. Umweltbundesamt, Deutschland.

Winkler R, Almer C, Bader C, Gonseth C, Laurent-Luchetti J, Thalmann P, Vielle M 2014: Energy consumption of buildings - direct impacts of a warming climate and rebound effects, in CH2014-Impact (ed), Toward Quantitative Scenarios of Climate Change Impacts in Switzerland, OCCR, FOEN, MeteoSwiss, C2SM, Agroscope and ProClim., pp 99–105

Appendix: non-CO_2 measures

Non-CO_2 measures are not part of the current study because the top-down impact assessment only focuses on direct CO_2 emissions. Nonetheless, there are other activities, which also reduce greenhouse gases. Three important non-CO_2 measures or activities with impacts on greenhouse gas emissions are described in Table 30 and discussed below.

Table 30: List of measures leading to greenhouse gas emission reductions other than CO_2 since 1990 (bottom-up assessment)

Cluster	Description	Time period	Cumulative savings 1990-2030
Non-CO_2 measures (Appendix: non-CO_2 measures)	**NMVOC incentive fee** The NMVOC incentive fee was introduced in 2000 to reduce VOC emissions. Previously, the OAPC defined measures aimed at reducing these emissions.	1990-2030	9 Mt CO_{2eq}
	Provisions relating to substances stable in the atmosphere (F-gases) Measures aiming at limiting the use of F-gases and at reducing emissions from the use of F-gases as far as possible.	1996-2030	27 Mt CO_{2eq}
	Ban on landfilling of combustible waste The deposition of waste in waste landfills is prohibited since 2000. In response to this prohibition, many waste incineration plants were built in the last 15 years, which lead to a reduction of methane emissions from landfilling of combustible waste.	2001-2030	13 Mt CO_{2eq}

Provisions relating to substances stable in the atmosphere (F-gases)

Synthetic gases (F-gases) are substitutes of ozone depleting substances (ODS). Their global warming potentials is much higher than that of the main greenhouse gases such as CO_2, CH_4 or N_2O. The emissions of F-gas emissions are rapidly increasing since 1995. Since then several measures were implemented to reduce the F-gas emissions. A description and calculation of a possible emission pathway without those as well as future measures has been carried out by Carbotech (2013). Please note that the analysis by Carbotech is based on IPCC 1997 Guidelines. The CO_{2eq} saving may differ when calculating the number with IPCC 2006 Guidelines (IPCC 2006).

Total investments concerning the F-gas savings are based on expert estimates. It is assumed that the price per tonne CO_{2eq} saving is around 60 CHF in 2014. It is also assumed that the price to achieve any F-gas savings will not be additionally higher than the typical future market price. Therefore, it is assumed that the price will linearly decrease, reaching zero CHF/t CO_{2eq} in 2025. The price is following a reduction rate of 3% per year between 1990 and 2024. In

1990 the price is therefore assumed to be approximately 200 CHF/t CO_{2eq}. The underlying price is comparable to the prices given in UBA (2010).

Methane emissions

Methane emissions originate from different sources. One possible source is waste landfills. The deposition of waste in waste landfills is prohibited since 2000. Because of this prohibition, waste incineration capacity has been expanded over the last 15 years. Waste landfills still cause CH_4 emissions but, obviously, they are decreasing. The decreasing trend is a direct result of the prohibition and the new waste incineration plants. In order to illustrate the impact of this prohibition with indirect impact on CO_{2eq} emissions the data of the latest Swiss greenhouse gas inventory (FOEN 2015) have been taken. It is assumed that the difference of CH_4 emissions from waste landfill sites between the year 2000 and the subsequent years are the result of the landfill prohibition.

Investments related to the CH_4 savings can be found in the construction costs for new waste incineration plants. The investment data for the time series 2000 – 2015 were provided by the VBSA[20]. It is assumed that no additional investments will be conducted in future as the result of the prohibition.

VOC emissions

A NMVOC incentive fee was introduced in 2000 in order to reduce these emissions. NMVOC emissions can react to CO_2 in the atmosphere and are, for that reason, also relevant for greenhouse gas emissions. Before the NMVOC incentive fee came into force, measures to reduce NMVOC emissions were regulated by the OAPC[21]. Both measures contribute to the reduction of indirect CO_2 emissions from NMVOC emissions. In order to estimate the CO_2 savings data of the latest greenhouse gas inventory (FOEN 2015) were taken (especially focused on so-called LU-VOC which were delivered by FOEN). The difference between 1990 and subsequent years is assumed to be the CO_2 savings due to the OAPC and the NMVOC incentive fee. The pathway for emissions 2013-2030 following the objectives given in the Swiss Informative Inventory Report (FOEN 2015a).

Estimated investments to achieve the CO_2 savings are based on estimated VOC abatement costs for stationary sources from the GAINS model (IASA 2015). The revenues of the NMVOC incentive fee were taken from the Swiss Customs Administration (EZV 2015a). It is assumed

[20] VBSA: Verband der Betreiber Schweizerischer Abfallverwertungsanlagen.
[21] OPAC: Ordinance on air pollution control

that the amount of the NMVOC incentive fee remains constant at 125 Mio. CHF for the time period 2015-2030.

CO_{2eq} savings and financial data

The bottom-up assessment concerning measures focusing on non-CO_2 emissions lead to CO_{2eq} savings of roughly 48 Mio. t cumulated over the entire period 1990-2030. Annual savings are expected to reach 2.75 Mio. t CO_{2eq} in 2030 (Figure 39). The main contribution stems from measures aiming at reducing F-gases. The reduction in F-gas emissions is responsible for 54% of the total savings within the time period 1990-2030. Other 28% of the reductions stem from waste related measures and 19% from the measures regarding VOC emissions.

To obtain these CO_{2eq} savings, cumulative gross investments of total CHF 6.5 billion are needed between 1990 and 2030. 65% of these investments are associated with the NMVOC incentive fee which is refunded to the public. Net investments account therefore for CHF 2.2 billion. 70% of the net investments has been used for the realisation of new waste incineration plants (which have a lifetime of approximately 40 years by the way). The other 30% are investments needed to reduce F-gas emissions.

Figure 39: Bottom-up impact assessment for non-CO_2 greenhouse gases