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Pathways to deep decarbonisation
An overview of Swiss climate policy and existing simulations of decarbonisation strategies

Report on results from Task A and B in the DDPP related mandate from FOEN

Zurich, 17 April 2015

Jürg Füssler, Damaris Bertschmann, Mario Betschart, Rolf Iten (INFRAS)
Reviewers: Philippe Thalmann, Marc Vielle (EPFL)

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Jürg Füssler

Authors

Jürg Füssler, Damaris Bertschmann, Mario Betschart, Rolf Iten (INFRAS)

Reviewers: Philippe Thalmann, Marc Vielle (EPFL)

INFRAS, Binzstrasse 23, 8045 Zurich

Tel. +41 44 205 95 95

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1. Official Swiss goals, options and strategies to meet the 2°C target

1.1. The national context for deep decarbonization and sustainable development

1.1.1. National circumstances

Switzerland's total energy use 2012 accounted for 882'280 TJ. 77.5% of the primary energy supply was imported whereas 22.5% was sourced domestically (Swiss Confederation 2013). The energy trade deficit represented 11 billion Swiss francs in 2012 (SFOE 2013). According to Switzerland's Sixth National Communication under the UNFCCC (Swiss Confederation 2013), 53.2% of the total final energy consumption was provided by oil, 24.1% by electricity and 12.9% by gas. The remaining 9.7% comprised wood, waste, coal and several renewable forms of energy. Electricity generation in Switzerland is dominated by hydroelectric power plants (58.7%) and nuclear power plants (35.8%). Since 2005, real GDP and final energy consumption started to diverge due to an increase in energy efficiency and outsourcing of production sites to other countries. As a result, Switzerland's GHG emissions 2012 amounted to 6.4 t CO_2eq per capita or 5.4 tCO_2 per capita (FOEN 2014) which is at the lowest end of OECD countries.

1.1.2. Policies

By ratifying the United Nations Framework Convention on Climate Change (UNFCCC), Switzerland committed to contribute to the stabilization of GHG emission at a level that would prevent dangerous anthropogenic interferences with the climate system. Switzerland ratified the Kyoto Protocol in 2003. The protocol entered into force in 2005. Switzerland has also committed to continue its emission reduction efforts und the Kyoto Protocol for the years 2013-2020. The new target is set at 20% below the 1990 emission level by 2020.

The Federal Council has defined its main policy focus areas for sustainable development in its Sustainable Strategy 2012-2015 (Swiss Federal Council 2012) which inter alia focuses on the combat against global warming.

Climate policy

The centrepiece of the Swiss climate policy is the so-called CO_2 Act. The first CO_2 Act covered the period 2008-2012, with the goal to limit CO_2 emissions from fossil fuel use for heating and transport to 10% below 1990 levels over the period 2008-2012. The revised CO_2 Act covers the period 2013-2020. A reduction of at least 20% of the domestic GHG emissions compared to their 1990 level is the main target of this revised CO_2 Act. This overall target was translated into sector specific sub-targets for buildings, transport and industry including reduction path-

ways. The revised CO_2 Act sets incentives to increase the use of renewable energies, to develop new and innovative technologies and creates new jobs in promising fields.

Energy policy

The Swiss energy policy, in particular the Energy Strategy 2050, pursues the objective of a secure energy supply, an increasing energy efficiency, the expansion and restructuring of electricity transmission grids, the expansion of hydropower and renewable energies and, if necessary, a fossil fuel-based electricity production as well as imports. A core element of the Energy Strategy 2050 is the gradual phase out of Switzerland's nuclear power stations by the end of their lifecycle (Swiss Federal Council 2013). The framework of the energy policy is provided by the Swiss Energy Act and the Energy Strategy 2050 which is also in line with the available CO_2 Act. The planned amendment of the Swiss Energy Act aims at the proposed targets of the Energy Strategy 2050, which are a 16% reduction of the energy consumption per capita and a decrease of the electricity consumption by 3% per capita until 2020 compared to year 2000 consumption levels. The reductions should be further increased until 2035. A reduction of 43% in energy consumption and a 13% lower electricity use per capita will be aspired.

A reform of the electricity market is under way as well. The opening of the entire market is planned from 2015. Besides this market opening a number of measures and reforms are planned for future years (see also measures included in Scenarios WEM and WAM in section 1.3).

1.2.   GHG emissions: current levels, drivers, and past trends
1.2.1.   Total GHG emissions

Switzerland emitted approximately 50.0 $MtCO_2eq$ in 2011 (excluding LULUCF and international bunker fuels). This value corresponds to 6.32 tCO_2eq per capita. Fuel combustion within the energy sector (power, transport, buildings) was by far the largest source of CO_2 emissions in the last years (see Figure-1-1 and Figure-1-2). Emissions of CH_4 and N_2O originated mainly from agriculture. F-gas emissions arise by definition from the industry sector (Swiss Federal Council 2013).

1.2.2.   Power

Switzerland's energy emissions 2011 mainly originate from the transport sector (32%) whereas emissions from the electricity production contribute only 8% to the total energy emissions. The electricity production itself is dominated by hydroelectric power plants (59%) and nuclear power plants (36%). The total energy emission accounted for 80% of the total GHG emissions in 2011 corresponding to 39.9 $MtCO_2eq$. The total GHG reduction 1990-2011 amounted for 5%.

1.2.3. Transport

32% of the total energy emissions come from the transport sector. The total transport emissions increased by 11% over the past years (1990-2011) but with fluctuations indicating a fairly strong correlation between the sector and economic development. The total GHG emissions caused by the transport sector reached 16.2 $MtCO_2eq$ in 2011.

1.2.4. Buildings

The energy related emissions of commercial and institutional buildings include emissions from stationary fuel combustion due to heating activities and from mobile off-road machinery (hobby gardening) as well as motorised equipment. Residential emissions originate from stationary fuel combustion in households and from hobby and gardening activities and other motorised equipment (FOEN 2014). In accordance to Switzerland's latest national inventory report (FOEN 2014), the commercial and residential emissions accounted for approximately 15.2 $MtCO_2eq$ in 2012 which are 37% of the total energy related emissions. Between 1990 and 2012 an impressive reduction of 16% was observed.

1.2.5. Industry

Industry related emissions comprise emissions from a variety of industrial processes such as cement production, ammonia production and the iron and steel production as well as emission from solvents. These emissions represent approximately 8% of Switzerland's total GHG emissions (FOEN 2014). In line with economic development, overall emissions in the industry sector showed a decreasing trend in the 90s and a rebound between 1998 and 2011 (Swiss Confederation 2013), reaching +9% higher emissions in 2012 in comparison to 1990 emission level. The total GHG emissions of all industrial processes represented 3.6 $MtCO_2eq$ in 2011. NMVOC emissions have been diminished substantially between 1990 and 2004 duo to their limitation and the introduction of the VOC tax in 2000 (Swiss Confederation 2013). Emissions related to solvents accounted for 0.2 $MtCO_2eq$ in 2011.
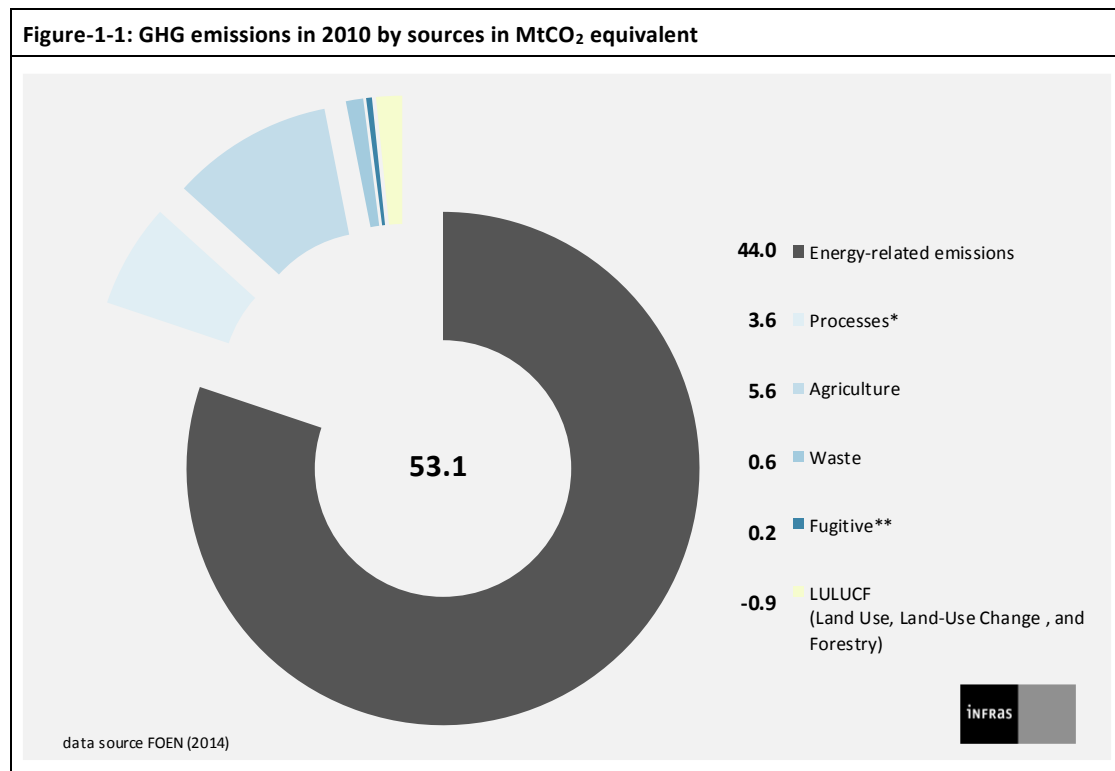
1.2.6. Agriculture

The agricultural emissions contributed about 11% to the total GHG emissions in 2011 which amount to 5.6 $MtCO_2eq$. Declining populations of cattle and swine as well as reduced fertilizer use led to a reduction of GHG emissions between 1990 and 2004. The CH_4 emissions have remained relatively stable since 2004.

1.2.7. Land Use Change and Forestry

The land use, land-use change and forestry emissions (LULUCF emissions) of Switzerland serve as net CO_2 sink in the order of 7% of the total GHG emissions 2011 and therefore, to approximately 1.9 $MtCO_2eq$ (Swiss Confederation 2013). Switzerland's LULUCF sector is dominated by biomass dynamics in forests. Therefore, relatively high variations of the removals are the consequence, in particularly driven by impacts of single destructive storms on the biomass productivity.
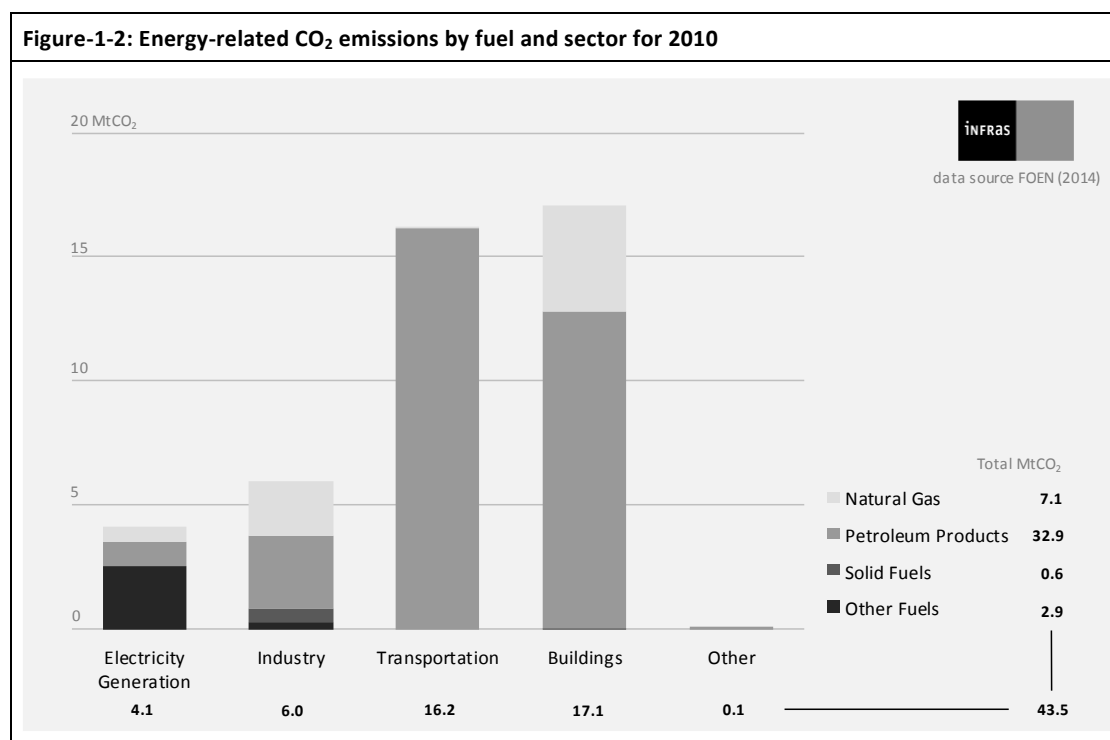
1.2.8. Waste

The emissions due to activities in sector waste contribute to 1% of Switzerland's total GHG emissions (FOEN 2014) and accounted only for 0.6 $MtCO_2eq$ in 2011. Switzerland's emissions originating from the waste sector decreased steadily throughout the period 1990-2012 (-41%). The main reason of the reductions since the year 2000 is a change in legislation. Disposal of combustible municipal solid wastes on landfills has been banned, leading to a decrease in methane emissions from landfill sites and an increasing amount of municipal solid waste being incinerated in waste incineration plants (Swiss Confederation 2013).

Figure-1-1: GHG emissions in 2010 by sources in $MtCO_2$ equivalent

53.1

44.0	■ Energy-related emissions
3.6	■ Processes*
5.6	■ Agriculture
0.6	■ Waste
0.2	■ Fugitive**
-0.9	■ LULUCF (Land Use, Land-Use Change , and Forestry)

data source FOEN (2014)

The figure illustrates Switzerland's total GHG emissions by sources. The data are given by FOEN (2014). Process related emissions (*) include emissions of the source category industrial processes according to FOEN (2014). Fugitive emissions (**) include all emissions from source category solvents and other product use (FOEN 2014)

Figure-1-2: Energy-related CO_2 emissions by fuel and sector for 2010

	Total MtCO₂
Natural Gas	7.1
Petroleum Products	32.9
Solid Fuels	0.6
Other Fuels	2.9

Electricity Generation	Industry	Transportation	Buildings	Other		Total MtCO₂
4.1	6.0	16.2	17.1	0.1		43.5

data source FOEN (2014)

The figure illustrates the energy-related CO_2 emissions for different subsectors and fuels in MtCO₂. Fugitive emissions due to pipeline leakage or flaring are also considered. Data source: FOEN (2014).

1.3. Swiss GHG projections and the total effect of measures

Switzerland fully revised its GHG emission scenarios over the past years considering the targets of the climate and energy policy. The latest set of GHG emission scenarios became available in 2012. For consistency reasons, the GHG emission scenario assume the same key parameter such as population growth, economic development and industrial production as underlying the energy scenarios (Prognos 2012) of the Energy Strategy 2050 (see also section 2.3.1). Independent scenarios for the agriculture and the LULUCF sector complement the energy scenarios (Swiss Confederation 2013). As recommended by the UNFCCC, three scenarios are available: a "with measures" scenario, a "with additional measures" scenario and a "without measures" scenario. The development in key variables such as population, economic development and industrial production are identical for all three scenarios, meaning that some of the main drivers of energy consumption remain the same. However, the scenarios are different in terms of energy efficiency, technology availability and use of different energy sources (Swiss Confederation 2013).

1.3.1. Scenario WOM

The "without measures" scenario (WOM) in the Swiss National Communication (Swiss Confederation 2013) is defined as the business-as-usual (BAU) scenario in the Energy Strategy 2050 (Prognos 2012). The WOM scenario assumes that measures currently implemented are continued at the present level with technological advances diffusing autonomously, leading to a slow gradual CO_2 intensity and energy efficiency. Thus, the emission projections in this scenario take all measures implemented before 2010 into account and provide only an outlook on future evolution without any further policy development. The WOM scenario results in a reduction of total emission of 5% between 1990 and 2020. Total GHG emissions will reach a level of approximately 48 $MtCO_2eq$ by 2030.

1.3.2. Scenario WEM

The so-called "with existing measures" scenario (WEM) reflects the current state of Switzerland's legislation, in particular of the revised CO_2 Act for the period 2013-2020, as closely as possible. A number of measures will be continued and intensified. Measures in the building sector, the CO_2 levy on heating and process fuels, new CO_2 emissions standards for new vehicles, improving electric efficiency, the feed-in tariff for renewable energy as well as measures in the waste, agricultural are only a few examples.

As a result of the measures considered by the WEM scenario, the total GHG emissions are set to decrease by approximately 15% between 1990 and 2020. Total GHG emissions of about 38 $MtCO_2eq$ per year will be achieved until 2030.

[The WEM scenario provides the basis for the reference Scenario of the current DDP project, which corresponds to the energy scenario "political measures (POM) option C and E"].

1.3.3. Scenario WAM

The "with additional measures" scenario (WAM) is considered as long-term target scenario of the Swiss government oriented for 2050 in key policy areas. Policies and measures have not yet been put in concrete terms but are assumed to be developed over time in order to reach the target set, which includes in particular substantial energy efficiency gains in all sectors. Energy consumption for the WAM scenario is based on the energy scenario "new energy policy, option E" of the latest energy scenarios (Prognos 2012). This scenario assumes that international efforts are made to reduce GHG emissions towards 1-1.5 tCO_2 per capita in 2050 and that policies and measures are coordinated internationally. The difference in the industry sector compared to the WEM scenario is entirely due to efficiency improvements (Swiss Confederation 2013).

In this context, total emissions are projected to decrease by approximately 22% between 1990 and 2020. This target is in line with Switzerland's commitment under the second commitment period of the Kyoto Protocol, which requires emission reductions declining to 20% below the 1990 level by 2020. The total GHG emissions are expected to reach the level of 30 $MtCO_2eq$ by 2030 including emissions of all sectors.

[The WAM scenario provides the framework for Switzerland's deep decarbonization pathways (DDPs) in order to reach the 2°C target in accordance with the entire Deep Decarbonization Pathways Project (DDPP).]

1.4. Non-CO$_2$ GHG emissions: current levels and projections

The chapters above only discuss GHG emissions in an aggregated manner, in particular as CO$_2$ equivalents, including CO$_2$ emissions and non-CO$_2$ greenhouse gas emissions as well. Although CO$_2$ emissions are the main driver for a changing climate, non-CO$_2$ emissions, such as methane (CH$_4$), nitrous oxide (N$_2$O) and fluorinated gases emissions (HFC, PFC and SF$_6$) play more than just a minor role.

Within this chapter the current levels, trends and projections of non-CO$_2$ GHG emissions are introduced in order to enhance the aggregated perspective about total CO$_2$ equivalent. For further information about specific measures and potentials for non-CO$_2$ GHGs see INFRAS (2014).

1.4.1. Current non-CO$_2$ emission levels

Methane

In 1990 Switzerland's CH$_4$ emissions (excluding emissions from Land Use Change and Forestry) amounted for 4.7 MtCO$_2$eq. A reduction by 0.9 MtCO$_2$eq between 1990 and 2010 led to total methane emissions of 3.8 MtCO$_2$eq by 2010. This reduction was mainly attributable to a reduction of livestock within the agriculture sector which led to a reduction of emissions from enteric fermentation. Additionally, a change in waste legislation contributed to this trend as well (FOEN 2014).

Nitrous oxide

N$_2$O emissions (excluding emissions from Land Use Change and Forestry) decreased by around 13% between 1990 and 2010 from originally 3.5 MtCO$_2$eq to 3.1 MtCO$_2$eq. The reduction of N$_2$O emissions is caused by a decline in manure management and agricultural soils emissions (FOEN 2014).

Fluorinated gases

The total amount of HFC emissions increased significantly due to their application as substitutes for CFC's. While 1990 no significant amounts of HFC were emitted, the emissions reached 1.1 MtCO$_2$eq in 2010. PFC emission declined in the same time by 63 MtCO$_2$eq and amounted for 37 MtCO$_2$eq in 2010. SF$_6$ emissions show large fluctuations between 1990 and 2010. In 1990 the total SF$_6$ emissions resulted in 144 MtCO$_2$eq. The SF$_6$ emissions accounted for 155 MtCO$_2$eq in 2010. The share of all F-gases (HFCs, PFCs and SF$_6$) in total emissions (excluding LULUCF) increased from 0.5% in 1990 to 2.5% in 2010 (FOEN 2014).

1.4.2. Projections: scenario WOM

The business-as-usual scenario results in a reduction of total emission of 5% between 1990 and 2020. Total GHG emissions will reach a level of approximately 48 $MtCO_2eq$ by 2030. In the same time the total amount of non-CO_2 GHG emissions will increase by 1.3 $MtCO_2eq$ (1990-2030). The main driver is an increase of HFC's emissions due to a missing phase-out and replacement of fluorinated gases.

Figure 1-3: Non-CO₂ GHG emissions WOM scenario
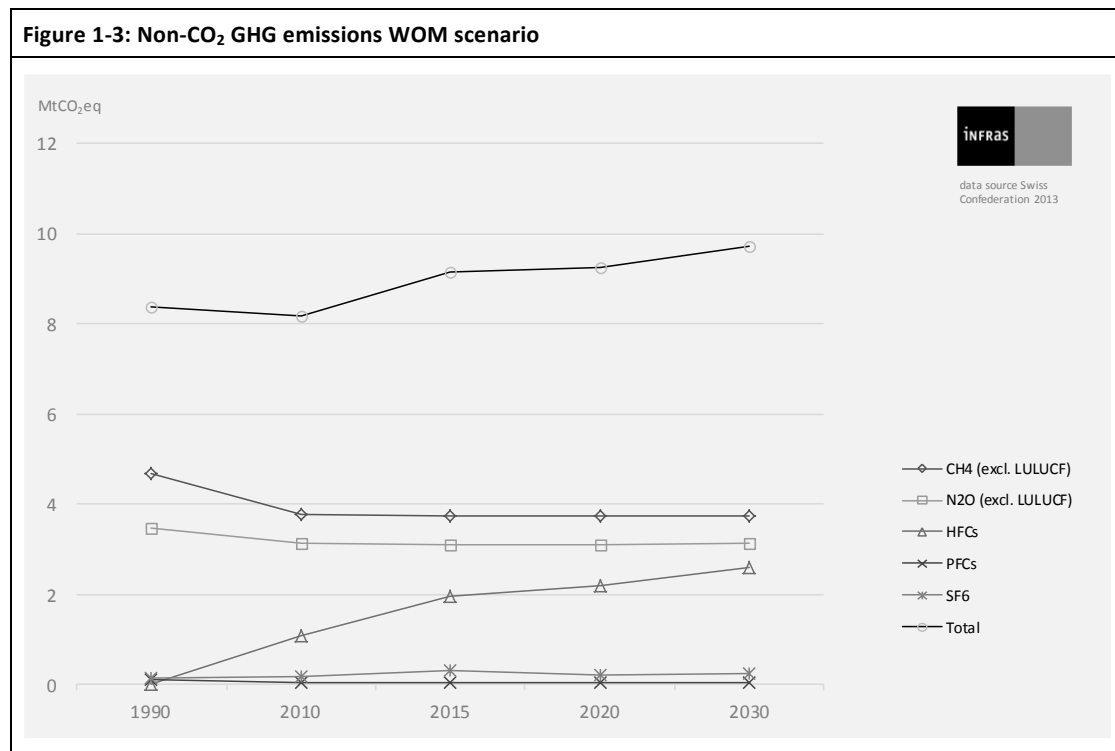
The figure illustrates the non-CO_2 emissions for different gases in $MtCO_2$ for the WOM scenario. Data source: Swiss Confederation (2013).

Methane

The WOM scenario calculates minor reductions only. The total CH_4 emissions will reach 3.7 $MtCO_2eq$ by 2015. The emissions will then remain stable until 2030 (Swiss Confederation 2013). Methane emissions are highly dominated by agricultural development. The projections for the agricultural emissions are based on the high price level scenario by Peter et al. (2010). It is assumed that technical, organizational and structural framework conditions remain largely unchanged. The time horizons of the projections reach in most cases until 2022. For subsequent years all values are kept constant (Swiss Confederation 2013).

Nitrous oxide

Considering the WOM scenario, the total N_2O emissions remain constant over time since the manure management distribution is assumed to remain constant as well (Swiss Confederation 2013).

Fluorinated gases

The WOM scenario predicts an increase in HFC emissions by 1.5 $MtCO_2eq$ until 2030 while PFC and SF_6 emissions remain stable on a low level. The scenario assumes no forced phase-out and replacement of fluorinated gases and therefore HFC emissions keep increasing (Carbotech 2013).

1.4.3. Projections: scenario WEM

The total GHG emissions are set to decrease by approximately 15% between 1990 and 2020 when considering the WEM scenario. At the same time non-CO_2 related emissions decrease by approximately 6% and another 2% until 2030. The emissions of non-CO_2 GHG emissions are mainly influenced by the future development of HFC emissions. While they are predicted to further increase until 2015 and then gradually decrease until 2030 all other drivers are assumed to remain stable.

Figure 1-4: Non-CO₂ GHG emissions WEM scenario
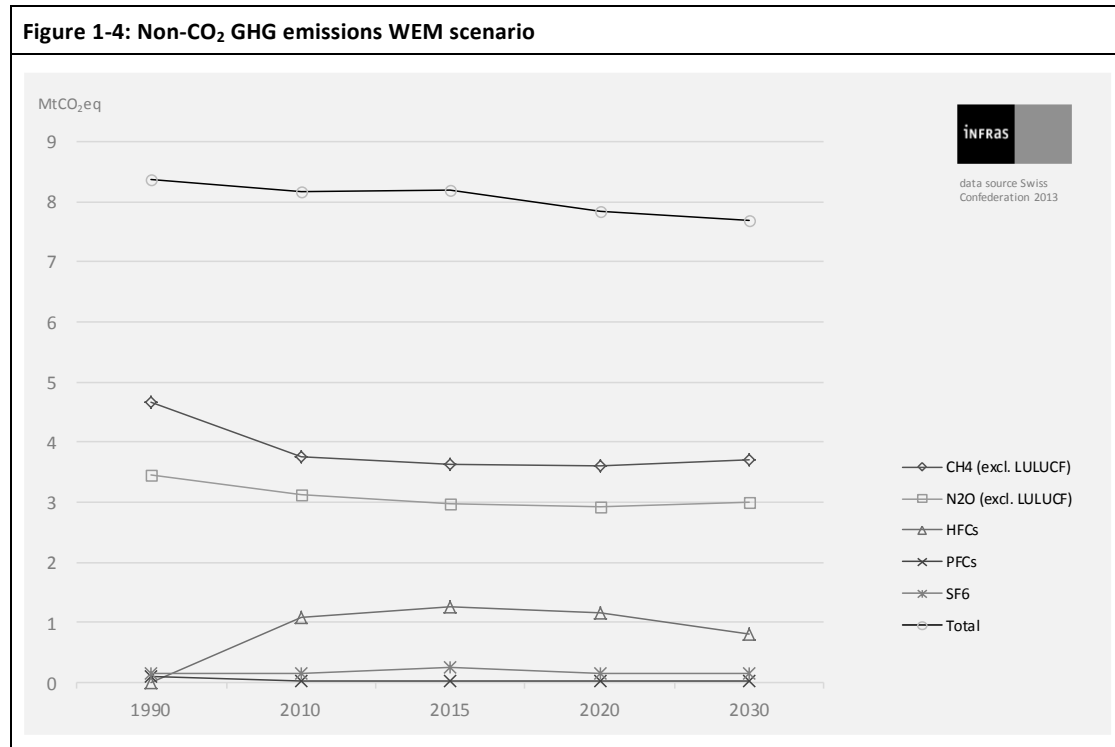
The figure illustrates the non-CO₂ emissions for different gases in MtCO₂ for the WEM scenario. Data source: Swiss Confederation (2013).

Methane

CH₄ emissions are projected to decrease by only 0.1 MtCO₂eq between 2010 and 2030 when considering the WEM emission pathway. It is assumed that many parameters such as manure management remain constant over time. Therefore, CH₄ emissions won't decrease significantly. These assumptions are based on an investigation about the repercussions of the Swiss agricultural policy 2014-2017 done by Zimmermann et al. (2011).

Nitrous oxide

Similar developments can be observed for the N₂O emission WEM pathway. The reductions between 2010 and 2030 are with 0.1 MtCO₂eq rather small. Because agricultural activities are the main source of N₂O emissions they will follow the assumptions and predictions based on Zimmerman et al. (2011).

Fluorinated gases

A different picture can be drawn for HFC emissions. The WEM projection proceeds on the assumption that HFC emission increase until 2015. Afterwards the emission will gradually decrease from 1.3 MtCO₂eq by 2015 to 0.8 MtCO₂eq by 2030. The main driver for this progress is

the future use of HFC as refrigerants which should continuously be replaced by non-HFC products (Carbotech 2013).

1.4.4. Projections: scenario WAM

In this context, total emissions are projected to decrease by approximately 22% between 1990 and 2020. Compared with the WOM and WEM projection the WAM scenario draws decreasing non-CO_2 GHG emissions for all gases. The total effect of the reductions accounts for -8% between 1990 and 2020 and even -22% between 1990 and 2030. It is assumed that total non-CO_2 emissions will reach 6.6 MtCO₂eq by 2030 and further decline until 2050.

Figure 1-5: Non-CO₂ GHG emissions WAM scenario
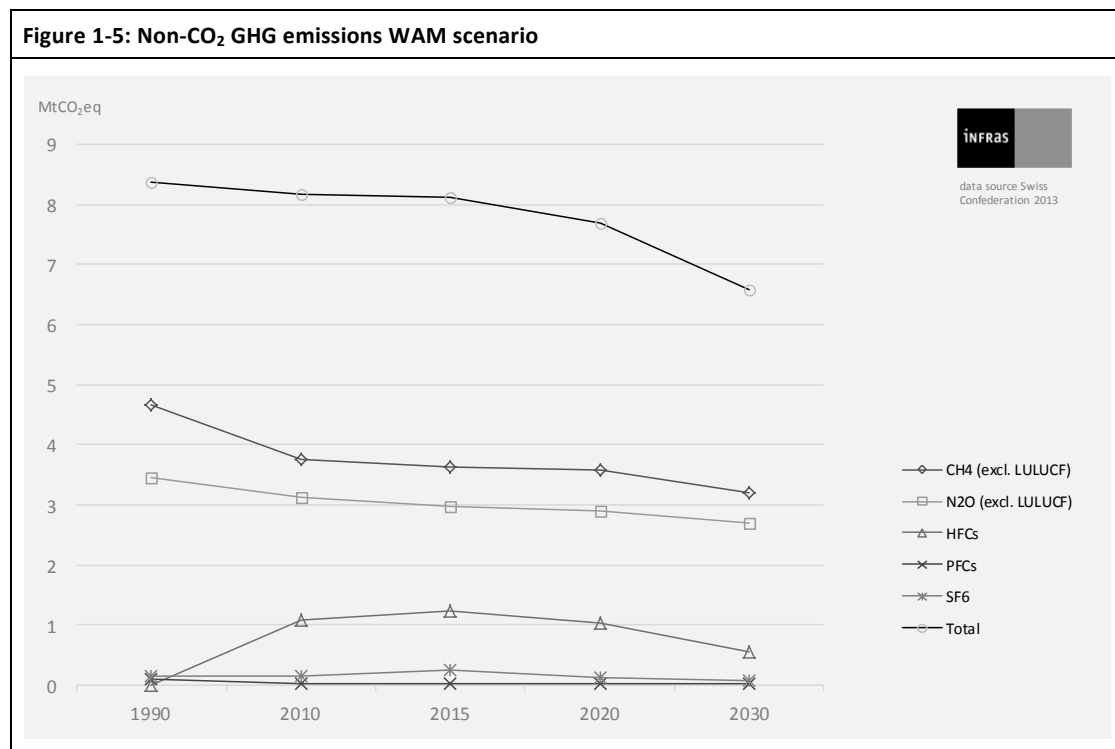
The figure illustrates the non-CO₂ emissions for different gases in MtCO₂ for the WAM scenario. Data source: Swiss Confederation (2013).

Methane

Methane emissions are projected to decrease by 0.6 MtCO₂eq until 2030. The reductions are mainly originated from decreasing emissions in the agriculture sector. While the agricultural WAM pathway follows the same course as in the WEM scenario up to 2020, substantial reductions are aspired until 2050. This projection for the agricultural sector is in line with the climate strategy for agriculture (FOAG 2011). Policies and measures have yet to be designed. Technical and organizational measures shall reduce GHG emissions by at least one third (Swiss Confeder-

ation 2013). The envisaged decrease of agriculture related emission is also in line with the roadmap for moving to a competitive low carbon economy in 2050 of the European Commission (EC 2011).

Nitrous oxide

N_2O emissions decrease by 0.4 $MtCO_2eq$ between 2010 and 2030. The same assumptions as described for methane above are underlying (Swiss Confederation 2013).

Fluorinated gases

Major impacts on non-CO_2 GHG emission are expected for HFC emissions when following the WAM scenario pathway. Between 2010 and 2030 a decrease from 1.1 $MtCO_2eq$ to 0.6 $MtCO_2eq$ is assumed. The reduction is motivated in a slightly faster phase-out and replacement of fluorinated gases when compare with the WEM projection (Carbotech 2013). The peak of HFC emission will be reached in 2015 with approximately 1.2 $MtCO_2eq$.

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2. Compilation of existing simulations of Swiss decarbonisation strategies (Task B)

2.1. Background

In order to identify and model deep decarbonisation pathways for Switzerland it is important to know the already existing work in this field. The goal of Task B is to give an overview of existing simulation models and give brief insight in their main results.

In Switzerland the modelling of the economic and environmental impacts of the implementation of energy and climate policies has a long tradition. Over time, a wide range of models have been developed which analyse in a multitude of studies a variety of policy issues. The studies can be separated in two phases: a) the pre Fukushima studies and b) the post Fukushima studies. In the pre Fukushima studies nuclear power is also in the long run an option. In the post Fukushima Studies Switzerland will in the long run abandon the nuclear power option.

In the following we first give an overview of the existing models. Most of the analysis focuses on the energy sector (section 2.2.1). But for climate policies also the modelling of other sectors like agriculture is of crucial importance (section 2.2.2). In section 2.3 we look at two for the Swiss policy making important studies and their respective models and main results in more detail. The section deepens the understanding of which kind of model is appropriate for which kind of questions. Furthermore it shows the results of simulation models analyzing the impacts of Swiss energy policy discussed and implemented after Fukushima. In the final part we summarize the insights.

2.2. Simulation models applied in Switzerland
2.2.1. Simulation models applied to the energy sector

General Overview

In the following we provide information about existing models, based on Mathys, Thalmann and Vielle 2012, who conducted a survey of existing energy models that describe Switzerland. The article gives a profound overview of nine simulation models applied in the Swiss context. This has been amended by four models which were of crucial importance for the development of the Swiss climate and energy policy after Fukushima. So we identified thirteen relevant models for further analysis:

- CEPE model (managed by ETHZ CEPE);
- CITE (ETHZ CER)
- ETEM (ORDECSYS)
- GEMINI-E3 (EPFL)

- GENESwIS (Econability)
- MERGE-ETL (PSI)
- Swiss MARKAL (PSI)
- Swissgem Switzerland (Ecoplan)
- Swissgem Worldwide (Ecoplan)
- Prognos bottom-up model (Prognos)
- INFRAS model based on Input-Output-calculations (INFRAS)
- MCKinsey Input-Output-Model (McKinsey)
- KOF general equilibrium model (KOF)

These models show various differences and similarities that are characterized in the following; again, Mathys, Thalmann and Vielle 2012 is the main source of these findings.

Typology

In order to understand the commons and differences between the models we first categorise them by two criteria:

- Regional focus: Is the model structure purely Swiss (national model) or internationally linked (international model)?
- Underlying methodology:
  - Bottom-up models describe the energy sector in details (disaggregated sector). They model energy demand, the energy sources to feed the demand and calculate the cost of different elements of energy supply. The strength of these models is their power to map a consistent energy system and possible developments of this system. They are able to answer questions like "what should the energy system look like so that e.g. 80% of energy demand is produced by renewable resources? ". Usually they do not answer questions outside of the energy sector like e.g. the economic impact of a specific energy system.
  - Top-down models describe the energy sector in less detail but have a focus on economic interactions. They answer questions like "what are the economic impacts if an energy system is implemented that is for 80% based on renewable resources?". Top-down models can usually be applied to all sectors as long as the sector of the main interest is described within the model in sufficient detail. Within the top-down models two types of models can be distinguished: General equilibrium models (GEM) and input-output-models (IOM). IOM are themselves a nucleus for the GEM.
    IOM describe the production function of all sectors on the one hand and the demand for products by all sectors, consumers, investors and exporters on the other hand. Thereby

the interdependences of all sectors are pictured. IOM describe the economic interdependences for a given year. Therefore production functions are fixed to the production pattern of that specific year. A dynamic simulation of the future is not foreseen.

GEM are further developed IOM. They allow for dynamic adjustment of production functions over time, underlie the demand side with utility functions and model the factor markets explicitly. Thereby they reproduce dynamic feedbacks by pricing mechanisms. Furthermore some consider different types of consumers. Hence distributional effects can be analysed.

The advantage of GEM is that they can model dynamic processes. If for the object of investigation changing production functions and feedback loops from the demand side or distributional effects are of crucial importance a GEM is the right analysing tool. To allow for these dynamic options the complexity of the model has to be increased. This requires that more uncertain assumptions have to be made. IOM do not model dynamic processes and thereby reduce the complexity and increase the transparency. If the interaction within the current economic framework is the main interest, the application of an IOM is adequate.

- Hybrid models combine bottom-up and top-down aspects in one model.

Structuring the thirteen models by these criteria, the following categories result:

Table 1: Typology of models			
	Bottom-up model	**Hybrid model**	**Top-down model**
National Model	ETEM Swiss MARKAL Prognos		GEM: ■ CEPE model ■ CITE model ■ GENESwIS ■ Swissgem Switzerland IOM: ■ INFRAS IO based model ■ McKinsey IOM
International Model		MERGE-ETL	GEM: ■ GEMINI-E3 ■ Swissgem Worldwide ■ KOF GEM

Soucre: Adapted from Mathys, Thalmann and Vielle 2012

Halve of the models are national top-down models. Two third of them are GEM models, only two are IOM models. National bottom-up models represent a quarter of the identified models. Whereas the bottom-up models MARKAL and Prognos cover Switzerland as a whole, the ETEM model is set up at a cantonal level and produces results for impacts on cantons. The remaining

three models are international models, whereof two are top down GEM models and one is a hybrid model. Not yet operational but in development is the ELECTRA model that links the GEMINI-E3 model with the Swiss MARKAL and CROSSTEM model (a bottom up model in development by PSI). The main focus of the analysis will be the Swiss electricity market. This model will also be a hybrid model. No bottom-up model describing Switzerland has international coverage. This is not surprising given the technological detail needed and the possibility to include international technology trends directly in the Swiss setting.

The following Table presents the main characteristics of the models:

Table 2: Characteristics of the models					
Model	Number of regions	Number of economic sectors	Number of Households	Number of explicitly modelled energy sources	Time dimension
Bottom-up					
ETEM	1	41	1	3 fossil, 5 renewable	2010-2050; 5 year steps; perfect foresight
Swiss MARKAL	1	44	4	4 fossil, 6 renewable	2000-2050; 5 year steps; perfect foresight
Prognos model	1	20	1	4 fossil, 6 renewable	2000-2050, perfect foresight
Hybrid					
MERGE-ETL	10	2	1	4 fossil, 4 renewable	2010-2100; 10 years steps; perfect foresight
Top-down					
CEPE model	1	42	14	4 fossil	2005; static model
CITE	1	12	1	2 fossil	2074; yearly steps; perfect foresight
GEMINI-E3	24	18	1	3 fossil	2001-2050; yearly steps; recursive dynamic
GENESwIS	1	31	1	3 fossil	2040; yearly steps; perfect foresight
Infras IO based model	1	40	1	0	2001; static model with possibility of exogenous adjustment of production function and productivity change
IOM McKinsey	1	40	1	0	2001; static model
KOF GEM	33	10	1	n.a.	2000
Swissgem Switzerland	1	26	14	4 fossil, 8 renewable	2005-2100; yearly steps; perfect foresight
Swissgem Worldwide	112	22	14	4 fossil, 8 renewable	2005-2015; yearly steps; perfect foresight

Source: Adapted from Mathys, Thalmann and Vielle 2012

- **Sectors and regions:** There is always a tradeoff between the number of regions and the number of sectors covered. Models that describe only Switzerland can dedicate more attention to the description of sectors and show impact on different sectors in more detail. Global models like GEMINI-E3 and Swissgem Worldwide and KOF GEM are less detailed with respect to sectors but describe international interaction more profoundly. National models are more adequate if the focus is on impacts on different sectors. If international interaction is a main aspect, global models are more adequate.

- **Household types:** Another dimension is the number of household groups represented by the models. Only the CEPE model, the Swissgem model family and the Swiss MARKAL model describe more than one household type. Models with more than one household type distinguish households by the income level. Additionally the CEPE model differentiates between retired and working households. With more than one representative household, these models can assess the redistributive impacts of policies.

- **Energy sources:** By nature, bottom-up models show a high degree of energy source details. Usually they have an extended description of technologies that are related to energy production and consumption. ETEM, Swiss MARKAL and the Prognos model show this feature. The top down GEM models describe the fossil energy mostly by distinguishing between coal, oil products and natural gas. CEPE describes also nuclear resources and CITE does not regard coal explicitly. Non-fossil energy sources are mostly not described explicitly. They are modeled implicitly. For example in the case of the implementation of a carbon tax, the models suppose that fossil energy is substituted by other inputs (namely capital, labor and other non-energy materials) that can be seen as renewable. CITE is in this respect different since it models technological change endogenously and not exogenously. Swissgem represents an exception by giving as a GEM a detailed representation of energy sources.
  In IOM models (INFRAS and McKinsey) not only renewable energies - like in GEM models - but also fossil energies are modeled implicitly.

- **Time horizon:** The IOM models of INFRAS and McKinsey and the CEPE model are comparative-static models which rely on a one period time horizon. These models can answer the question "what would happen, if today …". The advantage of this kind of models is the transparency and possibility to discuss assumptions. Since they do not simulate the future, they need less assumption and linkages and the results can be followed step by step and have a lower black box character. Dynamic elements (change productivity, production functions,) may be integrated exogenously but well discussable.
  All other models simulate possible changes of level, structure and way of production in the future. The advantage of these models is that they can describe a pathway in the future. As matters involving the energy sector are mainly related to medium and long term issues, the majority of the models are able to simulate outcomes up to 2050 and sometimes beyond.

- **Intertemporal optimization assumption:** All models simulating the future suppose that economic agents enjoy perfect foresight, except GEMINI-E3 that uses a recursive dynamic framework because perfect foresight is not very plausible and it is extremely time-consuming in the resolution of large simulation models. The static-one-period models do not need an assumption about intertemporal optimization.

2.2.2. Simulation models with focus on other climate relevant sectors

With respect to climate protection – beside energy – other greenhouse gas emitting sectors such as transport, industrial processes and solvents, agriculture, LULUCF and waste are important as well.

The waste sector in Switzerland is in this context not of big importance. The waste sector is therefore usually modeled together with the energy sector. Since electro mobility and energy are closely linked, transport emissions are also often modeled within energy models.

In Switzerland there are only a few sectors in the industry that release relevant amounts of process-related greenhouse gases. The emissions of them are normally extrapolated by some characteristic factors.

Separate models exist for analyzing the impact of agriculture and LULUCF. In the field of agriculture the Sector Information and Prognosis System for Swiss Agriculture (SILAS) and SWISSland (Swiss Structural Change Information System) exists. LULUCF is often modeled with MASSIMO3. These models are bottom-up models. Interactions with other economic sectors are not considered. In the following they are described briefly. The top-down models described in the previous part can also be applied for other climate relevant sectors other than energy.

SILAS (sectorial bottom-up model)

SILAS is a highly differentiated sector model. It models only the supply side of the agriculture sector. Interactions with other sectors are not modelled. It takes into account different regional conditions, thereby simulating and forecasting the impacts of different policy measures on agricultural production and income as well as the environment and public expenditures for agriculture. The model is calibrated by means of positive mathematical programming. Exogenous inputs are prices of products and means of production as well as direct payments. The time horizon covers the years up to 2017. SILAS is developed by the Swiss Federal Research Station for Agricultural Economics and Engineering, FAT Tänikon, and the Institute of Informatics University of Fribourg (Agroscope 2011).

SWISSland (Multiagent bottom-up model)

Whereas SILAS is a sectorial model that looks at agriculture as a whole SWISSland gives deeper insight on the level of singular plants. This enables additional projection of the agri-structural change and the income development of singular plants. The model follows a micro simulation approach that investigates the rational decision-making process of agents on a micro-economic level. In the model agents are represented by actual farms. The agent-based modeling approach also makes it possible to take non-rational agent decision-making behavior into account

and to permit interactions between the agents themselves and between the agents and their environment.

Outcome of the SWISSland model are variables which are characteristic for the development of the sector. These primarily include product quantities and prices, land use and employment trends, income trends in line with economic accounts for agriculture, sectoral input and output factors for the calculation of environmental impacts as well as important sectoral characteristic variables such as the number of farms, their size and type, or the number of farms changing their production method. One of the main assumptions of the model is that agents maximise their expected household income, which is the total of agricultural income and non-agricultural income. SWISSland is developed by the Swiss Federal Research Station for Agricultural Economics and Engineering, FAT Tänikon (Agroscope 2011).

MASSIMO3 (sectorial bottom-up model)

MASSIMO3 is a stochastic empirical single tree forest management scenario model, which was derived using data from the three successive National Forest Inventories (NFI). The major model components are a single tree growth component, a wood harvesting component and a component on natural regeneration. These model components as well as in-growth and mortality rates are empirically derived from NFI data. MASSIMO3 is a model based on data from the Swiss NFI and is therefore designed to perfectly reflect the specific characteristics of Swiss forests. On the other hand, direct comparability with other countries is not possible (Swiss Confederation 2013).

2.3.   Examples of available model analyses

The above models are used in a wide range of studies. As examples for a bottom-up and a top-down simulation we present the studies of Prognos (Prognos model) and Ecoplan (Swissgem Switzerland) in the context of the Swiss energy perspectives 2050. Both analyses represent a very important background for the design of the actual Swiss climate and energy policy. The main goal of this section is to provide a better understanding of how different types of models work and to show what questions can be answered with which kind of model.

2.3.1.   Bottom-up models: Prognos model

Research question

In the Study „Die Energieperspektiven für die Schweiz bis 2050 – Energienachfrage und Elektrizitätsangebot in der Schweiz 2000-2050" Prognos (2012) developed with their bottom-up

model three possible pathways of the Swiss energy system from 2000 to 2050 (policy scenarios
– see also section 1.3):

- Business as usual (BAU): Continue the current policy as of 2010 and a moderate further evo-
  lution of these policies and measures
- Political measures (POM): Enforce the climate and energy policy with new measures
- New energy policy (NEP): Reduce the CO_2-Emissions until 2050 to 1.5 t per capita.

The goal of the study is to show how the energy system develops in the framework of these
three scenarios and what CO_2-emissions and energy costs result within the context of the
three scenarios. The results are shown for 2020, 2035 and 2050.

The policies considered within the scenarios are described in the following table. The table only
describes modeled measures and not the effective implemented measures in Switzerland. E.g.
the existing feed-in tariffs are not considered, since they affect the supply side in a way not
modeled within the model framework. The same is true for the existing CO_2-tax. In addition,
the New energy policy scenario follows a top-down approach based on a pre-defined target for
2050, therefore the considered measures are not explicitly defined.

Table 3: Considered measures in the different scenarios		
Business as usual (BAU)	**Political measures (POM)**	**New energy policy (NEP)**
Households, buildings		**Strategic goal:**
■ Moderate updating of the exemplar regulation of the cantons in the field of energy ■ Subsidy program (200 m. CHF/a) for energetic building restoration (Building Program) ■ Boost renewables within the building restoration program ■ moderate update of standards	■ Tightening of the exemplar regulation of the cantons in the field of energy ■ Building restoration program: 　■ 300 m. CHF/a from 2014 　■ 600 m. CHF/a from 2016 ■ Tightening standards for devices and house automation ■ Stimulation of replacement reconstructions ■ Tightening the standards for the electricity demand of buildings	■ In 2050 1 to 1.5 t CO_2 per capita ■ Restricted biomass potentials **Deduced strategic conditions:** ■ Efficiency of renewable energies ■ Reduce space heating ■ Electricity efficiency is of crucial importance (amongst others air conditioning) ■ Electro mobility is necessary ■ Slightly change in transport volumes and modal split ■ Biomass is used as a priority for cargo transport and CHP electricity production.
Industry and services		
■ Subsidies of 16-27 m. CHF/a for energy efficiency measures on the basis of a bidding procedure ■ Voluntary commitments	■ Subsidies of 100 m. CHF/a for energy efficiency measures on the basis of a bidding procedure ■ Efficiency bonus on CO_2-Tax and cost covering feed-in tariffs ■ Optimisation in the operating of real estates ■ Boost ORC-facilities (increase steam turbine efficiency)	
Transport		
■ Reaching the emission threshold value of the EU directive: 130 g CO_2/km in 2015, 95 g CO_2/km in 2030 ■ Efficiency increases due to traffic design	■ Tightening the emission threshold value of the EU directive: 130 g CO_2/km in 2015, 95 g CO_2/km in 2020, 35g CO_2/km in 2050 ■ Improvements in traffic organisation	

Source: Bundesamt für Energie, Energieperspektiven 2050 – Zusammenfassung.

Modelling

Exogenous assumptions of the model are population and GDP growth, the structure of the economic sectors in Switzerland, primary energy prices, electricity production costs for renewable energies, and the increase in temperature and transport demand (implementation of the results of a study that analyses the traffic demand under the three policy scenarios). Concerning electricity generation capacities it is assumed that nuclear generation is continued until the end of the technical life span of the existing nuclear power plants which are then replaced by other technologies.

In a first step, the model calculates the energy demand under the three policy scenarios. The outcome is the energy demand per year and consumer group (households, service sector, industry and traffic) for the three scenarios.

In a second step the demand is matched with supply. Fossil fuels are mainly imported. The demand for electricity is matched with a reference development of the current electricity capacities. The analysis bases on an hourly simulation of demand and supply to ensure that the security of electricity supply is always given. The comparison of supply and demand results in the fact that demand will be above supply from the early 2020ies. Therefore in a third step the building of new capacities is defined (GW per technology). Thereby different technology mixes are assessed (gas only, gas and renewables, renewables only). From the various technology mixes of electricity generation the final electricity mix for the different technology mixes is deduced (yearly GWh per technology).

Based on the resulting generation system and electricity mix of the assessed alternatives, the costs of the power system including the electricity production and the electricity grid are estimated.

To define the environmental impact of the different energy systems the CO_2 emissions of each system are calculated.

Results

- Total energy demand will decline from 2010 to 2020 by 21% (BAU) to 33% (NEP). In the same period electricity demand will rise by respectively 18% (BAU) and 4% (POM). Only in the NEP scenario electricity demand will decline (-10%). In 2050 10% (BAU) to 20% (NEP) of electricity demand comes from the transport sector. To compare today 5% of electricity demand comes from the transport sector (mainly rail transport).
- On the supply side three scenarios are showed: a) only gas-fired power plants are built, b) construction of gas-fired and renewable power plants c) only renewable power plants are built. The government and parliament decided to follow the POM scenario. The share of renewable produced electricity in the POM scenario lies in 2050 by respectively 70% (a) and 87% (b and c). With scenario c) 10% of the electricity demand has to be covered by imports. However with scenario a) and b) the whole electricity demand can be covered by national production. Furthermore scenario b) and c) imply exports of electricity of 8% of national demand. The results show that it will not be possible to completely cover the Swiss electricity demand by domestic renewable resources, if the electricity demand stays stable.
- In the BAU scenario CO_2 emissions are reduced by 24 to 36% in 2050 relative to 2010, whereas in the POM scenario by 54% to 58% and in the NEP scenario by 70% to 78%. This

shows that the POM scenario, which the Swiss policy decided to follow, will not lead to a sustainable CO_2 emission level.

▪ The analysis shows that the total costs of energy are the highest in the BAU scenario and about the same for the POM and NEP scenario. A reason for this result is that the total energy demand is in the BAU scenario higher than in the POM and NEP scenario.

2.3.2. Top-down models: Swissgem Switzerland

Research question

In the Study „Energiestrategie 2050 – volkswirtschaftliche Auswirkungen", Ecoplan analyses the economic impact of the same policy scenarios as Prognos with its Swissgem Switzerland model (see section 2.3.1). The economic impact aspects considered are effects on GDP, employment, consumption, and welfare.

Modeling

In a first step a reference scenario ("BAU") is calculated. This reference scenario shows the economic development if the current policy is continued and no unforeseeable shocks happens. To build the reference scenario assumptions about growth of population and GDP have to be made. The economic impact of a given scenario will always be expressed as the change in e.g. GDP relative to the reference scenario.

Other than in the bottom-up model, the specific measures are not mapped in detail. As a starting point the change in energy demand resulted from the bottom-up analysis is taken as the guideline. To reach the given energy demand pathway it is assumed that taxes on fossil energies and electricity are implemented. In the model they are increased until the energy demand in the Swissgem model follows the energy demand given by the bottom-up model pathway of Prognos. This means that as exogenous input no measures are pictured but an energy demand pathway. The prices on energy are adjusted until the energy demand pathway given is reached.

Additional taxes lead to an increase in the income of the government and an increase in expenditures of consumers. To balance income and expenditure of all actors it has to be defined over which channels this balance will be reached. In the Ecoplan study three different ways to redistribute the tax revenues have been analysed. In the results presented below it is assumed that the government redistributes the tax revenues back to households and indus-

tries.[1] So actors see an increase in energy prices and an increase in income due to the redistribution of the tax revenues by the government. The difference of additional budget and additional costs can be calculated for each actor. Thereby distributional effects of climate measures can be shown if the GEM - as the Swissgem model - models different household types.

Based on the calculated change in budgets for each household type, the GEM estimates the change in production functions and output for each sectors and changes in the consumption patterns of each good. On the basis of the change in consumption and Input-Output table the model calculates the impact on the economy. Thereby as well the change in GDP and employment is calculated. Furthermore Ecoplan calculates impacts on welfare by summing up the change in GDP and the change in external costs (in a second version of the welfare definition also secondary benefits are considered). This aspect is not a typical aspect of a GEM.

Results

▪ To reduce the energy demand at the level of the POM scenario calculated by Prognos in 2020 a CO_2-tax of 70 CHF/t CO_2 and in 2050 a CO_2-tax of 210 CHF/t CO_2 is necessary. At the same time electricity prices have to be increased by 11% in 2020 and 22% in 2050. In the NEP scenario the CO_2-tax is 150 CHF/tCO_2 in 2020 and 1140 CHF/tCO_2 in 2050. Electricity prices have to be increased by 12% in 2020 and 40% in 2050.

▪ Compared to the BAU scenario the GDP is in 2050 respectively 0.6% (POM) and 2.7% (NEP) lower. The employment level is 0.2% (POM) and 0.7% (NEP) below the level of the BAU scenario and consumption respectively 0.3% and 1.9%.

▪ The welfare is under the POM scenario in 2050 0.2% and in the NEP 0.9% lower than in the BAU scenario. If secondary benefits are considered as well the welfare effect turns in the POM scenario slightly on the positive side (+0.1%).

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[1] Böhringer, Christoph, and André Müller (2014) "Environmental tax reforms in Switzerland. A computable general equilibrium impact analysis", Swiss Journal of Economics and Statistics 150(1): 1-21 simulates the three scenarios under different assumptions with respect to the revenue recycling.

2.3.3. Comparison of the two example studies

The following table shows in a short overview the two model approaches of the example studies.

Table 4: Comparison of the two study examples		
	Prognos study: Bottom-up model	**Ecoplan study: Top-down model Swissgem**
Research question	What would the Swiss energy System look like in 2020, 2035 and 2050 if a) the current policy were continued b) some more ambitious measures were implemented c) the CO2-emissions in 2050 were reduced to 1.5t per capita	What are the economic impacts if the energy system of Switzerland is implemented as shown in the bottom-up study of Prognos.
Assumptions	▪ population and GDP growth ▪ sectorial structure of the economy ▪ primary energy prices ▪ electricity production costs for renewable energies ▪ increase in temperature ▪ change in transport demand ▪ existing electricity generation capacities will run until the end of their life span	▪ population and GDP growth in the reference scenario ▪ energy demand ▪ sectorial structure of the economy ▪ technological change ▪ change in productivity
Results	For each scenario the following outputs are calculated: ▪ energy demand per demand sector ▪ energy mix (MWh per energy source) ▪ generation capacities (MW per energy source) ▪ total costs of the energy production	The following outputs are calculated with respect to the reference scenario (continuing the current policy): ▪ change in GDP ▪ change in employment ▪ change in consumption ▪ change in welfare ▪ distributional effects ▪ shadow price of the policy measure

2.4. Synthesis

The overview of the studies shows that especially in the energy sector a wide range of models were applied to analyse the Swiss situation. They can be divided in two kinds of models: a) bottom-up models that analyses the energy system and answer questions about the design of the energy system and b) top-down models that focus on the economic impacts of a specific policy measure. In the field of agriculture and LULUCF there exist also some bottom-up models. For the other climate relevant sectors no models exist or the sectors are considered in the energy sector as well (transport, waste). Since economic behavior is basically the same in all sectors all climate relevant sectors could also be analysed with the top-down models that are designed mainly for the energy sector.

It has been recognized that bottom-up and top-down models should be linked for the analysis of changes in the energy system and their economic impact. The challenge is to link conceptually different models. E.g. monetary values of production have to be transformed into physical quantities of production and vice versa. Bottom-up models are optimization models whereas top-down models are simulations models. Nevertheless, there exist now several attempts at such coupling. Sceia, Altamirano-Cabrera, Vielle and Weidmann 2012 coupled the GEMINI-E3 with the MARKAL model. A further development of this coupling is in progress in the ELECTRA project. The academic basic for the current Swiss energy policy is laid by a study of Prognos (bottom-up) and one of Ecoplan (Swissgem top-down model). The two models have harmonized the energy demand. Further coupling between these two models does not exist.

The two study examples show that strong actions have to be implemented if Switzerland is to reduce its CO_2 emissions to a sustainable level. Furthermore this is only possible in collaboration with the international community, since Switzerland for itself may not have a high enough potential demand for technologies to incentivise the large scale development of the necessary technologies alone. Under these circumstances the economic costs of achieving a sustainable CO_2 emission level are – with a 2.7% lower GDP compared to a business as usual scenario in 2050 – at a moderate level.

References Chapter 2

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