Assessment of Acceptable Swiss post-2012 Climate Policies[a]

André Sceia[b], Juan-Carlos Altamirano-Cabrera[c], Marc Vielle[d] and Nicolas Weidmann[e]

JEL-Classification: C68, D58, Q54, N70
Keywords: Climate policy, Environmental taxation, Hybrid modeling, Transport, Residential, Welfare economics

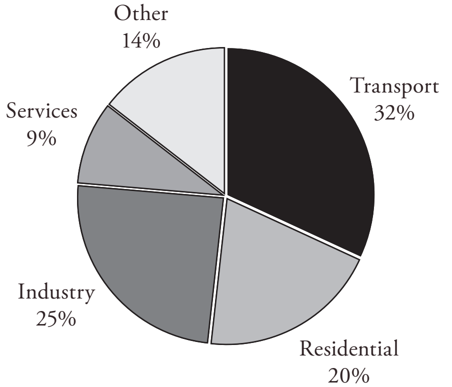
1. Introduction

Switzerland represents a small share of global greenhouse gas (GHG) emissions but is strongly engaged in meeting its abatement objectives and has proved to be at the forefront of international climate negotiations[1]. With 7.6 million inhabitants, GHG emissions amounted 51.3 million tons of CO_2 equivalent ($MtCO_2eq$) in 2007, slightly down from the 1990 level (52.7 $MtCO_2eq$). Since electricity is largely produced from hydro (56%) and nuclear (39%), transportation and housing are responsible for the major part of GHG emissions (see Figure 1).

Back in 1999, the Swiss Parliament adopted the Swiss CO_2 Law (Swiss Confederation, 1999), which entered into force on May 1st 2000, aiming at a 10 per cent reduction of CO_2 emissions below 1990 levels by 2010. Later, on July 9,

a This work has been undertaken with the support of NSF-NCCR climate and Federal Office for the Environment grants. We are very grateful to Martin Peter, Carten Nathani and the Federal Office of Statistics for providing us with disaggregated input-output tables. We also would like to thank Jacqueline Hug, Thorsten F. Schulz, Philippe Thalmann, Hal Turton as well as the two anonymous referees for their helpful comments. Remaining errors are under the sole responsibility of the authors.
b Economics and Environmental Management Laboratory – Swiss Federal Institute of Technology at Lausanne (EPFL), CH-1015 Lausanne, Switzerland. Email: andre.sceia@gmail.com.
c Universidad Autónoma Metropolitana-Azcapotzalco, Department of Economics, Research Group on Environment and Growth, Mexico City, Mexico.
d Economics and Environmental Management Laboratory – Swiss Federal Institute of Technology at Lausanne (EPFL), CH-1015 Lausanne, Switzerland.
e Energy Economics Group – Paul Scherrer Institute (PSI), CH-5232 Villigen, Switzerland.
1 e.g. the proposal to introduce a global carbon tax or the proposal to use the revenue of such a global carbon tax for solidarity in financing adaptation.

Figure 1: Sectoral Contributions to Swiss GHG Emissions (2007)



2003, Switzerland ratified the Kyoto Protocol to the UN Framework Convention on Climate Change with the objective to reduce all GHG emissions by 8 per cent below 1990 levels in the commitment period 2008 to 2012. The CO_2 Law encompasses various instruments in order to reach both of these objectives: (1) voluntary measures by the economy and individuals[2], (2) a CO_2 tax, if the voluntary measures are not effective enough, (3) measures taken in other policy areas having a positive impact on climate and (4) the exchange of emission allowances and other flexibility mechanisms of the Kyoto Protocol. Special partial targets for combustible[3] fuels (–15%) and transport fuels (–8%) have also been incorporated in the law. In 2007, the Federal Council has adopted an ordinance introducing an incremental CO_2 tax on combustible fuels (SWISS CONFEDERATION, 2007). As of 2010, the level of this tax was increased from 24 to 36 CHF. Furthermore, among the voluntary measures by the industry, the "Climate Cent" initiative is worth mentioning (SWISS FEDERAL OFFICE OF ENERGY, 2006; NIEDERBERGER, 2005). Since October 2005, the Climate Cent Foundation is funded by a charge levied on all imports of petrol and diesel at a rate of 0.015 CHF per liter. The Foundation invests the proceeds into projects designed to reduce greenhouse gas emissions both in Switzerland and abroad – using the flexibility mechanisms of the Kyoto protocol: Clean Development Mechanisms (CDM) and Joint

2 see BARANZANI, THALMANN, and GONSETH (2004) for details about Swiss voluntary measures.
3 In line with SWISS CONFEDERATION (2007), we define combustible fuels as fuels used (a) to produce heat, (b) to generate electricity in thermal plants and (c) to operate facilities combining heat and power.

Implementation (JI) – and is committed to reducing 12 $MtCO_2$, of which at least 2 $MtCO_2$ in Switzerland, over the period 2008–2012.

In the framework of the revision of the Swiss CO_2 Law for the post-2012 period and in view of the international negotiations taking place at the Conference of the Parties to the United Nations Framework Convention on Climate Change, the Swiss Government has proposed a set of instruments and two levels of abatement to define the Swiss climate policy for the post-2012 period. The proposed policies are the results of a consultation procedure that took place until March 2009 and has allowed major stakeholders and lobbies to defend their views and interests. We have to bear in mind that as Grossman and Helpman (2001) point out, the influence of lobby groups (e.g. business associations and environmental NGO's) may be able to affect the behaviour of politicians. This can be accomplished by providing information, by financing election campaigns, or by bringing environmental concerns to the forefront of the minds of the voters. It is commonly expected that the resulting policies from lobby pressure are not efficient. Under this pressure, governments tend to choose a policy that is a compromise between the efficient outcome and the lobbies' most preferred policy level (Persson and Tabellini, 2000).

As it is the case in the European Union (European Commission, 2009a), a first scenario is envisaged for the case where the climate negotiations would reach a moderate global abatement and a second more stringent scenario could be used in the case where the rest of the world would commit to strong emissions reductions. A detailed description of the envisaged targets and instruments is presented in Section 3.

The use of multiple environmental policy instruments is often motivated by practical considerations of implementation and by the fact that the use of a single policy instrument (for example a tradable permit scheme) is rather difficult (Johnstone, 2003; Michaelowa, 2004). However it is important to verify that the emission reduction is achieved in an efficient way, i.e. that the marginal abatement cost are equalized across sectors or at least not too distant. With this in mind and taking into account the views expressed during the consultation procedure on the revision of the Swiss CO_2 Law, the Swiss Government has devised policies composed of various instruments and sectoral targets, with the hope that they would be acceptable to the economy and the population. However, this mix of instruments and the resulting pressure from lobbies may not render an efficient solution. Then, we compare the use of these instruments with the implementation of a uniform carbon tax to evaluate the efficiency of the proposed policies. The implementation of a uniform carbon tax ensures that the marginal abatement costs are equalized across sectors.

In order to adequately evaluate the post-2012 Swiss climate policies, model all the envisaged instruments and consider the influence of the choices that will be made in the rest of the world, we have coupled the GEMINI-E3 model, a world-wide computable general equilibrium (CGE) model, with MARKAL-CHRES and MARKAL-CHTRA, two energy models describing respectively the Swiss residential and transportation sectors. This paper builds on the work undertaken in Sceia et al. (2009) and uses a new coupling approach to assess the climate policies currently under discussion.

This paper is organized as follows: Section 2 briefly presents the methodology, Section 3 describes the baseline scenario. The policy scenarios and their respective results are presented respectively in Sections 4 and 5, whereas Section 6 concludes.

2. Methodology

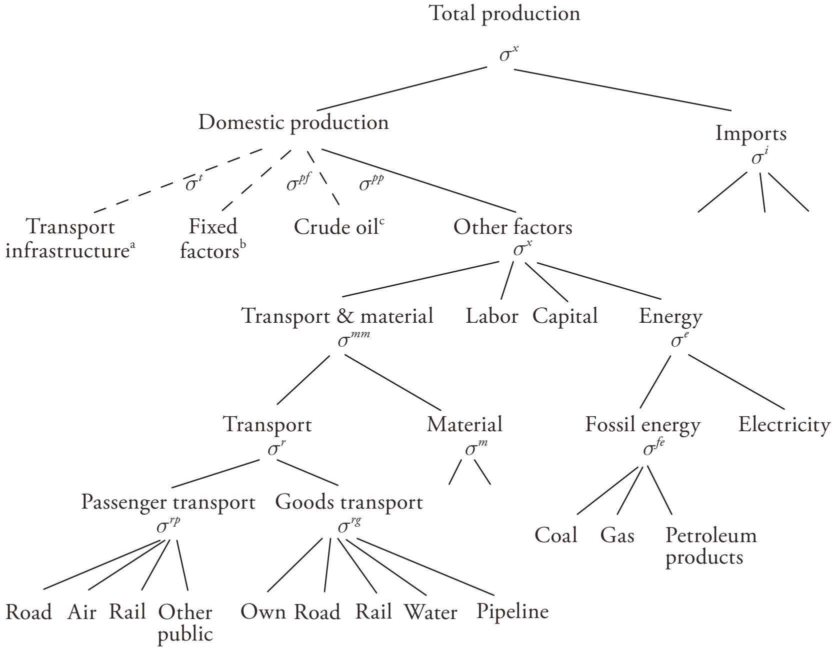
We use an aggregated version of GEMINI-E3[4], a dynamic-recursive CGE model with a highly detailed representation of indirect taxation, that represents the world economy in 6 regions and 18 sectors based on the year 2001. We define the regions as follows:

– CHE : Switzerland
– EUR : European Union[5]
– OEU : other European and Euro-Asian countries[6]
– JAP : Japan
– OEC : USA, Canada, Australia and New Zealand
– DCS : other countries, mainly developing countries

For Switzerland, we extend the number of sectors to 29 in order to more precisely present the transportation sector using the social accounting matrix (SAM) disaggregation performed in Infras (2006). The structure of the Swiss nested CES production function and utility function, are presented in Figures 2 and 3. The elasticities used in the model are presented in Table 1.

4 The complete GEMINI-E3 represents the world economy in 28 regions (including Switzerland) and 18 sectors. All information about the model can be found at http://www.gemini-e3.net, including its complete description (Bernard and Vielle, 2008).
5 Refers to the European Union Member States as of 2008.
6 Includes other European countries, Russia and the rest of the Former Soviet Union excluding Baltic States.

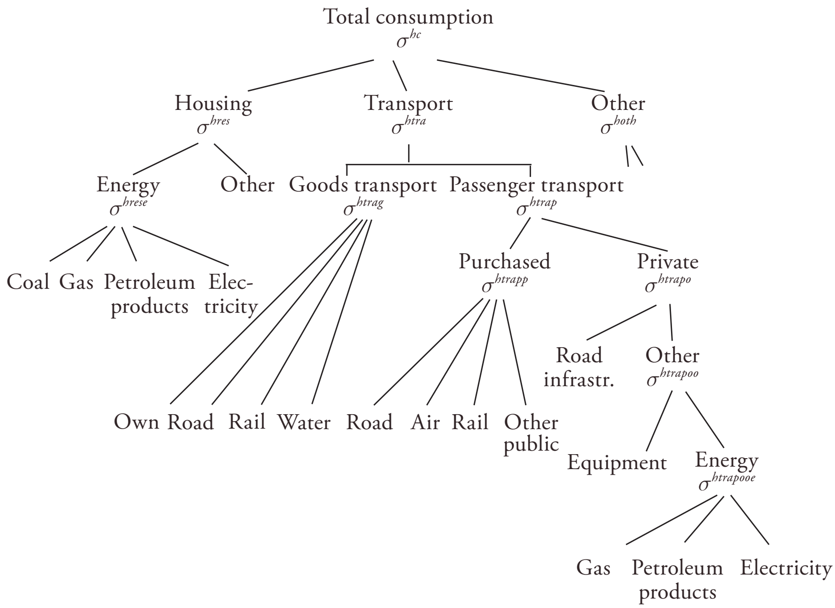
Figure 2: Structure of the Swiss Nested CES Production Function



a Present only in the production functions of transport sectors with the infrastructure corresponding to the mode of transport, i.e. sector 12a for sectors 12b, 12c and 12d; sector 17b for sector 13; sector 17c for sector 14 and sector 17d for sectors 12e, 12f and 12g.
b Present only in the production functions of sectors 01, 02 and 03.
c Present only in the production function of sector 04.

To complement the top-down model GEMINI-E3, we use the bottom-up models MARKAL-CHRES and MARKAL-CHTRA, which are energy models describing the Swiss residential energy system and the Swiss transportation energy system. They are submodules of a larger Swiss MARKAL model (SMM) developed at the Paul Scherrer Institute (PSI). The models contain respectively 173 and 184 technologies using different energy sources (coal, oil, diesel, gasoline, gas, electricity, wood, pellets and district heat). Both MARKAL models use a 3.5% discount rate (Amstalden et al., 2007). For a more detailed description of the models, see Schulz (2007) and Loulou and Labriet (2008).

Figure 3: Structure of the Households' Nested CES Utility Function



The harmonization or the integration of top-down and bottom-up models has been extensively studied but remains at the top of the agenda for researchers dealing with energy, environments and economy issues. Two main methods have been used. They are commonly referred to as soft-link and hard-link methods. While the first keep top-down and bottom up models separate, the later integrates both in a single model. The application of these methods is not uniform and different models are linked or integrated in different ways. We have used a soft-link method that is different from those found in other studies. DROUET et al. (2005) use a MARKAL model of the Swiss residential sector to complement a CGE model in which the residential sector has been removed. We keep GEMINI-E3 and both MARKAL models in their complete form and dynamically couple them. Contrary to SCHÄFER and JACOBY (2005), we link the models both in the calibration and simulation phases. With regard to the hard-link method, most studies only integrate a reduced form of one of the models types. Examples include MARKAL-macro models, as used in STRACHAN and KANNAN (2008), that integrate a simplified economic module in a bottom-up framework and CGE

Table 1: GEMINI-E3 Elasticities

Production function		
Parameter	Sector	Value
all regions		
σ	All	0.30
σ^{pf}	01	0.40
	02, 03	0.20
	04	0.10
σ^{pp}	All	0.10
σ^{e}	01 to 05	0.10
	06, 07, 12, 13, 14	0.20
	Others	0.40
σ^{fe}	01 to 04	0.10
	05	1.50
	06 to 11 & 15 to 18	0.90
	Others	0.30
σ^{r}	All	0.60
σ^{m}	All	0.20
σ^{x}	01,03	2.00
	2	10.00
	5	0.50
	12, 13, 14, 17	0.10
	18	0.05
	Others	3.00
σ^{mm}	All	0.20
only for Switzerland		
σ^{t}	All	0.10
σ^{r}	All	0.10
σ^{rp}	All	0.80
σ^{rg}	All	0.80

Consumption function		
	Value	
Parameter	CHE	other regions
σ^{hc}	0.20	0.50
σ^{hres}	0.00	0.80
σ^{htra}	0.10	0.50
σ^{hoth}	0.30	0.30
σ^{hrese}	0.00	–
σ^{htrag}	0.80	–
σ^{htrap}	0.50	0.50
σ^{htrapp}	0.50	–
σ^{htrapo}	0.30	–
$\sigma^{htrapoo}$	0.30	–
$\sigma^{htrapooe}$	0.00	–
σ^{htrao}	–	0.30
σ^{htraoe}	–	0.80

models complemented by a technological representation of a specific sector such a electricity generation (Wing, 2006) or specific industrial processes (Murphy, Rivers, and Jaccard, 2007; Schumacher and Sands, 2007). More complete integrations in a single modeling framework have been proposed by Frei, Haldi, and Sarlos (2003), Böhringer and Rutherford (2008) or Böhringer and Rutherford (2009) but are so far only implemented with stylized models.

Compared to previous studies (Sceia et al., 2011, 2009), our coupling procedure has been amended to allow GEMINI-E3 to calculate taxes according to given sectoral emission profiles. The models are run alternatively while the coupling variables are exchanged between the models, as shown in Figure 4, until a defined threshold on the variation of the taxes is reached.[7] The coupling procedure also takes into account a building improvement program (see Section 4.1.3 for details).

3. Baseline Scenario

The GEMINI-E3 model with the disaggregated transportation sectors, once linked to the MARKAL-CHRES and MARKAL-CHTRA models and calibrated to Swiss GDP and population figures, calculates a baseline scenario until 2030. For Switzerland, the GDP growth rate is in line with the Secretariat of Economic Affairs (SECO) estimates and is equal to 1.2% per year, whereas for other regions, they mainly follow forecasts from Energy Information Administration (2008), whereby world annual growth amounts to 2.8%.

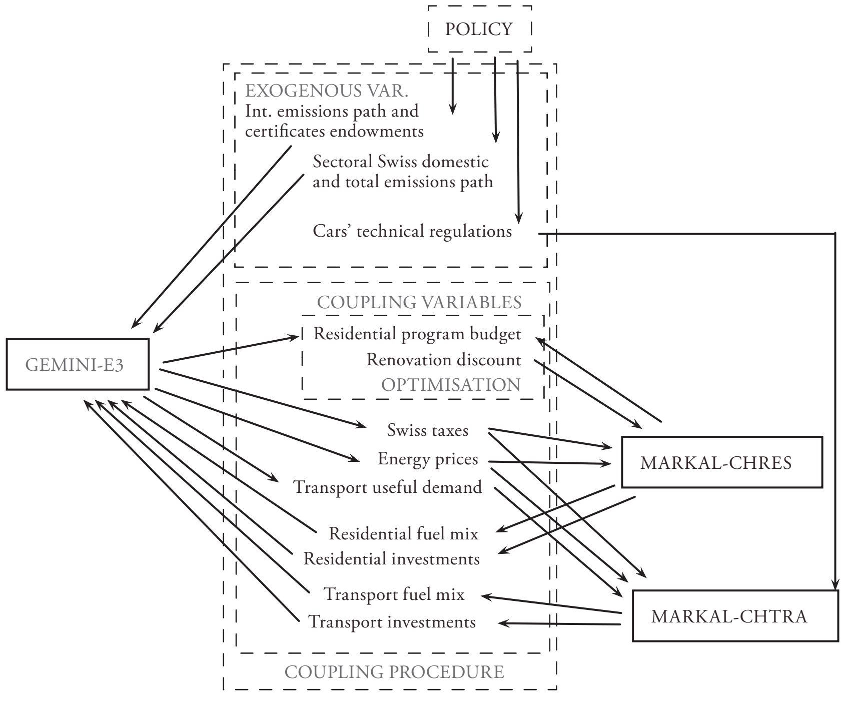
The baseline oil prices are also a key assumption for the model. We use a smoothed series of historical prices and keep the oil prices at 50 USD_{2008}/bbl until 2020. The price of oil is then assumed to grow linearly to 100 USD_{2008}/bbl in 2050, thus reaching 66 USD_{2008}/bbl in 2030. For Switzerland, the calibration of the model with regard to the combustible fuels consumption is made assuming that temperatures will correspond to the average over the years 1970–1992.

In our baseline scenario, the world GHG emissions reach a little more than 55 $GtCO_2eq$ by 2030, which is in line with OECD (2008). Figure 5 presents the GHG emissions for each region until 2030.

Table 2 presents the variations of the Swiss baseline emissions for the transport, residential and emission trading system (ETS) sectors (Refined Petroleum, Electricity, Mineral Products, Chemical Rubber Plastic, Metal and Metal

7 For more details on the coupling procedure see Sceia (2010).

Figure 4: Coupling Schema



Products and Paper Products Publishing) as well as the emissions from air transport (national and international) and all other CO_2 emissions. It also presents the variation of all emissions which will be subject to the CO_2 tax on combustible fuels, i.e. those from the residential sector and those from the other sectors. On average, the Swiss baseline GHG emissions will decrease annually by 0.6%. Note that this reduction is comparable to the one of Japan, which has a similar GDP growth (Energy Information Administration, 2008). The calibration of the baseline emissions is based on Swiss Federal Office of Energy (2007) Scenario I.A, which assumes the continuation of present climate policies and the construction of new nuclear power plants to replace those that will be phased out over the coming decades.

The baseline reduction of GHG emissions in Switzerland is explained by four major factors: (1) moderate GDP growth, (2) increasing energy efficiency, (3) the continuation of existing climate policies and (4) oil prices reaching

Figure 5: Baseline CHG Emissions ($GtCO_2eq$)

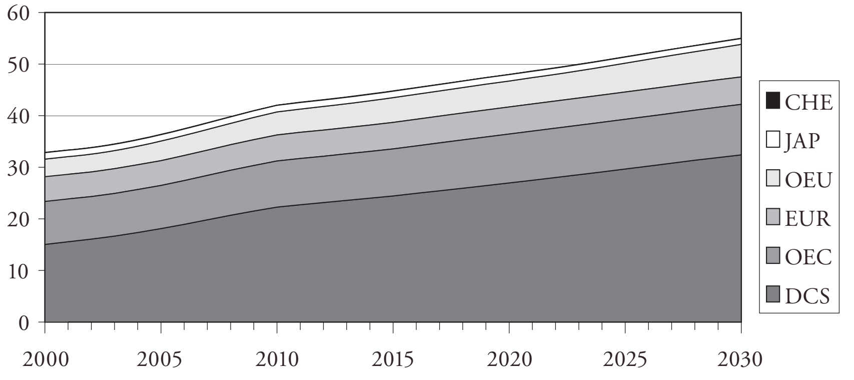


Table 2: Variation of the Baseline GHG Emissions

	Emissions in 1990[a]	2020 (% of 1990)	2030
Transport	12.3	9	10
Households	8.4	15	22
Transport sectors	3.9	–4	–17
Residential	11.3	–17	–28
ETS Sectors	5.4	–16	–22
Other sectors	15.5	–5	–18
Air transport	4.3	–6	–17
Other	11.2	–5	–18
Domestic CO_2	44.6	–6	–13
Domestic CO_2 (w/o Air transport)	40.2	–6	–13
Combustible fuels	22.5	–11	–23
Other GHG	8.2	–9	–11
CH_4	4.3	–24	–27
N_2O	3.6	–24	–25
Fluorinated gases	0.2	476	489
Domestic GHG emissions	52.8	–6	–13

a in $MtCO_2eq$.

66 USD_{2008}/bbl in 2030. The next section presents the policy scenarios which are envisaged to further reduce Swiss GHG emissions.

4. Policy Scenarios

4.1 Swiss Scenarios

Two scenarios are under consideration, a first one where international agreements target rather limited abatement, and a second one where stronger abatement is agreed upon by all world nations. Since no specific threshold allowing to differentiate the two cases has yet been defined, we define two sets of international abatement targets (see Section 3.2) using expert judgment and the scenarios of the Energy Modeling Forum[8] 22 (Clarke et al., 2009).

The envisaged Swiss post-Kyoto policies, described in detail in Table 3, are not aimed at achieving a first best optimum but rather take into account the specificities and interests of the various stakeholders that will be affected by the policies. Indeed, the policies divide the economy in four parts, which will face different carbon prices.

4.1.1 Taxes, Levies and CO_2 Markets

The energy intensive sectors (ETS sectors) will participate as of 2013 in an ETS similar to the European Union (EU) ETS (Böhringer, Rutherford, and Tol, 2009a; Tol, 2009) and they will be allowed to purchase a part of the required abatement through the purchase of certified emissions reductions (CER) abroad. Our model simplifies the original policy requirement in four ways. Firstly, the future policies envisage that only large companies will participate in the emission trading whereas we assume that the totality of the sector takes part in the trading. Secondly, the companies taking part in the ETS might have the possibility not only to purchase CERs on the international market but also European Union Allowances (EUA) on the EU-ETS in case the ETS and EU-ETS are linked. We model a single international carbon market and therefore make no distinction between CER and EUA. Thirdly, similarly to the EU-ETS (Hepburn et al., 2006;, Demailly and Quirion, 2006), it is envisaged that 80% of the allowances are distributed at first according to grand-fathering and only

8 For more information about the Energy Modeling Forum see http://emf.stanford.edu.

Table 3: Swiss Emissions Targets

	Scenario 1		Scenario 2	
	2020	2030	2020	2030
ETS[a] Certificates purchase cap[b] (% of ETS abatement)	–1.75 % p.a. 40		–2.9 % p.a. 50	
Transport[c] (% of 1990 CO_2 emissions)	–25	–42	–40	–60
Technical regulations on cars[d]	target on average emissions of new cars			
Combustible fuels[c] (% of 1990 CO_2 emissions)	–25	–33	–35	–50
Building improvement program[e] (2010-2020)	200 Mio. CHF p.a.			
Resulting overall target (% of 1990 GHG Emissions)	–21	–31	–30	–45
Total certificates purchase cap[c] (% of 1990 GHG Emissions)	9	14	14	21

a Starts in 2013 on the basis of the average emissions in the period 2008-2012.
b The cap on the purchase of certificates in the ETS sectors increase linearly over the periods 2010-2020 and remains unchanged from 2020-2030.
c The values of the objectives increase linearly over the periods 2010-2020 and 2020-2030.
d Modeled as a ban on *standard* cars as of 2015.
e Modeled as a discount on refurbishment costs (energy saving technologies).

progressively the auctioned share grows to 70% in 2020 . We assume that 100% of the allowances are auctioned as of 2013. Fourthly, we only consider emissions related to the use of fossil fuels, i.e. CO_2 emissions from cement production, other than those resulting from the use of fossil fuels to produce heat, are not counted.

The transport sectors are potentially affected by two instruments. Firstly, as of 2010, the importers of transportation fuels will be required to offset a part of the transport emissions through the purchase of CERs. Assuming that the additional costs due to the purchase of the certificates will be passed on to the consumers through an increase in the price of transport fuels, we have modeled this through the implementation of a levy (tax), whose revenues are sufficient to purchase the required amount of foreign certificates. Secondly, in order to ensure a minimum domestic abatement the sum of the purchases from the ETS and transport sectors is limited. Therefore, if the total cap on the purchase of CERs (i.e. the sum of the ETS and transport sectors purchases) is reached and taking into account that the ETS sectors have the priority in the purchase mechanism, a CO_2 tax will be introduced on transportation fuels to ensure achieving the abatement target of the transportation sectors.

As for the current CO_2-Law, combustible fuels will continue to be subject to a tax. Nevertheless an exemption will be introduced for those sectors taking part in the ETS. Finally, air transport is not subject to any constraint.

In order to evaluate the relative efficiency of the envisaged scenarios, we have also simulated the implementation of a uniform CO_2 tax, applied to the whole economy except from air transport, aimed at achieving equal domestic and total reductions.

In addition to the various economic instruments, two specific programs will also contribute to the overall Swiss abatement effort: an average emission target for the CO_2 emissions of new passenger cars and a building improvement program.

4.1.2 Car Regulations

Both policies under consideration envisage an average emission target value for the CO_2 emissions of new passenger cars, with the same requirements as those that will be imposed in the EU (European Commission, 2009b). The average emissions of new cars will be limited to 130 gCO_2/km as of 2012 and to 95 gCO_2/km in 2020[9].

Despite the technological richness of the MARKAL-CHTRA model, the descriptions of the available and future vehicles does not go into sufficient details to model precisely this aspect of the policy. Instead, as of 2015, we have implemented a technical restriction on the purchase of the less efficient diesel and gasoline personal cars (5.4 l/100km and 6.1 l/100km). This leaves the following choices to the consumers: gas internal combustion engines (ICE) cars (8.2 l/100km), efficient diesel and gasoline ICE cars (5.1, 5.8 l/100km), as well as hybrid cars using gas, diesel and gasoline (6.2, 4.2, 4.9 l/100km). As MARKAL models are perfect foresight models, due to anticipations, the restrictions have an effect before their implementation and, already in 2013, approximately one half million tons of CO_2 are avoided. The abatement achieved by this measure exceeds 1.1 $MtCO_2$ in 2020, which represents respectively 26% and 18% of the required transport sector abatement efforts in scenarios 1 and 2.

9 In the baseline, the 130 gCO2/km target is met in the year 2015. The 95 gCO_2/km target is not met, although the average emission intensity of new cars continues to decline and reaches around 115 gCO_2/km by 2030.

4.1.3 Building Improvement Program

In the period 2010–2020, the revenue of the tax on combustible fuels will be affected up to one third of the total amount or maximum 200 Mio. CHF to a building improvement program, and the rest will be redistributed to households and economic sectors through social security. The building improvement program consists of financial help from the government to undertake refurbishments of houses and buildings with the scope of improving their energy efficiency.

The use of a hybrid model with a bottom-up residential sector allows for modeling endogenously this building improvement program. We have implemented a procedure which determines a reduction in the investment prices of energy saving technologies (e.g. insulation) as well as efficient technologies such as heat pumps or solar. This affects relative prices in MARKAL-CHRES and ensures that households increase their investments in these technologies. The price rebate is calculated so that the difference between the real costs of the investments and the actual costs borne by the households after the rebate is equal to the 200 Mio. CHF available for the program. In GEMINI-E3, we have considered that the government spends this amount in constructions (services sector). In view of the fact that our model has a single representative household that owns the capital, and assuming that companies would return the money to the capital owner, we have modeled the redistribution of the unspent revenue of the tax on combustible fuels as a simple lump-sum transfer.

When analyzed independently from all other instruments, we find that the building improvement program would save annually up to 680,000 tCO_2 by 2020, representing 23% and 15% of the abatement required in the residential sector in scenarios 1 and 2, at a shadow price of 295 CHF_{2010}/tCO_2eq.

4.2 International Scenarios

Climate policies will only be efficient in the long run if major agreements are found to limit emissions globally. There is no doubt that the historical responsibility of climate change lies with developed countries and that it would be unfair to jeopardize the development process of the rest of the world. Nevertheless, it remains true that, without appropriate coordinated action of emerging nations, any efforts by the developed countries would be vain.

With that in mind, the level of emissions abatement to be included in the future Swiss policies will depend on involvement of the rest of the world in resolving the climate change problem. In this paper we consider two scenarios, where two different international agreements are agreed upon and enforced.

The proposed targets for the two scenarios for 2020 and 2030 are presented in Table 4. In the first scenario, a weak international agreement is reached, whereas the second scenario all countries more actively participate in the global effort. The second scenario is based on International Energy Agency (2009) where DCS get binding targets as of 2020. World emissions in 2030 would be approximately at the level of 2001. Figures 6 and 7 show the international abatement targets for both scenarios.

Table 4: International Emissions Targets (% of 2001 Emissions)

Target year	2020		2030	
Scenario	1	2	1	2
CHE	–21	–30	–31	–45
EUR	–20	–30	–30	–45
OEC	–20	–30	–30	–47
JAP	–20	–30	–30	–47
OEU	–[a]	–10	–10	–23
DCS	–[a]	–[a]	0[b]	–13[b]

a baseline emissions
b % of 2020 emissions

For the sake of simplicity, we assume that all regions, except Switzerland, fully participate in a global emissions cap and trade system, allowing to equalize marginal abatement costs across all regions and providing a single world price for carbon[10]. When no binding target is defined for a region, we cap its emissions to the baseline emissions in order to avoid that the overall effect of the policies is jeopardized by carbon leakage.

10 For simulations taking into account delayed participation or fragmented climate regimes see van Vuuren et al. (2009) and Hof, den Elzen, and van Vuuren (2009).

Figure 6: Scenario 1 GHG Emissions Targets ($GtCO_2eq$)

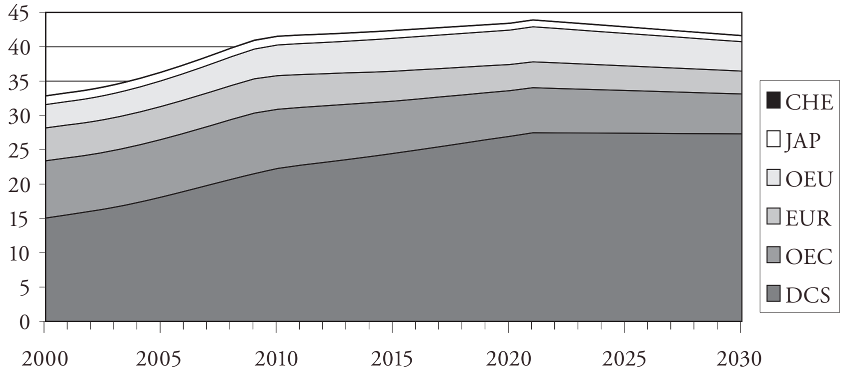
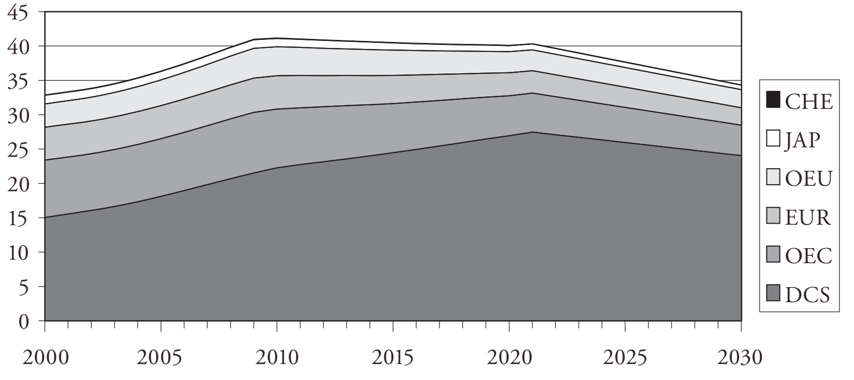


Figure 7: Scenario 2 GHG Emissions Targets ($GtCO_2eq$)



5. Results

5.1 Scenario 1

5.1.1 Carbon Prices and Emissions Reductions

Tables 5 and 6 present respectively the taxes that allow to achieve the objectives and the detailed emission abatements in the various parts of the Swiss economy. As expected, the levy collected on transport fuels to offset the emissions of the transport sector is small in view of the low price of foreign CO_2 certificates. The additional combustible fuel tax is significant as it would have to reach approximately 137 CHF_{2010}/tCO_2eq by 2020 to obtain 25% abatement, despite the technical possibilities offered by MARKAL-CHRES and the building improvement program. The price of the allowances in the ETS market remains rather low in view of the fact that the baseline abatement in those sectors is quite pronounced already, leaving small additional abatement to meet the target. As a consequence, the ETS carbon price equals the international price of CERs.

Table 5: Swiss Environmental Taxes and Prices of Certificates/Allowances in Scenario 1 (CHF_{2010}/tCO_2eq)

	2013	2015	2020	2030
Transport CO_2 tax	0.06	0.2	1	5
Heating fuels tax	47	65	137	37
ETS certificate price	1	2	4	13
World certificate price	1	2	4	13
Uniform tax	*11*	*11*	*11*	*13*

The uniform tax presented in the last line of Table 5 allows for an equivalent total CO_2 abatements as the combination of the tax, levy and ETS markets. It is determined with a cap on the purchase of CERs set at the level of one reached with the combination of the instruments and maintaining both the building improvement program and the technical regulations on cars.

The figures relative to abatement of the emissions due to combustible fuels and those from the residential sector in Table 6 suggest that modeling the use of combustible fuels in commercial buildings with an energy-systems model, as it is the case in the residential sector, would lower the estimation of the combustible fuels tax. Indeed, it seems reasonable to assume that technologies available for residential buildings can to a large extent also be used for commercial buildings and that the tax should trigger a similar magnitude of abatement. Even if a part of the difference can be explained by the implementation of the building improvement program which triggers an abatement in the residential sector of 0.6 $MtCO_2$ and the fact that some industrial processes are still part of the other sectors, the effect of the tax on the other sectors (-20%) seems rather limited when compared to the reductions in the residential sector (-47%).

Table 6: Variation of the Swiss GHG Emissions in Scenarios 1 and 2 (% of 1990)

		Scenario 1		Scenario 2	
	1990[a]	2020	2030	2020	2030
Transport	12.3	2	–3	2	–3
incl. CER		–25	–42	–40	–60
Households	8.4	5	5	5	6
Transport sectors	3.9	–5	–19	–6	–21
Residential	11.3	–39	–47	–53	–75
ETS Sectors	5.4	–18	–26	–20	–32
incl. CER		–23	–35	–30	–48
Other sectors	15.5	–10	–19	–15	–23
Air transport	4.3	–5	–17	–5	–16
Other	11.2	–13	–20	–19	–26
Domestic CO_2	44.6	–15	–23	–21	–32
Domestic CO_2 (w/o Air transport)	40.2	–16	–23	–22	–33
Combustible fuels	22.5	–26	–34	–36	–51
Other GHG	8.2	–10	–10	–11	–11
CH_4	4.3	–25	–26	–27	–26
N_2O	3.6	–25	–25	–26	–26
Fluorinated Gases	0.2	477	490	477	491
Domestic GHG	52.8	–14	–21	–19	–28
Total GHG	52.8	–21	–31	–30	–43

a in $MtCO_2eq$.

Both the transport and the ETS sectors can purchase CERs within predefined limits. Table 7 shows that in the first scenario the ETS sectors purchase a very limited amount of CERs to reach their target. In the transport sectors the small amount levied on fuel imports allows for the purchase of sufficient certificates to meet the 25% abatement target, but it is mainly the introduction of the regulations on cars that triggers the domestic abatement that can be observed when comparing Tables 2 and 6. The purchase cap on CERs is not reached, indicating that the the ETS price and the transport fuels levy ensure sufficient domestic abatement without having to impose an additional tax on transport fuels.

Table 7: Swiss Purchase of Certificates in Scenarios 1 and 2 ($MtCO_2eq$)

	Scenario 1		Scenario 2	
	2020	2030	2020	2030
Transport	3.3	4.8	5.1	7.0
ETS	0.3	0.5	0.5	0.9
Total	3.5	5.3	5.6	7.8
Purchase cap	4.8	7.6	7.4	11.3
%1990 GHG emissions	9%	14%	14%	21%

5.1.2 Economic and Welfare Impacts

Table 8 presents the impacts on welfare (households' surplus) as well as its decomposition into the gains and losses of the terms of trade (GTT), the trade of emissions permits and the deadweight loss of taxation (DWL)[11]. Furthermore, it presents the impacts of the uniform CO_2 tax that would allow an equivalent total and domestic CO_2 reductions. The welfare components are presented as a percentage of total households' consumption (HC). In the first scenario, the impact of the climate policies on welfare is above a third of a percentage point. The DWL is the main element influencing the welfare as both the GTT and the capital transfers due to the purchases of permits remain limited.

The numbers in Table 8 also show that if a uniform CO_2 tax is used instead of the combination of instruments, the resulting negative welfare effects are smaller. The difference between the two welfare effects can be seen as the loss of efficiency caused by the differentiation of the carbon price among sectors.

As expected, the overall impact of climate policies is negative for both production and consumption. Nevertheless, some sectors are more affected than others and some even benefit from the policies. The most affected sector is the refined petroleum sector, whose demand from households drops by 29% in 2030. Such structural changes are obviously the aim of climate policies. The production of refined petroleum products as well as imports are also quite strongly affected as they both decrease by approximately 10% compared to the baseline. In this scenario, the gas sector turns out to be the economically viable alternative to petroleum products. The households' consumption of gas increase (66%)

11 See annex 6 for more detail on the calculation of the welfare components.

is obviously supported by a strong increase of imports (39%). The electricity sector also strongly benefits from the policies and sees its production increase by almost 4% in 2030. In view of the small transport fuels levy, as expected, most transport sectors are only slightly negatively affected. The rail and road passenger transport sectors do nevertheless slightly benefit from a slight reduction in personal car usage. Furthermore, pipeline transport production increases by up to 5.8% as it benefits from the increase in gas consumption.

Table 8: Economic Impacts of Scenarios 1 and 2 in Switzerland (% of HC)

	Scenario 1		Scenario 2	
	2020	2030	2020	2030
Households' Surplus	–0.33	–0.34	–0.49	–0.47
GTT	0.06	–0.03	0.14	0.09
Sales of permits	0.00	–0.01	–0.01	–0.08
Deadweight Loss	–0.39	–0.29	–0.62	–0.47
in case of uniform tax				
Households' Surplus	*–0.26*	*–0.34*	*–0.39*	*–0.43*
GTT	*–0.04*	*–0.08*	*0.09*	*0.06*
Sales of permits	*0.00*	*–0.02*	*–0.01*	*–0.08*
Deadweight Loss	*–0.21*	*–0.24*	*–0.47*	*–0.41*

Each scenario having a specific international framework, it is interesting to say a word about international results despite the fact that they are not directly comparable with those of Switzerland. The first scenario assumes that OEU and DCS are not subject to emissions caps (other than their baseline emission) before 2020. As a consequence, both of these regions are in a position to sell CERs and have therefore positive welfare effect. The effects in other regions are smaller than in Switzerland, as the price of carbon is equal across sectors, no minimal share of domestic abatement is imposed and all GHGs are included in policies. In view of the small price of world certificates, the Swiss welfare losses are mainly due to the combustible fuels tax which is a purely national measure and is therefore not connected to the international emissions certificates market (see Figure 11).

5.1.3 The Residential and Transport Sectors

The coupled MARKAL-CHRES and MARKAL-CHTRA models allow us to analyze the technological implications of the scenarios more in detail.

Figure 8 shows that in the residential sector the combination of the combustible fuel tax and the building improvement program reduce both the heating oil and gas usage by respectively 14% and 66% compared to the baseline in 2030. Except in existing multi-family houses where the use of heating oil remains predominant, electric heat pumps become the predominant technology for space heating, which triggers the major part of the increase of electricity use (21% compare to the baseline). The instruments also trigger an increase of 9% in the use of insulation and other energy saving technologies.

Figure 9 presents the passenger cars usage by car types in billion vehicle kilometers per year(bvkm/a) and shows that the car regulations have a significant impact on the composition of the vehicle fleet. The increase of gas powered vehicle is responsible for the increase of gas consumption by households as it largely compensates the decrease observed in the residential sector. The regulations also trigger an increased presence of all types of hybrid cars.

5.2 Scenario 2

The second scenario targets a total reduction of GHG emissions by 30% in 2020 and 44% in 2030 using the instruments presented in Table 3.

5.2.1 Carbon Prices and Emissions Reductions

Tables 9 and 6 present respectively the taxes that allow to achieve the objectives of scenario 2 and the detailed emissions abatements in the various parts of the Swiss economy. The levy collected on transport fuels, despite being up to five time higher than in the first scenario, remains at very reasonable levels as the price of foreign emission certificates remains low. Such a levy would trigger an increase in the price of gasoline of approximately 1.9 cents per liter. The combustible fuels tax is expected to increase strongly if an abatement of 35% by 2020 is desired. Indeed, achieving such a strong domestic abatement over a single decade would require significant incentives and despite the building improvement program a tax on combustible fuels reaching 294 CHF_{2010}/tCO_2 would be necessary. As in the first scenario, the price of allowances in the ETS market remains rather low, in view of the moderate abatement compared to the baseline and because of the possibility to undertake 50% of this abatement abroad through the purchase of cheap emission certificates, in particular before 2020. By 2030 the certificates

Figure 8: Baseline / Scenario 1 / Scenario 2 Fuel Mixes in the Residential Sector (PJ)

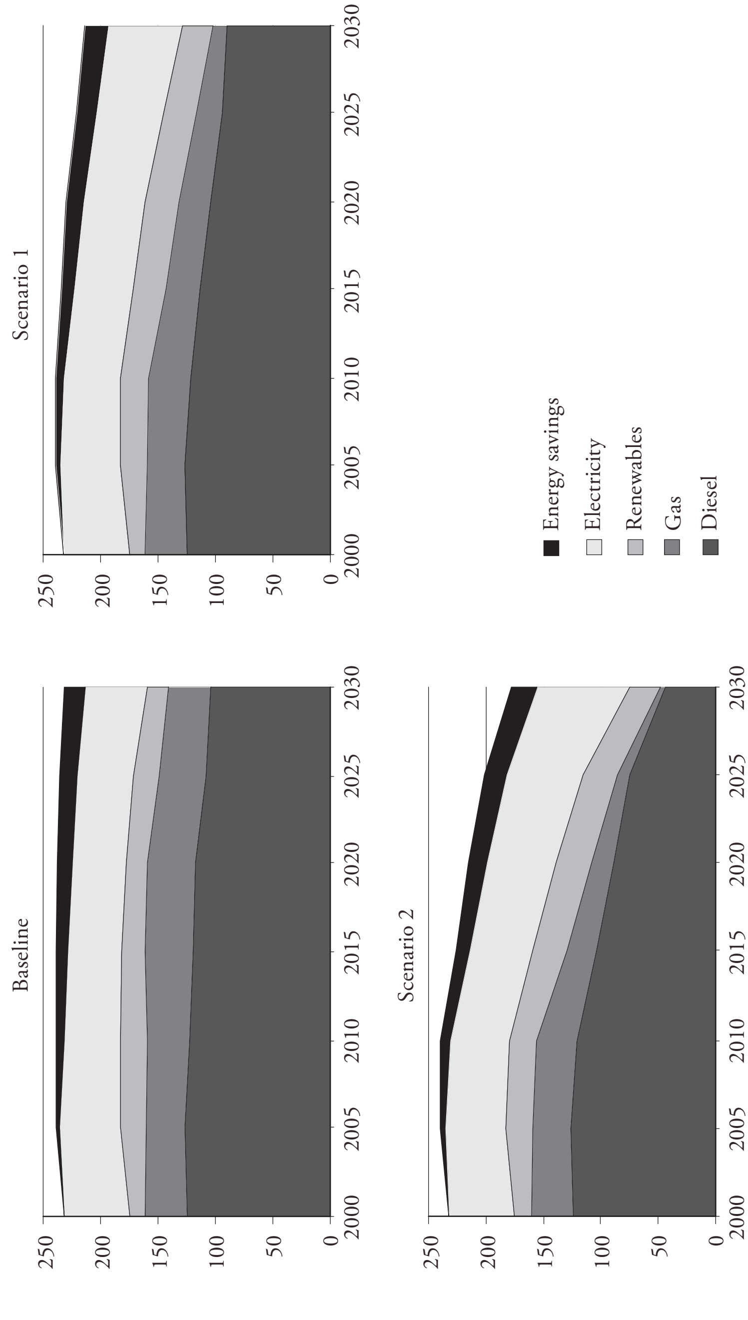
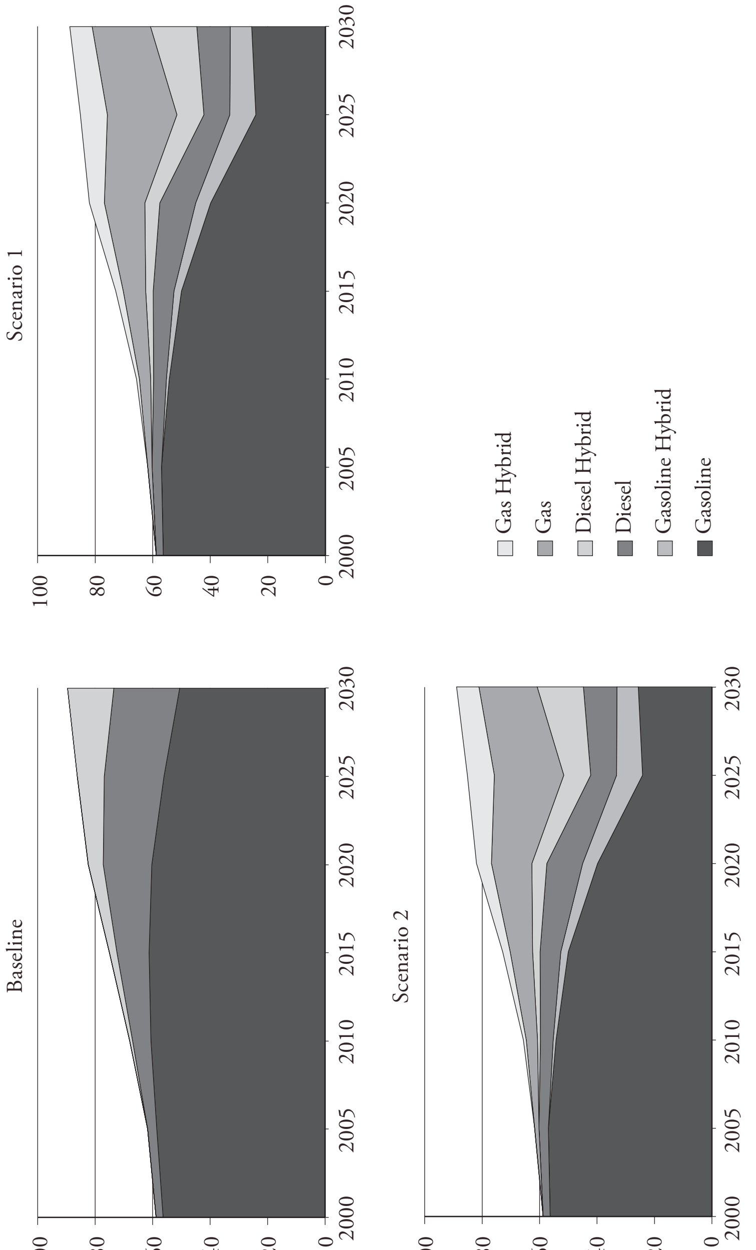


Figure 9: Baseline / Scenario 1 / Scenario 2 Use of Personal Cars by Types (bvkm/a)

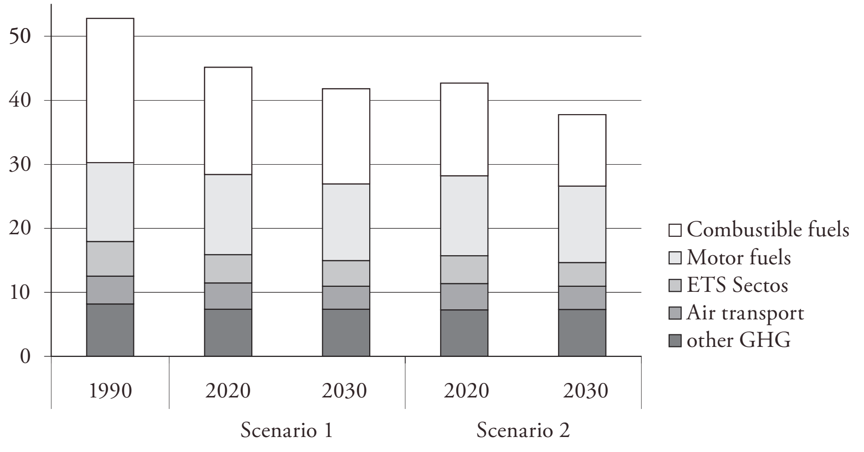


would reach 47 CHF_{2010}/tCO_2. Figure 10 presents the domestic emissions for the various sectors and confirms that the share of emissions caused by motor fuels increases significantly from 23% in 1990 to 29% in 2030. Combustible fuels, ETS sectors excluded, see their share shrink from 43% to 36%.

Table 9: Swiss Environmental Taxes and Prices of Certificates/Allowances in Scenario 2 (CHF_{2010}/tCO_2eq)

	2013	2015	2020	2030
Transport CO2 tax	0.33	0.9	4	28
Heating fuels tax	76	114	294	207
ETS certificate price	3	5	9	47
World certificate price	3	5	9	47
Uniform tax	*48*	*72*	*159*	*126*

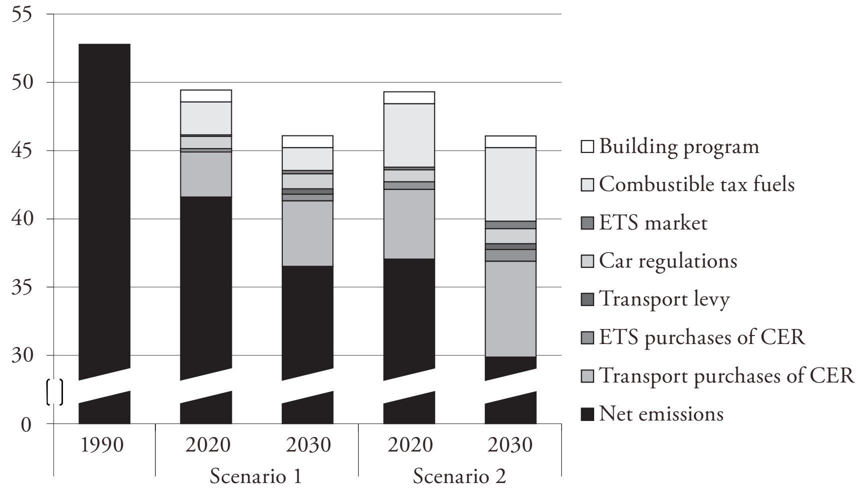
Figure 10: Domestic Swiss GHG Emissions ($MtCO_2eq$)



The tax on combustible fuels seems particularly high when compared to the uniform tax that would allow an equal domestic and total reduction of emissions and might trigger questions on the social equity aspects of the envisaged policies.

Figure 11 shows clearly that the transport sector contributes greatly to achieving the overall objective in both scenarios, but to a very large extent through the purchase of CERs. The tax on combustibles fuels achieves 65% of the domestic abatement in 2030 and when adding the contribution of the building improvement program this share rises to 75%. When considering the total emissions reductions, 77% is achieved by the combustible fuels tax and the purchases of CER by the transport sector.

Figure 11: Net Swiss GHG Emissions, CER Purchases and Abatements by Responsible Instrument ($MtCO_2eq$)



Regarding the purchase of emission certificates by the transport and the ETS sectors, Table 7 shows that, similarly to the first scenario, the overall emission cap is not reached and as a consequence no additional tax on transport fuels is required. The purchase of foreign emission certificates by the transport fuel importers financed by the levy reaches 7.8 tCO_2eq in 2030, which represents approximately 15% of 1990 emissions. As in the previous scenario the domestic abatement in the transport sector is attributable to the regulations on passenger cars rather than to the small increase of transportation fuels' prices.

5.2.2 Economic and Welfare Impacts

Table 8 presents the impacts of scenario 2 on welfare. As expected, the impact on welfare is more substantial than in the first scenario. The DWL reaches 0.6% of households' consumption in 2020 and the gains of the terms of trade are not sufficient to offset this. Again, the comparison with the uniform tax case confirms that setting up instruments which lead to differentiated marginal costs of abatement is suboptimal in terms of welfare. In view of the low prices of foreign emission certificates, the influence of their purchase on welfare remains low.

As expected, the overall impact of climate policies on both production and consumption is negative and stronger than in the previous scenario. The strongest effect is on the petroleum products sector, which is significantly affected (-18% of production in 2030), mainly because of a strong decrease in final consumption (-46%). When comparing with the previous scenario, with higher taxes gas turns out to be less of a viable substitute to petroleum products and therefore the substitution toward electricity is stronger. Gas consumption nevertheless increases by more than 50% and electricity consumption jumps by almost 40%. The electricity sector is the major beneficiary in this scenario as it increases its production by 6.7% in 2030. Again, the air transport sector is very slightly affected as it does not face any carbon price.

From the international perspective, the second scenario assumes stronger abatements and international agreements that would involve in the long run all regions with specific emissions reductions. By 2020, nevertheless, it is expected that DCS would only be restricted to their baseline emissions and, as a consequence, it is the only region selling large amounts of CER and therefore enjoying welfare gains. Switzerland is more affected than other regions before 2020, with the exception of OEU which is extremely sensitive to climate policies in view of its energy and energy intensive goods exports. In 2030, compared to Switzerland, EUR and OEC face stronger welfare effects, due in particular to a greater baseline GDP growth that leads to greater emissions increases compared to the base year.

5.2.3 The Residential and Transport Sectors

Figure 8 shows that the high tax on combustible fuels combined to the building improvement program reduces the use of gas and diesel in the residential sector by respectively 90% and 57% in 2030 compared to the baseline. The use of electric heat pumps, which have an energy efficiency three to four time superior to conventional diesel boilers, allows compensating a large share of the final energy demand and increases the use of electricity by 50%. The rest of the final energy is compensated by an increase of 44% in the use of renewables and an additional installation of energy saving technologies (19%).

Figure 9 shows that only the car regulation influence the personal cars fleet composition. Indeed, the limited amount of the levy remains without effect for the personal cars. The use of the uniform tax does not further affect the personal cars fleet and has no impact of other parts of the transport sector, which are very inelastic over the time horizon until 2030.

6. Conclusions

The use of hybrid and coupled models in the framework of the economic assessment of climate policies is increasingly popular and this study underlines the benefits of this methodology. It also presents an innovative soft-coupling procedure between a world CGE model (GEMINI-E3) and two energy-systems models (MARKAL-CHRES and MARKAL-CHTRA) modeling specifically the Swiss residential and transport sectors. Linking the models allows modeling the numerous aspects of the future climate policies, which can be of both technical and economic nature.

Our coupled model simulates all the different policy instruments that are envisaged in Switzerland for the post-Kyoto period endogenously and therefore allows analyzing both envisaged scenarios in different international frameworks. In the first scenario, we simulate moderate abatement targets with weak and incomplete international agreement, whereas the second scenario aims at more stringent abatement in the case where stronger international abatement objectives would be agreed upon.

Our simulations show that both policies have moderate economic impacts on the Swiss economy. In the first scenario, the various instruments would trigger a loss of welfare of about a third of a percent in 2020. In the second scenario, the maximum welfare loss would reach half percent in the same period. With a model that would consider induced technical progress and first-mover advantages, those economic impacts should be even lower. Furthermore, the welfare costs do not account for the avoided damages due to climate change, the potential adaptation costs or the ancillary benefits such as the avoided local air pollution. Nevertheless, we also show that welfare costs of mitigation could be further reduced by the introduction of a uniform tax.

Two major factors affect the efficiency of climate policies. On the one hand, within a given country, the necessity to differentiate the carbon prices faced by different sectors is generally defended by arguments related to international competitiveness and carbon leakage. GRUBB, AZAR, and PERSSON (2005) pinpointed that concerns about competitiveness led to excessive generosity for some sectors in the first phase of the EU-ETS allocation. In our framework, we show that while ensuring the global emissions abatement levels, thus avoiding leakage, the competitiveness argument does not hold in Switzerland. Indeed, Swiss welfare suffers from the advantage given to transport and ETS industries by the introduction of the diversified instruments and overgenerous caps on CERs purchases. On the other hand, national restrictions on the purchase of CERs are a major factor affecting the efficiency of climate policies but they are necessary from the perspective of international equity. In the Swiss case, all sectors facing the combustible tax are deprived from using any sort of flexibility mechanism, thus increasing the cost of emissions abatement.

Both scenarios trigger an important switch away from petroleum products. In the first scenario, this turns out to be very beneficial for the gas sector that profits from the increase of gas internal combustion engine (ICE)and hybrid personal car. In the second scenario, a doubling of the tax on combustible fuels pushes further toward the use of electricity in the residential sector. Both policies generate gains from the terms of trade but they do not offset the deadweight loss of taxation.

Interestingly, in both scenarios the caps on the purchase of foreign emission certificates are not reached. The implications are twofold. On the one hand, the envisaged tax on transport fuels is not necessary to ensure the minimum domestic abatement and, on the other hand, additional purchases of certificates, particularly in the residential sector, would be possible without jeopardizing the domestic emissions targets.

From the technology perspective, we show that the demand for private cars is very inelastic to the price of transport fuels and that the car regulations are the only instrument affecting the personal cars fleet composition. The car regulations are responsible for a strong presence of hybrid cars and gas cars in general. This might be significantly different if additional vehicles types, in particular personal cars such as plug-in hybrids and electric, would be included in MARKAL-CHTRA. As expected, the high taxes in the residential sector trigger a switch away from diesel and gas in favor of renewables and electricity, mainly thanks to the installation of efficient heat pumps.

In conclusion, both scenarios seem realistic and do not have dramatic impacts on the Swiss economy. This is due partly to the fact that in both scenarios the price of foreign emission certificates remains relatively low, allowing for cheap offsetting of Swiss emissions in transport and ETS industries. Nevertheless, the comparison with the uniform tax confirms that Swiss society as a whole would be better off without the differentiation of the economic instruments between different sectors. Nevertheless, such differentiation is aimed at increasing the acceptability of climate policies, and, as shown in Fredriksson (1997), the deviation from an optimal pollution tax can be explained by the influence of lobby groups.

One important weakness of our assessment is related to the uncertainties surrounding the assumptions on which our work is based. There are different sources of uncertainties, some are linked to exogenous assumptions (like GDP growth and world energy prices), others are related to the cost of technologies that are into account (in Markal or in GEMINI-E3 (through elasticities of substitution or the nested CES functions)), finally the climate target is itself uncertain. In Haurie, Tavoni, and van der Zwaan (2011) the authors stress several recommendations to integrate uncertainties in modeling climate policies, in the case of Computable General Equilibrium models one solution is to use Monte Carlo simulations, this option for example has been applied to the GEMINI-E3 model in Babonneau et al. (2011).

References

Amstalden, Roger W., Michael Kost, Carsten Nathani, and Dieter M. Imboden (2007), "Economic Potential of Energy-Efficient Retrofitting in the Swiss Residential Building sector: The Effects of Policy Instruments and Energy Price Expectations", *Energy Policy*, 35(3), pp. 1819–1829.

Babonneau, Frédéric, Alain Haurie, Richard Loulou, and Marc Vielle (2011), "Combining Stochastic Optimization and Monte Carlo Simulation to Deal with Uncertainties in Climate Policy Assessment", *Environmental Modeling and Assessment*, pp. 1–26.

Baranzini, Andrea, Philippe Thalmann, and Camille Gonseth (2004), *Voluntary Approaches in Climate Policy*, chap. "Swiss Climate Policy: Combining VAs with other Instruments under the Menace of a CO_2 Tax", pp. 249–276, Edward Elgar Publishing Limited.

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

Böhringer, Christoph, and Thomas F. Rutherford (2002), "Carbon Abatement and International Spillovers", *Environmental and Resource Economics*, 22, pp. 391–417.

Böhringer, Christoph, and Thomas F. Rutherford (2004),"Who Should Pay how Much?", *Computational Economics*, 23, pp. 71–103.

Böhringer, Christoph, and Thomas F. Rutherford (2008), "Combining Bottom-Up and Top-Down", *Energy Economics*, 30(2),pp. 574–596.

Böhringer, Christoph, Thomas F. Rutherford, and Richard S. J. Tol (2009), "The EU 20/20/2020 Targets: An Overview of the EMF22 Assessment", *Energy Economics*, In Press, Corrected Proof.

Böhringer, Christoph, and Thomas F. Rutherford (2009), "Integrated Assessment of Energy Policies: Decomposing Top-Down and Bottom-Up", *Journal of Economic Dynamics and Control*, 33(9), pp. 1648–1661.

Clarke, Leon, Jae Edmonds, Volker Krey, Richard Richels, Steven Rose, and Massimo Tavoni (2009), "International Climate Policy Architectures: Overview of the EMF 22 International Scenarios", *Energy Economics*, In Press, Accepted Manuscript.

Demailly, Damien, and Philippe Quirion (2006),"CO2 Abatement, Competitiveness and Leakage in the European Cement Industry under the EU ETS: Grandfathering versus Output-Based Allocation", *Climate Policy*, 6, pp. 93–113(21).

Drouet, L., A. Haurie, M. Labriet, P. Thalmann, L. Viguier, and M. Vielle (2005), "A Coupled Bottom-Up/Top-Down Model for GHG Abatement Scenarios in the Housing Sector of Switzerland", in *Energy and Environment*, R. Loulou, J.-P. Waaub, and G. Zaccour (eds), pp. 27–61, Springer, New York (United States).

Energy Information Administration (2008), *International Energy Outlook 2008*, Washington D.C.: EIA/DOE.

European Commission (2009a), "Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 – On the Effort of Member States to Reduce their Greenhouse Gas Emissions to Meet the Community's Greenhouse Gas Emission Reduction Commitments up to 2020", *Official Journal of the European Union*, L 140, pp. 136–148.

European Commission (2009b), "Regulation (EC) No 443/2009 of the European Parliament and of the Council of 23 April 2009 – Setting Emission Performance Standards for New Passenger Cars as Part of the Community's Integrated Approach to Reduce CO_2 Emissions from Light-Duty Vehicles", *Official Journal of the European Union*, L 140, pp. 1–15.

Fredriksson, Per G. (1997), "The Political Economy of Pollution Taxes in a Small Open Economy", *Journal of Environmental Economics and Management*, 33(1), pp. 44–58.

Frei, Christoph W., Pierre-André Haldi, and Gérard Sarlos (2003), "Dynamic formulation of a top-down and bottom-up merging energy policy model", *Energy Policy*, 31(10), pp. 1017–1031.

Grossman, G. M., and E. Helpman (2001), *Special Interest Politics*, M.I.T Press, Cambridge, Ma.

Grubb, Michael, Christian Azar, and U. Martin Persson (2005), "Allowance Allocation in the European Emissions Trading System: A Commentary", *Climate Policy*, 5, 127–136(10).

Harrison, W. Jill, J. Mark Horridge, and K. R. Pearson (2000), "Decomposing Simulation Results with Respect to Exogenous Shocks", *Computational Economics*, 15, pp. 227–249.

Haurie, A., M. Tavoni, and B. van der Zwaan (2011), "Modeling Uncertainty and the Economics of Climate Change: Recommendations for Robust Energy Policy", *Environmental Modeling and Assessment*, pp. 1–5.

Hepburn, Cameron, Michael Grubb, Karsten Neuhoff, Felix Matthes, and Maximilien Tse (2006), "Auctioning of EU ETS phase II Allowances: How and Why", *Climate Policy*, 6, pp. 137–160(24).

Hof, Andries, Michel den Elzen, and Detlef van Vuuren (2009), "Environmental Effectiveness and Economic Consequences of Fragmented versus Universal Regimes: What Can We Learn from Model Studies?", *International Environmental Agreements: Politics, Law and Economics*, 9(1), pp. 39–62.

Infras (2006), "Die Nutzen des Verkehrs, Teilprojekt 2: Beitrag des Verkehrs zur Wertschöpfung in der Schweiz", Tech. rep., Federal Office for Spacial Development and Federal Road Office.

International Energy Agency (2009), "How the Energy Sector Can Deliver on a Climate Agreement in Copenhagen", Tech. rep., IEA/OECD.

Johnstone, N. (2003), "The use of Tradable Permits in Combination with other Policy Instruments", Working Party on National Environmental Policy ENV/EPOC/WPNEP(2002)28/FINAL, OECD, Paris, France.

Loulou, Richard, and Maryse Labriet (2008), "ETSAP-TIAM: the TIMES Integrated Assessment Model Part I: Model Structure", *Computational Management Science*, 5(1), pp. 7–40.

Michaelowa, Axel (2004), "Policy Integration as a Success Factor for Emissions Trading", *Environmental Management*, 33(6), pp. 765–775.

Murphy, Rose, Nic Rivers, and Mark Jaccard (2007), "Hybrid Modeling of Industrial Energy Consumption and Greenhouse Gas Emissions with an Application to Canada", *Energy Economics*, 29(4), pp. 826–846.

Niederberger, Anne Arquit (2005), "The Swiss Climate Penny: An Innovative Approach to Transport Sector Emissions", *Transport Policy*, 12(4), pp. 303–313.

OECD (2008), *Environmental Outlook to 2030*, OECD.

Persson, T., and G. Tabellini (2000), *Political Economics and Economic Policy*, M.I.T Press, Cambridge, Ma.

Sceia, A. (2010), *Three Steps toward Modeling Swiss post-2012 Climate Policies*, Ph.D. thesis, EPFL.

Sceia, A., J.-C. Altamirano-Cabrera, T.F. Schulz, and M. Vielle (2009), "Sustainability, Neutrality and Beyond in the Framework of Swiss post-2012 Climate Policy", NCCR-Climate Working Papers.

Sceia, André, Juan-Carlos Altamirano-Cabrera, Laurent Drouet, Thorsten Schulz, and Marc Vielle (2011), "Integrated Assessment of Swiss GHG Mitigation Policies After 2012", *Environmental Modeling and Assessment*, pp. 1–15.

Schäfer, Andreas, and Henry D. Jacoby (2005), "Technology Detail in a Multisector CGE Model: Transport under Climate Policy", *Energy Economics*, 27(1), pp. 1–24.

Schulz, T. F. (2007), *Intermediate Steps toward the 2000 Watt Society in Switzerland : An Energy-Economic Scenario Analysis*, Ph.D. thesis, ETH Zurich.

Schumacher, Katja, and Ronald D. Sands (2007), "Where are the Industrial Technologies in Energy-Economy models? An innovative CGE Approach for Steel Production in Germany", *Energy Economics*, 29(4), pp. 799–825.

Strachan, Neil, and Ramachandran Kannan (2008), "Hybrid Modeling of Long-Term Carbon Reduction Scenarios for the UK", *Energy Economics*, 30(6), pp. 2947–2963.

Swiss Confederation (1999), «Loi fédérale du 8 octobre 1999 sur la réduction des émissions de CO_2 (Loi sur le CO_2)», (RS 641.71).

Swiss Confederation (2007), «Ordonnance du 8 juin 2007 sur la taxe sur le CO_2 (Ordonnance sur le CO_2)», (RS 641.712).

Swiss Federal Office of Energy (2006), «Limites des instruments et des mesures d'encouragement / activités Confédération, cantons et centime climatique», Tech. rep., Département fédéral de l'environnement, des transports, de l'énergie et de la communication Office fédéral de l'énergie.

Swiss Federal Office of Energy (2007), «Perspectives énergétiques pour 2035 (tome 1) synthèse», Tech. rep., Département fédéral de l'environnement, des transports, de l'énergie et de la communication Office fédéral de l'énergie.

Tol, Richard S. J. (2009), "Intra- and Extra-Union Flexibility in Meeting the European Union's Emission Reduction Targets", *Energy Policy*, 37(11), pp. 4329–4336.

van Vuuren, Detlef P., Michel G. J. den Elzen, Jasper van Vliet, Tom Kram, Paul Lucas, and Morna Isaac (2009), "Comparison of Different Climate Regimes: The Impact of Broadening Participation", *Energy Policy*, 37(12), pp. 5351–5362.

Wing, I. (2006), "The Synthesis of Bottom-Up and Top-Down Approaches to Climate Policy: Electric Power Technologies and the Cost of Limiting US CO_2 Emissions", *Energy Policy*, 34, pp. 3847–3869.

Appendix

Welfare Costs

Similarly to other general equilibrium models, GEMINI-E3 assesses the welfare costs of policies through the measurement of the classical Dupuit's surplus, i.e. in the modern formulation the Equivalent Variation of Income (EVI) or the Compensating Variation of Income (CVI). It is well acknowledged that surplus is to be preferred to changes in GDP or changes in Households' Final Consumption because these aggregates are measured at constant prices, according to the methods of National Accounting, and do not capture a main effect of climate change policies that is the change in the structure of prices. Moreover, it is highly informative to split the welfare costs in its three components: the Deadweight Loss of Taxation (DWL), the Gains from Terms of Trade (GTT) and the net revenue resulting from the trade of of emission certificates (CE).

Decomposition of the welfare costs is a complex issue that has been addressed in the literature, mainly by Böhringer and Rutherford (2002, 2004) in the case of climate change policy, and by Harrison, Horridge, and Pearson (2000) in a more general framework. In this study, we aim at an approximate decomposition providing for a general idea of the relative importance of each component. This is justified by the fact that the changes in prices, in particular the prices of foreign trade, are fairly small. Table 10 presents the various steps allowing for the decomposition. In practice, we first calculate the surplus in line with the specification of the utility function. Then we approximate the GTT and calculate CE, to finally obtain the DWL by difference between the welfare gains and GTT plus CE[12].

12 Calculation of the DWL is required in order to determine the true marginal cost of abatement (i.e. the welfare loss for a unit additional abatement). This marginal cost of abatement differs from the one usually represented in marginal abatement curves, which in fact represents the carbon tax associated to each level of abatement, when there are distortions (fiscal or economic) in the economy.

Table 10: Measurement and Components of Welfare

$$S = R - \Delta CVI$$

Total Welfare Gain = Variation of Income − Compensative Variation of Income

$$= -DWL + GTT + CE$$

= −Deadweight Loss of Taxation + Gains from Terms of Trade + Net Trade of Certificates

$$GTT = \sum Exp_0 \Delta Pexp - \sum Imp_0 \Delta Pimp$$

SUMMARY

In the framework of the revision of the Swiss CO_2-Law and in the preparation of the international negotiations that place at the Conference of the Parties to the United Nations Framework Convention on Climate Change, the Swiss Government has proposed a set of instruments and two levels of abatement to define the Swiss climate policy for the post-2012 period. By 2030, Switzerland would recuce its GHG emission by 30% or 45%, depending on whether or not the rest of the world world would commit to strong emissions reductions. The proposed policies are the result of consultation procedures take into account the views of major stakeholders and lobbies and allow for differienciated carbon prices in different sectors of the Swiss economy. Linking a Cumputable General Equilibrium (CGE) and two sectoral energy models, we evaluate the policies for the two scenarios. We find important disparities in the prices of carbon faced by the different economic sectors and higher welfare costs than those that would be triggered by a uniform carbon tax.