Evaluation of a Swiss carbon tax with the Computable General Equilibrium Model GEMINI-E3*

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December 22, 2006

1 Introduction

This report computes the magnitudes of carbon taxes that would be needed to meet strong CO2 emissions reductions targets in Switzerland by 2020 and 2050. It also assesses the economic impacts of meeting those targets through carbon taxes. The analysis is based on the multi-sectoral and multi-regional, computable general equilibrium (CGE) model of the world economy GEMINI-E3 [4] which includes a representation of the Swiss economy.

The report is articulated in four sections. The first section provides information on the GEMINI-E3 model. Section 2 presents the reference case scenario in which no new CO_2 reduction policies are applied. Section 3 contains the results of the CO_2 abatement scenario and the last section concludes.

*The authors gratefully acknowledge the support of the Swiss Federal Office for the Environment, Federal Office of Energy and Swiss National Centre of Competence in Research on Climate (NCCR-Climate)

2 Modeling Framework

The GEMINI-E3 is a dynamic-recursive CGE model that represents the world economy in 28 regions (including Switzerland) and 18 sectors (see table 1), which contains a highly detailed representation of indirect taxation [4]. The version of GEMINI-E3 used in this study is formulated as a Mixed Complementarity Problem (MCP), which is solved using GAMS and the PATH solver [13, 14]. GEMINI-E3 is built on a comprehensive energy-economy data set, the GTAP-6 database [10] that provides a consistent representation of energy markets in physical units, detailed Social Accounting Matrix (SAM) for a large set of countries or regions and bilateral trade flows between them. Moreover, we have completed the data from the GTAP database with information on indirect taxation and government expenditures from International Energy Agency [17, 16, 15], OECD [20, 19] and International Monetary Fund [18]. For non CO_2 greenhouse gases (GHG) data on emissions and abatement costs come from the U.S. Environmental Protection Agency [21].

The fifth version of GEMINI-E3 and its successors, have been especially designed to calculate the social marginal abatement costs [6] (MAC, i.e. the welfare loss of a unit increase in pollution abatement).

The original version of GEMINI-E3 is described in [4][2]. Various versions of the model have been used to analyze the implementation of economic instruments allowing for GHG emissions reductions in a second-best setting [5]. The following studies are examples of various analyses carried out with GEMINI-E3: assess the strategic allocation of GHG emission allowances in the enlarged EU market [24], analyze the behaviour of Russia with regard to the ratification process of the Kyoto Protocol [2, 3], assess the cost of implementation of the Kyoto protocol in Switzerland with and without international emissions trading [7], or assess the effects of the increase of oil prices on global and regional GHG emissions [23].

Apart from a comprehensive description of indirect taxation, the specificity of the model is to simulate all relevant markets: e.g. commodities (through relative prices), labour (through wages) as well as domestic and international savings (through rates of interest and exchange rates). Terms of trade (i.e. transfers of real income between countries resulting from variations of relative prices of imports and exports) and “real” exchange rates can also be accurately represented.

[2]for a complete description of the model refer to all technical document available at: http://gemini-e3.epfl.ch.

Table 1: Dimensions of the GEMINI-E3 Model

Countries or Regions		**Sectors**
Annex B		***Energy***
Germany	DEU	01 Coal
France	FRA	02 Crude Oil
United Kingdom	GBR	03 Natural Gas
Italy	ITA	04 Refined Petroleum
Spain	ESP	05 Electricity
Netherlands	NLD	***Non-Energy***
Belgium	BEL	06 Agriculture
Poland	POL	07 Forestry
Rest of EU-25	OEU	08 Mineral Products
Switzerland	CHE	09 Chemical Rubber Plastic
Other European Countries	XEU	10 Metal and metal products
United States of America	USA	11 Paper Products Publishing
Canada	CAN	12 Transport n.e.c.[1]
Australia and New Zealand	AUZ	13 Sea Transport
Japan	JAP	14 Air Transport
Russia	RUS	15 Consuming goods
Rest of Former Soviet Union	XSU	16 Equipment goods
Non-Annex B		17 Services
China	CHI	18 Dwellings
Brazil	BRA	
India	IND	***Household Sector***
Mexico	MEX	
Venezuela	VEN	***Primary Factors***
Rest of Latin America	LAT	Labor
Turkey	TUR	Capital
Rest of Asia	ASI	Energy
Middle East	MID	Fixed factor (sector 01-03)
Tunisia	TUN	Other inputs
Rest of Africa	AFR	

[1] n.e.c. : not elsewhere classified

Time periods are linked in the model through endogenous real interest rates, which are determined by the equilibrium between savings and investments. National and regional models are linked by endogenous real exchange rates resulting from constraints on foreign trade deficits or surpluses.

GEMINI-E3 provides the following outputs for each region or country and for each year: carbon taxes, marginal abatement costs, price of tradable permits (when relevant), abatement of GHG emissions, net sales of tradable permits (when relevant) and total net welfare loss, which is also made available in a disaggregated manner as net loss from terms of trade, pure deadweight loss of taxation, net purchases of tradable permits when relevant. Macroeconomic aggregates such as production, imports and final demand are also provided by the model, as well as real exchange rates, real interest rates and sectoral data such as changes in production or usage of production factors.

For this study we use an aggregated version of the model in 6 regions rather than 28 (see table 2).

Table 2: GEMINI-E3 Regional Description

Name	Countries
CHE	Switzerland
EUR	European Union (25)
OEU	Other European countries (Russia, Ukraine, Norway, etc)
JAP	Japan
OEC	USA, Canada, Australia, New Zealand
PVD	Other Countries (mainly developing countries)

3 The reference scenario

The reference scenario will allow the model to quantify the efforts that Switzerland and others regions will have to undertake to reach their CO_2 reduction target. This so-called “Business as usual” scenario encompassed all energy policies enforced by all regions up to 2001, which is the base year of the GTAP database. The dynamic aspects of the model depend on a calibration procedure which is explained below.

3.1 International energy prices

Oil price projections used in this reference scenario are mainly taken from the last International Energy Outlook (IEO) published by the US Department of Energy (DOE) [12]. The DOE expects lower investments and oil production in key oil producing regions, in view of various restrictions on access and contracting, which affect oil exploration and production costs.

In our projection we suppose that oil prices in 2010 are at 36 USD per barrel and then increase to 57 USD in 2030. After 2030, oil prices rise linearly up to 69 USD per barrel in 2050. Table 3 shows a comparison of several oil price projections collected by the DOE [11].

Table 3: Forecast of world oil prices (USD_{2004} per barrel)

	2010	2020	2030	2040	2050
GEMINI-E3	35.80	50.70	56.97	62.93	69.51
International Energy Outlook 2006					
Reference	47.29	50.70	56.97		
High price	62.65	85.06	95.71		
Low price	40.29	33.99	33.73		
International Energy Agency	35.00	37.00	39.00		
International Energy Agency (*deferred investment*)	41.00	46.00	52.00		
Petroleum Industry Research Associates	44.10	63.35			
Petroleum Economics Ltd	47.84	49.80			
Global Insight Inc.	37.82	31.53	34.50		
Altos Partners	27.58	34.02	40.03		
Energy and Environmental Analysis Inc.	46.74	42.79			
Strategic Energy and Economic Research Inc.	29.54	32.00	36.50		

Source [11]

Concerning natural gas price, we assume an indexation of gas prices to oil prices of 0.5 (i.e. the price of gas increases by 5% when the oil price increases by 10%). Regarding coal, we assume that the import prices in USD remain stable in real term. (See table 4)

Table 4: Gas and coal import prices for Switzerland (USD_{2004} per tep)

	2010	2020	2030	2040	2050
Gas	648	722	819	861	905
Coal	71	71	71	71	71

3.2 GDP, energy demand and GHG emissions

The baseline for all countries but Switzerland is calibrated using projections of CO_2 emissions, energy consumption, GDP, and populations for the years 2000 to 2030, as provided by the Energy Information Administration [12]. From 2030 to 2050, we have supposed a linear convergence of GDP growth to 2% for developed regions (except for European countries and Japan) and 3.5% for developing regions. For Switzerland, the GDP growth values are based on the economic projections devised by SECO [9]. The annual average GDP growth rate is expected to be 1.2% from 2001 to 2020, and 0.6 % from 2020 to 2050. Table 5 summarises the projected annual GDP growth for each region.

Table 5: Projected Average Annual Growth in GDP

	2001-2010	2010-2020	2020-2030	2030-2040	2040-2050
CHE	1.5%	0.9%	0.4%	0.6%	0.7%
EUR	2.2%	2.2%	2.1%	1.7%	1.7%
OEC	3.2%	2.9%	2.7%	2.5%	2.0%
JAP	1.9%	1.4%	0.9%	0.9%	0.9%
OEU	4.0%	3.5%	3.0%	2.5%	2.0%
PVD	5.9%	4.8%	4.5%	4.0%	3.5%
World	3.4%	3.1%	3.0%	2.8%	2.5%

Table 6 presents details of CO_2 emissions' projections. World CO_2 emissions start at 6.7 GtC in 2000 to reach 17 GtC in 2050. Swiss CO_2 emissions represents 0.7% of the total Europe CO_2 emissions in 2001 and only 0.4% in 2050.

Table 7 provides the Swiss non CO_2 emissions projections.

Figure 1 shows the projected GDP, the final energy consumption and CO_2 emissions in Switzerland. The baseline supposes a slight increase of final energy consumption from 2001 to 2020, followed by in a slow decrease to reach 23.3 Mtep in 2050. These optimistic results are mainly due to the limited GDP growth and increasing energy efficiency assumptions. CO_2 emissions stay almost

Table 6: Baseline CO_2 Emissions in MtC-eq per year

	2001	2010	2020	2030	2040	2050
CHE	13.6	13.9	13.7	13.3	13.3	13.3
EUR	1055	1161	1254	1345	1398	1458
OEC	2149	2431	2711	3040	3365	35
JAP	312	333	345	346	347	347
OEU	679	737	846	1084	1557	1786
PVD	2571	3972	5300	6785	8335	9836
World	6780	8647	10470	12613	15015	17016

Table 7: Baseline non CO_2 Emissions in MtC-eq per year in Switzerland

	2001	2010	2020	2030	2040	2050
CH4	1.0	0.9	0.9	0.8	0.7	0.6
N_2O	0.9	0.8	0.8	0.7	0.6	0.5
Fluorinated Gases	0.1	0.3	0.4	0.3	0.3	0.3
Total	2.0	2.0	2.0	1.8	1.6	1.4

unchanged from 2001 to 2020, and would be reduced by approximately 0.34 MtC-eq during the 2020–2050 period.

Figure 2 shows the baseline CO_2 emissions by sector in Switzerland from 2001 to 2050. In 2001, the Swiss economy is characterized by a low share of energy-intensive industries in the carbon balance. For example, the electricity sector represented only 1 percent of total CO_2 emissions and the biggest carbon emitter among industries is the chemical industry, which accounts only for about 3 percent of total emissions. 40 percent of total emissions are due to households, almost 20 percent to the transportation sector and 15 percent to the services sector.

As shown in figure 3, the reference case assumes a limited growth in final energy consumption over the 2001–2050 time span. The 0.1% average annual increase of final energy consumption is largely explained by higher electricity and gas consumption (+0.4% and +0.3% respectively).

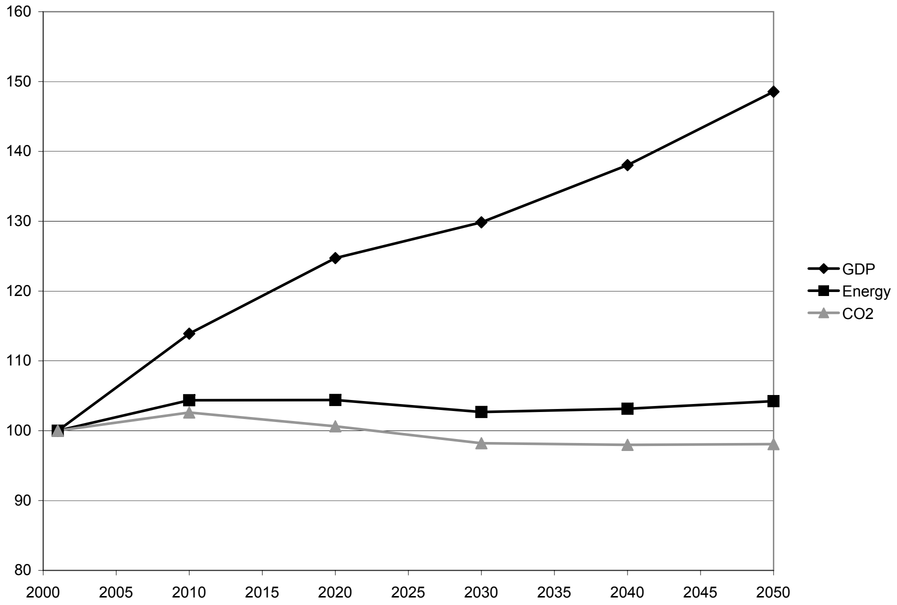

Figure 1: Projected GDP, CO_2 emissions, and energy consumption growth in Switzerland, 2001–2050 (2001=100)

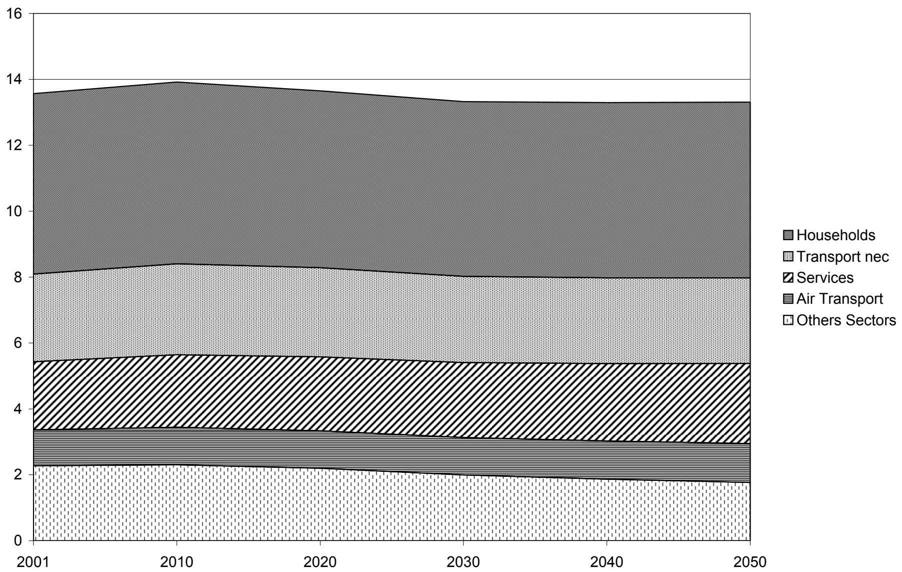

Figure 2: Reference scenario CO_2 emissions by sector in Switzerland, 2001–2050 (in MtC per year)

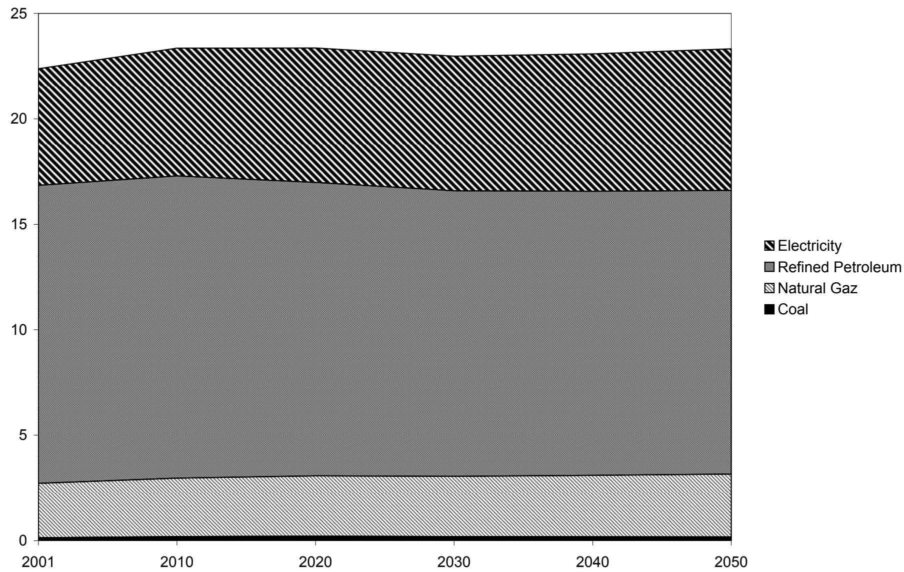

Figure 3: Change in energy consumption in Switzerland, 2001–2050 (in Mtep)

4 The CO_2 reduction scenarios

When policy-makers consider targets for CO2 emissions reductions, it is important that they know the economic consequences over time of those targets. The consequences will depend very much on the instruments selected to meet the targets and on what other countries will do. Here we assume that the most cost-efficient instrument to obtain CO2 emissions reductions is selected, namely a uniform carbon tax. Note that this is not the most cost-efficient instrument for GHG emissions reductions because it concentrates efforts on a single, albeit very important, GHG. Furthermore, we assume that other countries also engage in efforts to reduce their GHG emissions.

We consider two policy scenarios.In the first scenario (*Kyoto2020*), Switzerland reduces its emissions by 20% (in comparison to the 1990 level) by the year 2020. In the second scenario (*Kyoto2050*), Switzerland extends strong reduction of 10% per decade until 2050. In both scenarios, abatement is obtained through a uniform CO_2 tax affecting all economic sectors.

We assume that European countries and Japan will meet their objectives as agreed upon in the Kyoto Protocol and, after 2012, that their GHG emissions remain at constant level, a so-called *Kyoto forever* assumption. In the OEC region (mainly composed of the USA) we assume a 5% reduction of emissions from

2006 to 2012, compared to the baseline level of 2012. The level of emissions is then expected to remain constant for the rest of the simulation period.

In all regions but Switzerland, GHG abatement is obtained through a multi-gas strategy in which all GHG emissions are taxed using a 100-year GWPs equivalent between gases. The Swiss targets are met only by abating CO_2 emission. Finally, we also assume that other regions (OEU and PVD) do not implement any energy or climate policies.

The fiscal revenue generated by the carbon tax (or the GHG tax) is redistributed to households through a lump sum transfer.

Table 8 gives the level of CO_2 reductions for the two scenarios and the reference case.

Table 8: Swiss CO_2 emissions in MtC per year

	2001	2010	2020	2030	2040	2050
Reference case	13.6	13.9	13.7	13.3	13.3	13.3
Kyoto2020	13.6	12.5	9.4			
Kyoto2050	13.6	12.5	9.4	8.5	7.7	6.8

5 Results

5.1 Scenario Kyoto2020

Table 9 presents the GHG emissions reduction and the CO_2 taxes needed to obtain them for the regions which implement a climate policy. The differences in CO_2 taxes are first due to different abatement levels applied in the various regions but also to differences in marginal abatement cost curves slopes. As shown by [1] and [7], we find that the Swiss economy is set apart by very high marginal abatement costs. As a consequence, a Swiss carbon tax could have to reach 468 USD per tonne of CO_2 in 2020 to reduce the emissions by 20% in comparison to the 1990 level. What else can explain the much lower level of taxation in all other regions? First, the GHG abatement for the other regions are met not only by reducing CO_2 but also other non CO_2 greenhouse gases. This reduces significantly the carbon price and the welfare cost. Secondly, the structure of the Swiss energy system is known for its reduced possibilities of CO_2 abatement at low cost. Electricity is produced mainly from non CO_2 energy sources (hydro and nuclear power plants), and the main CO_2 emitters are the transport sector and the households. In the current version of GEMINI-E3, those latter have very limited CO_2 abatements options.

Table 9: Emissions reduction and CO_2 price - scenario *Kyoto2020*

	2010	2020
CO_2 Emissions reduction in %		
CHE	-10%	-31%
GHG Emissions reduction in %		
EUR	-8%	-17%
OEC	-4%	-13%
JAP	-13%	-21%
CO_2 tax in USD per ton		
CHE	66	468
GHG tax in USD per ton		
EUR	7	18
OEC	2	10
JAP	17	38

Figure 4 compares the structures of final consumption in Switzerland in 2020 for the reference case and the *Kyoto2020* scenario. As shown in the figure, the reduction of CO_2 consumption is obtained by a lower consumption of natural gas (-62%) and refined petroleum (-25%).The consumption of electricity increases by a small 1% and coal almost disappears (-93%).

Figure 5 presents the sectoral changes in final energy reduction in Switzerland in the year 2020. The highest reductions are observed in the mineral products sector and in transport sectors.

Figure 6 provides detailed information about CO_2 emissions reduction achieved in 2020 in Switzerland by sector under the *Kyoto2020* scenario. As expected, even if the transportation sector and households account for the major reductions in absolute terms, the reduction effort would be higher in the energy intensive industries, due to a reduction in demand, a loss of international competitiveness in those sectors as well as a higher substitution between energy sources.

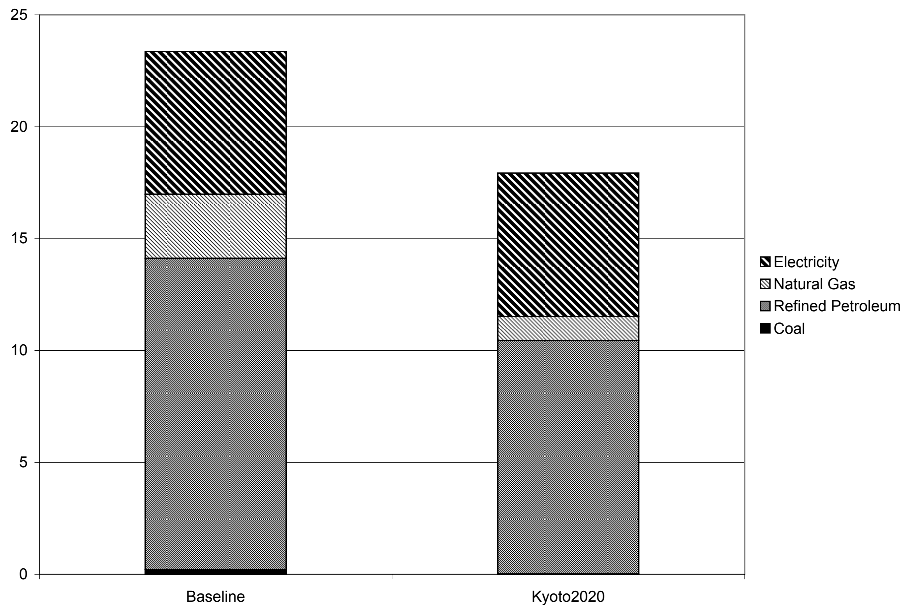

Figure 4: Final energy consumption in Switzerland for the baseline and the *Kyoto2020* scenario , 2020 (in Mtep)

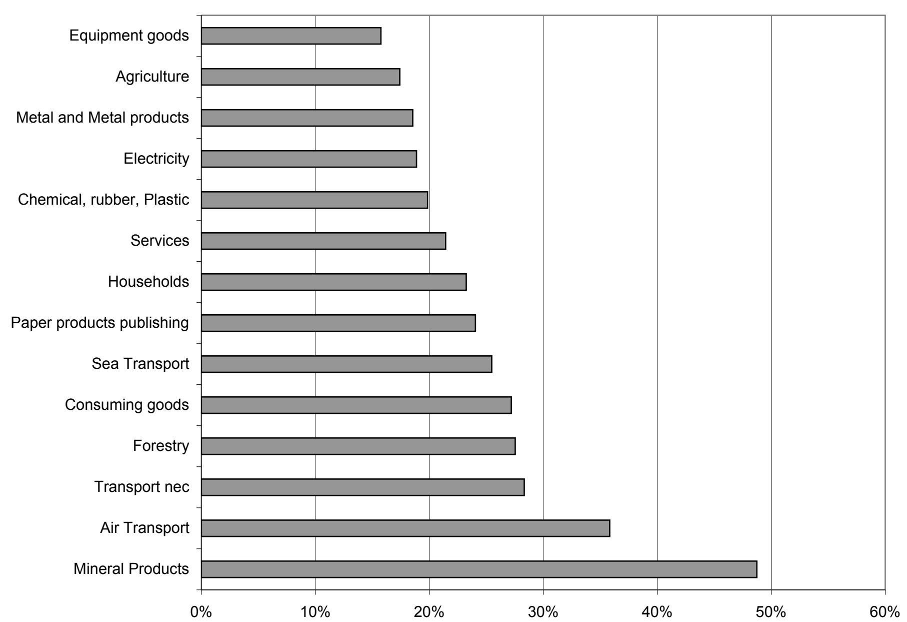

Figure 5: Final energy reduction by sector in Switzerland for the *Kyoto2020* scenario, 2020 (in % change)

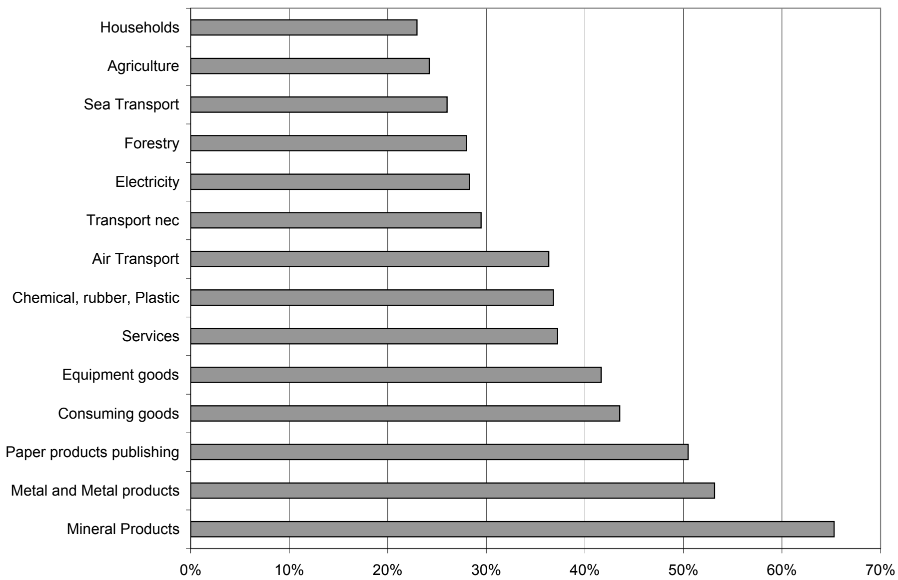

Figure 6: CO_2 emissions reduction by sector in Switzerland for the *Kyoto2020* scenario, 2020 (in % Change)

Welfare cost is a useful indicator to measure the economic impact of climate policies on the economy. In this report, welfare change is estimated in equivalent variation. The equivalent variation measures the amount of additional income (at current price) that consumers would need every year to be compensated for the losses of income caused by the policy change [22]. We must point out that our measures do not take into account the future welfare gain resulting from the limitation of climate change nor the ancillary benefits of reduced air pollution. The welfare cost in Switzerland for achieving the *Kyoto2020* target is projected to be around 3'211 millions CHF_{2001} in 2020, which represents about 1% of total household consumption (see table 10).

Table 10: Tax and Welfare Cost in Switzerland - scenario *Kyoto2020*

	2010	2020
CO_2 tax in CHF_{2001}	111	790
CO_2 abatement in % of baseline	-10%	-31%
Welfare cost in millions CHF	-288	-3'211
Welfare cost in % of total household consumption	-0.10%	-1.01%

5.2 Scenario Kyoto2050

For the *Kyoto2050* scenario, the carbon price must be raised drasticaly to reach 1440 USD in 2050 as shown in the table 11. This is a consequence of the structure of GEMINI-E3 which does not include backstop technologies (especially in the transport sector) and could, therefore, not reach substantial abatement without enforcing a high carbon tax. Limiting the scope of the tax to CO_2 abatement in Switzerland also explains the differences between the tax levels reached nationally and those in other regions.

Table 11: Emissions reduction and CO_2 price - scenario *Kyoto2050*

	2020	2030	2040	2050
CO_2 Emissions reduction in %				
CHE	-31%	-36%	-42%	-49%
GHG Emissions reduction in %				
EUR	-17%	-21%	-23%	-25%
OEC	-13%	-22%	-28%	-32%
JAP	-21%	-20%	-20%	-19%
CO_2 tax in USD per ton				
CHE	468	629	930	1440
GHG tax in USD per ton				
EUR	18	33	44	59
OEC	10	22	42	57
JAP	38	32	28	24

Table 12 provides taxes and welfare costs in Switzerland for the *Kyoto2050* scenario. The welfare cost in percent of total household consumption doubles between 2020 and 2050, which is an obvious consequence of the drastic reduction of CO_2.

Table 12: Tax and Welfare Cost in Switzerland - scenario *Kyoto2050*

	2020	2030	2040	2050
CO_2 tax in CHF_{2001}	790	1’061	1’568	2’429
CO_2 abatement in % of the baseline	-31%	-36%	-42%	-49%
Welfare cost in millions CHF	-3’211	-4’287	-6’209	-9’117
Welfare cost in % of total households consumption	-1.01%	-1.22%	-1.56%	-2.00%

Figure 7 compares the final energy consumption in Switzerland in the year 2050 for the reference case and the *Kyoto2050* scenario. The trend observed in the previous scenario can also be observed here. The natural gas consumption is reduced by 76% and the one of refined petroleum by 43%. The consumption of electricity is increased by 1% and coal is hardly used anymore (-97%).

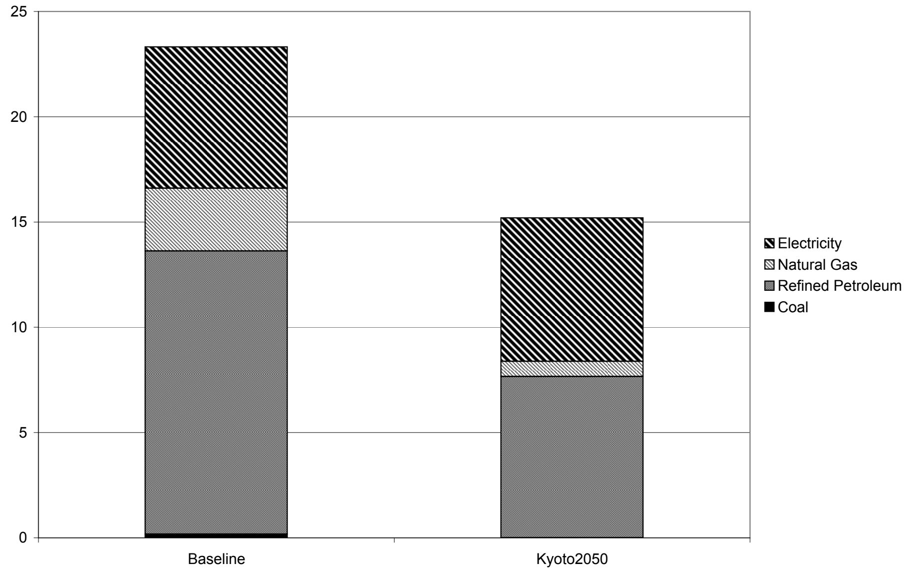

Figure 7: Final energy consumption in Switzerland for the baseline and the *Kyoto2050* scenario, 2050 (in Mtep)

In the absence of technological break-through or an available backstop technology, the possibilities to replace fossil fuels by non-fossil fuels are very limited in Switzerland. As a result, the reduction in CO_2 emissions is essentially obtained by a reduction in overall energy consumption, which is essentially obtained by a reduction in economic activity.

6 Conclusions

This report analyzes the impact of CO_2 constraints on the Swiss economy with the GEMINI-E3 model. The GEMINI-E3 model used for this study divides the world in 6 regions, of which one is Switzerland. The baselines have been calibrated to the projections reported by SECO [9] in the case of Switzerland, whereas for other regions we have used projection published by DOE [12].

We have analyzed two scenarios in which different constraints on the Swiss CO_2 emissions are imposed. The first scenario supposes a 20% reduction in 2020 compared to 1990 levels (*Kyoto2020*). The second forces a CO_2 abatement of 50% by the year 2050 (*Kyoto2050*).

The results obtained show that the CO_2 price associated with both scenarios could be high: 468 USD in the scenario *Kyoto2020* and 1440 USD in the scenario *Kyoto2050*, wheras welfare losses are respectively 1 and 2% of total households consumption. This report confirms the findings reported in others studies [1] [7], which underline that marginal abatement costs of CO_2 emissions are relatively high in Switzerland when compared to those in other developed countries. This result is explained by the structure of the Swiss economy and in particular of its electricity sector which has only limited potential for low-cost abatement . The lack of backstop technologies in the structure of GEMINI-E3 also explains the large costs, which are necessary to reduce substantially the emissions in sectors such as the transport sector.

There are different possibilities to reduce the cost of implementation of CO_2 limitation in the Switzerland. On one hand Switzerland could benefit from the mechanisms envisaged in the Kyoto Protocol, namely the Clean Development Mechanisms, the Joint Implementation and the Emissions Trading. For example, joining to the European emission trading system would reduce the price of carbon and limit the impact of a climate policy on competitiveness for energy intensive industries. On the other hand, multigas policies would also reduce the welfare cost of GHG abatement. Several studies [8] show that the inclusion of non-CO_2 GHGs (namely CH_4, and N_2O and fluorinated gases) in the mitigation strategy significantly reduces the welfare cost of a long term GHG emission abatement. In parallel to this study we have also analyzed a multigas strategy scenario, in which, similarly to the *Kyoto2050* scenario, a 50% is reached in 2050. The analysis has shown that the resulting tax and welfare costs would be respectively reduced by 30 and 40% compared to the *Kyoto2050* scenario.

Concerning the GEMINI-E3 model, several works are ongoing in order to introduce more technological considerations in the framework of a general equilibrium model. These new versions will allow for a better understanding of long term climate policies with strong GHG abatement.

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