ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Research group on the Economics and Management of the Environment (REME)

Final Report

Assessment of the economic impacts of the revision of the Swiss CO_2 law with a hybrid model

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August 20, 2009

Acknowledgements

This work has been undertaken with the support of NSF-NCCR climate and FOEN grants.

We are very grateful to Martin Peter, Carsten Nathani and the Federal Office of Statistics for providing us with disaggregated input-output tables as well as to Hal Turton, Nicolas Weidmann and Thorsten F. Schulz from the Paul Sherrer Institute for their help with the Swiss MARKAL models.

We would also like to thank Jacqueline Hug from FOEN for her availability and skilled advice as well as for providing all the required information in a transparent and timely manner.

Abbreviations

BAU	Business As Usual
CDM	Clean Development Mechanism
CER	Certified Emission Reductions
CES	Constant Elasticity of Substitution
CHF	Swiss Franc
CO2	Carbon dioxide
CO2eq	Carbon dioxide equivalent (calculates on the basis of global warming potential)
DWL	Deadweight Loss of Taxation
ETS	Swiss Emission Trading Scheme
EU	European Union
EU ETS	European Emission Trading Scheme
EUA	EU Allowances
FOEN	Federal Office for the Environment
G	Giga (10^9)
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GTT	Gains from Terms of Trade
IOT	Input-Output Table
IPCC	Intergovernmental Panel on Climate Change
J	Joule
JI	Joint Implementation
Mio. / M	Million / Mega (10^6)
NOGA	Nomenclature Générale des Activités économiques
P	Peta (10^{15})
SECO	Secretariat of Economic Affairs
SFOE	Swiss Federal Office of Energy
t	Ton
T	Tera (10^{12})
USD	United States Dollar

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Chapter 1

Executive summary (French)

Cette étude conduite par le laboratoire de Recherches en Économie et Management de l'Environnement (RÉME) de l'EPFL pour l'Office Fédéral de l'Environnement (OFEV) a pour but d'évaluer les impacts économiques des propositions de révision de la loi suisse sur le CO_2 pour la période post-Kyoto.

A cet effet nous avons tout d'abord mené une modélisation spécifique et originale visant à coupler un modèle d'équilibre général calculable mondial (le modèle GEMINI-E3 (Bernard and Vielle, 2008)) et deux modules de représentation technologique du système énergétique suisse issus du modèle MARKAL Suisse (Schulz, 2007). L'intérêt de ce couplage est de palier aux faiblesses respectives des deux modèles et d'intégrer dans cette modélisation :

- Une représentation de l'environnement international et en particulier des politiques climatiques qui pourraient voir le jour et de déterminer ainsi un prix international du CO_2 auquel pourrait faire face la Suisse;
- Un couplage macro-économique complet permettant de prendre en compte l'ensemble des interactions d'une politique climatique suisse transitant par le bouclage des revenus et par les interactions entre secteurs économiques (effets directs et indirects intersectoriels);
- Une représentation technologique des secteurs du transport et du résidentiel dont on sait qu'ils représentent en Suisse une part importante des émissions et donc un réel enjeu. Cette modélisation permet outre de prendre en compte plus précisément les politiques sectorielles envisagées, d'intégrer les générations d'équipements existants et les nouvelles technologiques qui pourraient se développer compte tenu d'un prix du carbone significatif.

Les scénarios retenus ont été définis en étroite collaboration avec l'OFEV et distinguent deux scénarios internationaux de politique climatique :

- Le premier scénario suppose qu'un accord international de faible ampleur serait atteint sur la période 2009-2050, conduisant en 2050 à des émissions mondiales supérieures de 70% par rapport à celles de 2001;
- Le second scénario suppose une mobilisation accrue de toutes les parties prenantes à la négociation climatique conduisant à une baisse de 12% en 2050 des émissions mondiales par rapport aux émissions de 2001.[1]

Compte tenu de ces scenarios internationaux, il a été supposé que la Suisse adaptait sa politique climatique en conséquence. Nous avons cherché à coller au plus près des propositions suisses et dans chacun des scénarios les instruments suivant ont été implémentés :

- Un marché de droits d'émission négociables est mis en place pour les secteurs intensifs en énergie à l'image du système européen défini dans le cadre de la directive climat énergie (Européenne, 2008). De plus, nous avons retenu pour ces secteurs la possibilité d'acheter des certificats internationaux de réduction d'émissions de CO_2 dans des proportions cependant limitées;
- Concernant le secteur des transports un prélèvement est mis en œuvre au niveau des importations d'hydrocarbures pour financer l'achat de certificats internationaux de réduction d'émissions de CO_2;
- Pour les autres secteurs et notamment le secteur résidentiel une taxe sur les combustibles fossiles est mise en place pour obtenir un objectif de baisse des émissions de CO_2.
- Nous supposons de plus la mise en place de deux politiques sectorielles visant :
  - Un financement d'une réduction des émissions CO_2 dans le secteur résidentiel (payé au moyen d'une partie du revenu de la taxe sur les combustibles fossiles);
  - Une valeur cible pour les emission de CO_2 des nouvelles voitures immatriculées.

[1]La faiblesse apparente des réductions d'émissions au niveau mondial s'explique en grande partie par les augmentations d'émissions attendues dans les pays en voie de développement. Dans le scénario de base, leurs émissions augmentent de 73% d'ici à 2020 et de 204% d'ici à 2050 (par rapport à 2001) . De plus, il n'est envisagé dans aucun des scénarios que ces pays se voient attribuer des réduction d'émissions avant 2030.

Le tableau 1.1 résume les différentes mesures retenues dans ces deux scénarios pour la Suisse. Ces mesures ayant pour but de permettre une réduction des émissions de 20% dans le premier scénario et de 30% dans le second. Elles assurent aussi qu'une part important de l'abattement se fasse en Suisse.

Table 1.1: Objectifs de réductions pour la Suisse (% des émissions de 1990)

	Scénario 1		Scénario 2	
	2020	2050	2020	2050
ETS[a]	-1.75 % p.a.		-2.9 % p.a.	
Max. Certif.	40%		50%	
Transports[b]	-25%	-75%	-40%	-100%
Régulation techniques pour voitures	valeur cible sur les émissions moyennes des nouvelles voitures [c]			
Combustibles[b]	-25%	-50%	-35%	-80%
Programme résidentiel (2010-2020)	200 Mio CHF p.a. [d]			
Max. de certificats[b](% of 1990 GES)	9%	25%	14%	36%

[a] Débute en 2013 sur la base des emissions moyennes de la période 2008-2012
[b] Les valeurs des objectif sont atteintes par des accroissement linéaire sur les périodes 2010-2020 et 2020-2050.
[c] Modélisé comme une interdiction des voitures *standard* à partir de 2015
[d] Modélisé comme une subvention sur les coûts de rénovation (technologies d'économie d'énergie)

Les résultats des deux scénarios sont résumés dans le tableau 1.2.

Les principaux résultats des deux scénarios sont les suivants pour l'année 2020 :

- Le prélèvement sur le secteur des transports serait limité et situé dans une fourchette allant de 1.15 CHF/tCO_2eq à 4.52 CHF/tCO_2eq selon le scénario retenu, ce qui équivaudrait à environ 0.25 ou 1 centime de CHF par litre de carburant;
- Pour le secteur ETS ce prix serait de 12 CHF/tCO_2eq à 28 CHF/tCO_2eq selon le scénario, soit un prix inférieur à celui estimé pour l'ETS européen (cf. Commission of the European Communities, 2007);
- La taxe sur les autres secteurs et en particulier dans le secteur résidentiel serait au contraire très élevée et située dans un intervalle allant de 213 CHF/tCO_2eq à 468 CHF/tCO_2eq;
- Les achats de certificats étrangers par les secteurs des transports et ETS n'atteindraient pas les limites fixées dans les scénarios, ce qui implique que le secteur des transports ne serait pas soumis à une taxe additionelle;

Table 1.2: Principaux résultats économiques

Scénario 1	2013	2015	2020
Prélèvement transport[a]	0.07	0.25	1.15
Taxe sur les combustibles[a]	57.51	91.43	212.94
Prix des droits d'émissions ETS[a]	1.26	3.20	12.29
Prix des certificats mondiaux[a]	1.26	2.10	4.44
PIB volume (% baseline)	-0.09%	-0.14%	-0.26%
Surplus des ménages (%CF)	-0.52%	-0.58%	-0.56%

Scénario 2	2013	2015	2020
Prélèvement transport[a]	0.39	1.09	4.52
Taxe sur les combustibles[a]	74.35	153.08	467.85
Prix des droits d'émissions ETS[a]	3.89	10.10	27.86
Prix des certificats mondiaux[a]	3.50	5.50	11.14
PIB volume (% baseline)	-0.09%	-0.16%	-0.33%
Surplus des ménages (%CF)	-0.55%	-0.63%	-0.71%

[a] CHF_{2008}/tCO_2eq

- Le coût macro-économique, qu'il soit exprimé en terme de variation de PIB ou de surplus, serait modéré; dans le cas le plus défavorable, en 2020, il serait égal à une baisse de 0.33% du PIB ou à une perte de surplus évaluée à 0.71% de la consomation finale (CF).
- La modélisation du programme résidentiel influence grandement les estimations de taxe sur les combustibles. En effet, si l'effet du programme résidentiel est considéré exogène et permettant une réduction des émissions allant jusqu'à 2.2MtCO_2 en 2020, la valeur de la taxe en 2020 ne serait plus que de 59 CHF/tCO_2eq dans le premier scénario alternatif et de 214 CHF/tCO_2eq dans le second alternatif.

Compte tenu de ces résultats nous pouvons tirer les enseignements suivants:

- Le cloisonnement des marchés (transports, ETS et autre secteurs) conduit à des différences de prix du CO_2 qui, selon la théorie économique, sont sources d'inefficacités. Il a donc un réel gain à faire converger ces prix. De plus, l'inclusion des autres gaz à effet de serre dans la politique climatique permettrait aussi de réduire les coûts d'abattement tout en maintenant des objectifs équivalents.
- L'ouverture de l'ETS Suisse à l'ETS européen, qui ne semble ici pas nécessaire compte tenu du prix du carbone dans l'ETS Suisse, peut cependant être conseillée.

Elle permettrait à la Suisse de bénéficier d'un marché beaucoup plus important et de limiter ainsi les risques de variations du prix du droit d'émission dont sont caractérisés les marchés d'ampleur limitée, que cela soit au niveau des acteurs ou de la taille du marché en tonnes de CO_2;

- Les scénarios retenus pour la Suisse ne supposent pas de taxation ou d'action en faveur de la réduction des gaz à effet de serre autres que le CO_2 alors que l'on sait qu'il existe de réelles possibilités d'abattement de ces gaz à des coûts faibles (van Vuuren et al., 2006; Weyant et al., 2006), en particulier pour les gas issus de processus industriels comme les gas fluorés. Dans ces conditions il serait peut-être bon d'intégrer partiellement ou totalement ces gaz dans les mesures visant à atteindre les objectifs helvétiques;

- La modélisation du programme résidentiel a aussi des consequences importantes sur la valeur de la taxe sur les combustibles ainsi que sur les effets économiques des politiques. Dans notre modélisation principale, le programme résidentiel ne permet de réduire les émissions que de 0.3 $MtCO_2$ contre les 2.2 $MtCO_2$ estimées pas l'office fédéral de l'énergie (OFEN). Une différence partiellement imputable à la différence d'étendue du programme résidentiel qui se limite aux technologies de préservation de l'énergie dans notre modèle, alors qu'il inclut des mesures de promotion des énergies renouvelables dans le modèle de l'OFEN. Dans un exercice parallèle, forçant artifiellement une baisse des émissions aux valeurs estimées pas l'OFEN, la valeur de la taxe pour 2020 descend respectivement à 59 et 214 CHF_{2008}/tCO_2eq pour chacun des deux scenarios. Les effets sur le PIB et le surplus sont bien évidement aussi plus faibles.

- Enfin, il faut noter que le prix du permis du CO_2 international est très dépendant des hypothèses de participation des pays en développement, l'hypothèse d'une participation totale retenue pour la période 2009-2020 est peut-être quelque peu optimiste au regard de l'évolution de la négociation internationale. La non participation de ces pays, même au mécanisme de développement propre, pourrait impacter fortement le prix du certificat et dans ces conditions augmenter le coût pour la Suisse de la mise en place de sa politique de lutte contre le réchauffement climatique.

Chapter 2

Final report

2.1 Introduction

In Switzerland, as in many other OECD countries, transportation and housing are responsible for the major part of greenhouse gas (GHG) emissions. In the framework of the assessment of the policies envisaged in Switzerland for the revision of the CO_2-Law for the post-2012 period, the Federal Office for the Environment (FOEN) expressed its interest in having a detailed modeling of both transportation and housing sectors in order to precisely evaluate the economic impacts of the future policies. In earlier studies (see Sceia et al. (2008) and Sceia et al. (2009)) the EPFL had undertaken similar evaluations, coupling the GEMINI-E3 model, a worldwide CGE model, with MARKAL-CHRES, an energy model describing the Swiss residential energy system. In this report we present an hybrid model with a detailed technological representation of both residential and transportation sectors as well as its use to assess the policies considered after the consultation procedure of the revision of the Swiss CO_2-Law.

This report is organized as follows: section 2.2 presents the models and the methodology, section 2.3 presents the baseline scenario, section 2.4 and 2.5 present the policy scenarios and their respective results and section 2.6 concludes.

2.2 Methodology

2.2.1 GEMINI-E3

We use an aggregated version of GEMINI-E3, a dynamic-recursive CGE model with a highly detailed representation of indirect taxation, that represents the world economy in 6 regions and 18 sectors[1]. For Switzerland, we extend the number of sectors to 29 in order to precisely present the transportation sector. The sectors replacing the original "transport nec", "sea transport" and "air transport" are presented in table 2.1. We define the regions as follows: Switzerland (CHE), European Union (EUR)[2], other European and Euro-asian countries (OEU)[3], Japan (JAP), USA, Canada, Australia and New Zealand (OEC) and other countries, mainly developing countries (DCS). The model is formulated as a Mixed Complementarity Problem which is solved using GAMS and the PATH solver (Ferris and Munson, 2000; Ferris and Pang, 1997). GEMINI-E3 is built on a comprehensive energy-economy data set, the GTAP-6 database (Dimaranan, 2007) that provides a consistent representation of energy markets in physical units and a detailed Social Accounting Matrix (SAM) for a large set of countries or regions and bilateral trade flows between them. Moreover, we complete the data from the GTAP database with information on indirect taxation, energy balances and government expenditures from the International Energy Agency (International Energy Agency, 2002a,b, 2005), the OECD (OECD, 2005, 2003) and the International Monetary Fund (IMF, 2004). For Switzerland, we use data from the 2001 input-output table devised at the Swiss Federal Institute of Technology (ETH) in Zürich (Nathani et al., 2006) as well as the transportation disaggregation performed in Infras (2006) and transform it to the GEMINI-E3 format (Sceia et al., 2009). Data on emissions and abatement costs for non CO_2 GHG comes from the U.S. Environmental Protection Agency (United States Environmental Protection Agency, 2006).

Previously, GEMINI-E3 has been used to study the strategic allocation of GHG emission allowances in the enlarged EU market (Viguier et al., 2006), to analyze the behavior of Russia with regard to the ratification process of the Kyoto Protocol (Bernard et al., 2003), to assess the costs of implementation of the Kyoto protocol in Switzerland with and without international emissions trading (Bernard et al., 2005) and to assess the effects of an increase of oil prices on global GHG emissions (Vielle and Viguier, 2007).

Apart from a comprehensive description of indirect taxation, the specificity of the model is that it simulates all relevant markets: commodities (through relative prices), labor (through wages) as well as domestic and international savings (through 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 are also accurately modeled. GEMINI-E3 also calculates the deadweight loss for each region on the basis of the consumers' surplus and the gains or losses from the terms of trade.

[1]The complete GEMINI-E3 represents the world economy in 28 regions (including Switzerland) and 18 sectors (see table A.1 in appendix A for the detailed classification). All information about the model can be found at http://www.gemini-e3.net, including its complete description (Bernard and Vielle, 2008).

[2]Refers to the European Union Member States as of 2008.

[3]Includes other European countries, Russia and the rest of the Former Soviet Union excluding Baltic States.

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.

In order to calibrate and couple GEMINI-E3 with MARKAL-CHRES and MARKAL-CHTRA, we have replaced the Stone-Geary utility function by a nested constant elasticity of substitution (CES) function and modified the existing CES production function. The nesting structures are presented in chapter 2.2.1 and 2.2.1. The complete and aggregated GEMINI-E3 dimensions are presented in appendix A table A.1.

We have also included an international emission certificates market that allows to model a global cap and trade system. Each region receives annually a free endowment of emission certificates, equal to the emission policy target. Moreover, in Switzerland, we have implemented a tax on heating fuels, a levy on transport fuels aimed at financing the purchase of foreign emissions certificates as well as an Emissions Trading Scheme (ETS) for energy intensive sectors (not linked to the EU-ETS).

New transportation sectors

In order to better represent the Swiss transport sector in GEMINI-E3 and allow the coupling with a transport energy model for Switzerland, we use a disaggregation of the three original transport sectors (land, air and maritime) into 14 sectors (see table 2.1). The disaggregation affects two of the original sectors, i.e. "transport nec" (12) and "services" (17). The numbering of the new sectors allows to identify how the new transport sectors were originally aggregated.

Table 2.1: Transport sectors

Code	Transport sectors	Code	Transport sectors
12a	Rail infrastructure	14	Air transport
12b	Rail passenger transport	17d	Road infrastructure
12c	Rail goods transport	12e	Road commercial passenger transport
12d	Other public transport	12f	Road goods transport
13	Water transport	12g	Road goods own transport
17b	Water transport infrastructure	12h	Pipeline
17c	Air transport infrastructure	17e	Other transport help, support and intermediaries

Infrastructure This version of the model specifically describes the various transport infrastructures (roads, railway lines, ports and canals as well as airports) as specific economic sectors. This differentiation allows, in particular, for adequate accounting of the use of road infrastructure, which, in other studies (e.g. Paltsev et al., 2004), is paid through fuel taxes.

Own transport Numerous companies perform a part or all of their transport on their own account, i.e. without calling upon services of transport companies. In a standard input-output matrix, this activity is accounted as an intermediate input from a sector to itself. The own transport activity also requires specific inputs (e.g. vehicles and fuel), which are traditionally spread across the sectors using them. To the contrary, the transport disaggregation we use represents the own transport as a separate sector and, therefore, allows for an adequate modeling of the substitution possibilities between purchased and own transport services.

International trade and transport Since we have a disaggregated representation of the transport sectors only in Switzerland, we need a special procedure to link the exports and imports of those sectors with the rest of the international trade which is at a more aggregated level. Furthermore, the model explicitly calculates the transport margins related to the international trade and allocates them to the adequate transport sectors. We have modified the equations related to international trade and international transport margins, allowing for the disaggregation of imports and trade margins and the aggregation of exports. In the following equations, i indexes the 29 sectors in Switzerland (CHE) whereas j is the index of the 18 sectors used in all other regions (r). The sectors $12a, \ldots, 12h$ are aggregated into sector 12 and sectors $17a, \ldots, 17e$ are aggregated into sector 17.

As in the standard GEMINI-E3, imports (M_{ir}) are computed from total demand according to the Armington assumption (Armington, 1969):

$$M_{iCHE} = Y_{iCHE} \cdot \lambda^x_{iCHE} \cdot (1 - \alpha^x_{iCHE}) \cdot \left[\frac{PY_{iCHE}}{\lambda^x_{iCHE} \cdot PI_{iCHE} \cdot \left(1 + \kappa^i_{iCHE}\right)} \right]^{\sigma^x_{ir}} \quad (2.1)$$

where σ^x_{iCHE}, α^x_{iCHE} and λ^x_{iCHE} represent the CES parameters, respectively the elasticity of substitution, the share parameter and the technology shifter, PY_{iCHE} is the price of composite good, PI_{iCHE} the price of import and κ^i_{iCHE} the duty rate. The import prices are defined as follows:

$$PI_{iCHE} = \lambda^i_{iCHE} \cdot \left[\sum_r \alpha^i_{irCHE} \cdot \left[\sum_j (\Phi_{jirCHE} \cdot PX_{jr} \cdot (e_r / e_{CHE})) \right]^{1-\sigma^i_{iCHE}} \right]^{\frac{1}{1-\sigma^i_{iCHE}}} \tag{2.2}$$

with PX_{jr} being the price of exports of the aggregate good j, e_r is the exchange rate and Φ an aggregation/dissaggregation matrix of the form:

$$\Phi_{jirCHE} = \begin{bmatrix} 1 & & & & & & & & \\ & \ddots & & & & & & \mathbf{0} & \\ & & 1 & & & & & & \\ & & & \underbrace{1 \cdots 1}_{12a \cdots 12g} & & & & & \\ & & & & 1 & & & & \\ & & & & & \ddots & & & \\ & \mathbf{0} & & & & & 1 & & \\ & & & & & & & \underbrace{1 \cdots 1}_{17a \cdots 17e} & \\ & & & & & & & & 1 \end{bmatrix} \tag{2.3}$$

$$\Phi_{ijCHEr} = \begin{bmatrix} 1 & & & & & & & & \\ & \ddots & & & & & & & \\ & & 1 & & & & & & \\ & & & \phi_{12a} & & & & & \\ & & & \vdots & & & & \mathbf{0} & \\ & & & \phi_{12g} & & & & & \\ & & & & 1 & & & & \\ & & & & & \ddots & & & \\ & & & & & & 1 & & \\ & & & & & & & \phi_{17a} & \\ & \mathbf{0} & & & & & & \vdots & \\ & & & & & & & \phi_{17e} & \\ & & & & & & & & 1 \end{bmatrix} \tag{2.4}$$

ϕ_{12x} and ϕ_{17x} being the shares of exports of the various new sectors over the original sectors 12 and 17.

Imports are then computed by origins (MR_{iCHEr}) with an another CES function:

$$MR_{iCHEr} = M_{iCHE} \cdot \lambda^{i}_{iCHE} \cdot \alpha^{i}_{iCHEr} \cdot \left[\frac{PI_{iCHE}}{\lambda^{i}_{iCHE} \sum_j (\Phi_{jirCHE} \cdot PX_{jr} \cdot (e_r/e_{CHE}))} \right]^{\sigma^{i}_{ir}} \tag{2.5}$$

.

Exports are calculated as follows:

$$EX_{iCHE} = \sum_h MR_{iCHEh} \tag{2.6}$$

and the price of Swiss exports on the international market are calculated with the following formula:

$$PX_{jCHE} = \sum_i (\Phi_{ijCHEr} \cdot PB_{iCHE} \cdot (1 + \kappa^{x}_{iCHE})) \tag{2.7}$$

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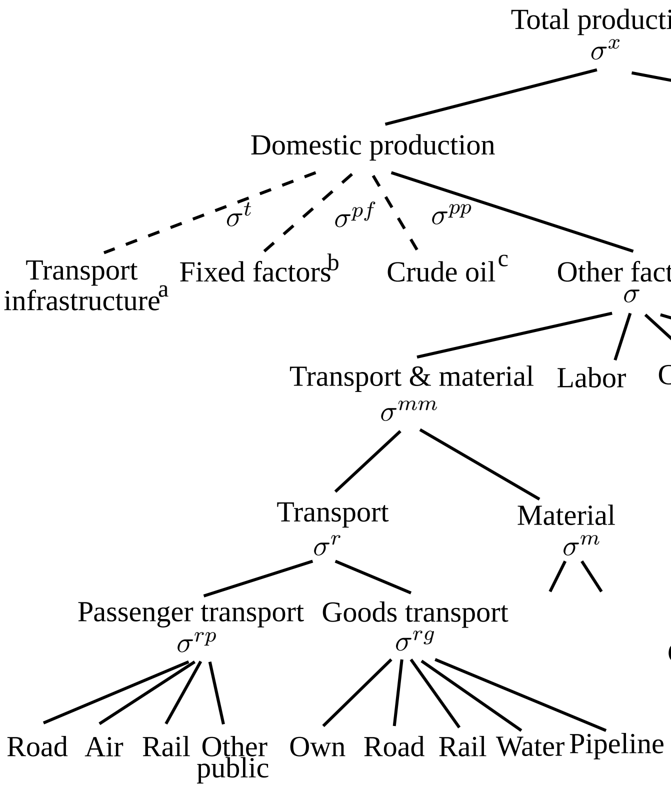
Revised production functions

As explained in chapter 2.2.1, the Swiss transport sector has been disaggregated for the sake of this analysis and in order to allow for the coupling with a bottom-up model. Consequently, the Swiss CES production function is slightly different from those in the other regions (see Bernard and Vielle, 2008). Figure 2.1 presents the Swiss nested CES production function. The σ^x refer to the elasticity parameter of each node (values can be found in table A.2 and in Bernard and Vielle, 2008). The major differences between these nested CES functions and those used for other regions are, firstly, the presence of the infrastructure at the top level for the transport sectors, secondly, the disaggregation of transport into passenger and freight transport and, thirdly, the detailed disaggregation of the freight and passenger transport nest.

In the mathematical formulation, the following equations have to be modified or included in the model. For the Swiss transport sectors, other than the infrastructure sectors, the domestic production (XDT_{iCHE}) is equal to

$$XDT_{iCHE} = Y_{iCHE} \cdot \lambda^{x}_{iCHE} \cdot \alpha^{x}_{iCHE} \cdot \left[\frac{PY_{iCHE}}{\lambda^{x}_{iCHE} \cdot PDT_{iCHE}} \right]^{\sigma^{x}_{iCHE}}$$
$$, \forall i = 12b, 12c, 12d, 13, 14, 12e, 12f, 12h \tag{2.8}$$



[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.

Figure 2.1: Structure of the Swiss nested CES production function

where the variables and parameters are the same as in equation 2.1. Then, the domestic production of transport sectors is separated in the intermediate consumption of the relevant infrastructure (IC_{ikCHE}, with k=12a,16c,16a and 16b) and an aggregate of other inputs (X_{ir}) through other CES functions, which vary slightly according to the mode of transport.

The infrastructure intermediate consumption is calculated as:

$$IC_{ikCHE} = XDT_{iCHE} \cdot \lambda^{pi}_{iCHE} \cdot (1 - \alpha^{pi}_{iCHE}) \cdot \left[\frac{PDT_{iCHE}}{\lambda^{pi}_{iCHE} \cdot PIC_{12aCHE}} \right]^{\sigma^{pi}_{iCHE}} , \forall i = 12b, 12c, 12d, 12e, 12f, 12h, 13, 14 \quad (2.9)$$

with $k = 12a$ for $i = 12b, 12c, 12d$, $k = 16c$ for $i = 12e, 12f, 12h$, $k = 16a$ for $i = 13$ and $k = 16b$ for $i = 14$.

The consumption of other inputs (X_{ir}) is equal to:

$$X_{iCHE} = XT_{iCHE} \cdot \lambda^{pi}_{iCHE} \cdot \alpha^{pi}_{iCHE} \cdot \left[\frac{PDT_{iCHE}}{\lambda^{pi}_{iCHE} \cdot PD_{iCHE}}\right]^{\sigma^{pi}_{iCHE}} , \forall i = 12b, 12c, 12d, 13, 14, 12e, 12f, 12h. \quad (2.10)$$

PDT_{ir} is the price of domestic production for sectors 12b,12c,12d,13,14,12e,12f and 12h, PIC_{iCHE} the price of the intermediate consumptions of the relevant infrastructure sector, and PD_{iCHE} the price of other inputs. PDT_{iCHE} is therefore calculated as follows:

$$PDT_{iCHE} = \lambda^{pi}_{iCHE} \cdot \left[\alpha^{pi}_{iCHE} \cdot PD^{1-\sigma^{pi}_{iCHE}}_{iCHE} + (1 - \alpha^{pi}_{iCHE}) \cdot PIC^{1-\sigma^{pi}_{iCHE}}_{ikCHE}\right]^{\frac{1}{1-\sigma^{pi}_{iCHE}}} , \forall i = 12b, 12c, 12d, 13, 14, 12e, 12f, 12h \quad (2.11)$$

with the index k refereing to the infrastructure sector relevant for the mode of transport.

The second difference, is at the level of the transport nest itself, where for all regions the aggregated transport (TR_{ir}) is spited into sectors 12 to 14, whereas for Switzerland we first differentiate between passenger and goods transport using the following CES functions:

$$PATR_{iCHE} = TR_{iCHE} \cdot \lambda^{r}_{iCHE} \cdot \alpha^{r}_{iCHE} \cdot \left[\frac{PTR_{iCHEr}}{\lambda^{r}_{iCHE} \cdot PPATR_{iCHE} \cdot}\right]^{\sigma^{r}_{iCHE}} \quad (2.12)$$

$$GOTR_{iCHE} = TR_{iCHE} \cdot \lambda^{r}_{iCHE} \cdot (1 - \alpha^{r}_{iCHE}) \cdot \left[\frac{PTR_{iCHEr}}{\lambda^{r}_{iCHE} \cdot PGOTR_{iCHE} \cdot}\right]^{\sigma^{r}_{iCHE}} \quad (2.13)$$

The prices of the various nests are calculated as follows:

$$PTR_{iCHE} = \lambda^{r}_{iCHE} \cdot \left[\alpha^{r}_{kiCHE} \cdot PPATR^{1-\sigma^{r}_{iCHE}}_{kiCHE} + (1 - \alpha^{r}_{kiCHE}) \cdot PGOTR^{1-\sigma^{r}_{iCHE}}_{kiCHE}\right]^{\frac{1}{1-\sigma^{r}_{iCHE}}} \quad (2.14)$$

$$PPATR_{iCHE} = \lambda^{rp}_{iCHE} \cdot \left[\sum_{k=12b,12d,12e,14} \alpha^{rp}_{kiCHE} \cdot PIC^{1-\sigma^{rp}_{iCHE}}_{kiCHE} \right]^{\frac{1}{1-\sigma^{rp}_{iCHE}}} \tag{2.15}$$

$$PGOTR_{iCHE} = \lambda^{rp}_{iCHE} \cdot \left[\sum_{k=12c,12f,12g,12h,13} \alpha^{rp}_{kiCHE} \cdot PIC^{1-\sigma^{rp}_{iCHE}}_{kiCHE} \right]^{\frac{1}{1-\sigma^{rp}_{iCHE}}} \tag{2.16}$$

Finally, the goods and passenger transport sectors are allocated to the new transport sectors with the following formulas:

$$IC_{kiCHE} = PATR_{iCHE} \cdot \lambda^{rp}_{iCHE} \cdot \alpha^{rp}_{kiCHE} \cdot \left[\frac{PPATR_{iCHE}}{\lambda^{rp}_{iCHE} \cdot PIC_{kiCHE} \cdot} \right]^{\sigma^{rp}_{iCHE}} \forall k = 12b, 12d, 12e, 14 \tag{2.17}$$

$$IC_{kiCHE} = GOTR_{iCHE} \cdot \lambda^{rg}_{iCHE} \cdot \alpha^{rg}_{kiCHE} \cdot \left[\frac{PGOTR_{iCHE}}{\lambda^{rg}_{iCHE} \cdot PIC_{kiCHE} \cdot} \right]^{\sigma^{rg}_{iCHE}} \forall k = 12c, 12f, 12g, 12h, 13 \tag{2.18}$$

Revised final consumption

Figure 2.2 presents the Swiss nested CES utility function. Similarly to the production function, it differs from other regions at the level of the transportation sectors in view of the increased disaggregation of the transport sectors in Switzerland. First, the transport consumption is composed of passenger and goods transport. Secondly, the passenger transport is either private or purchased. Thirdly, the private transportation, i.e. private cars, is separated in consumption of road infrastructure and other goods and services, namely equipments and energy. Finally, goods transport, purchased passenger transport and energy used in transport are aggregates of sectors {12b,12d,12e,14}, {12c,12f,12g,13} and {3,4,5} respectively.

The residential side of the households' consumption is calculated as in Sceia et al. (2009) but the transport nest is calculated as follows.

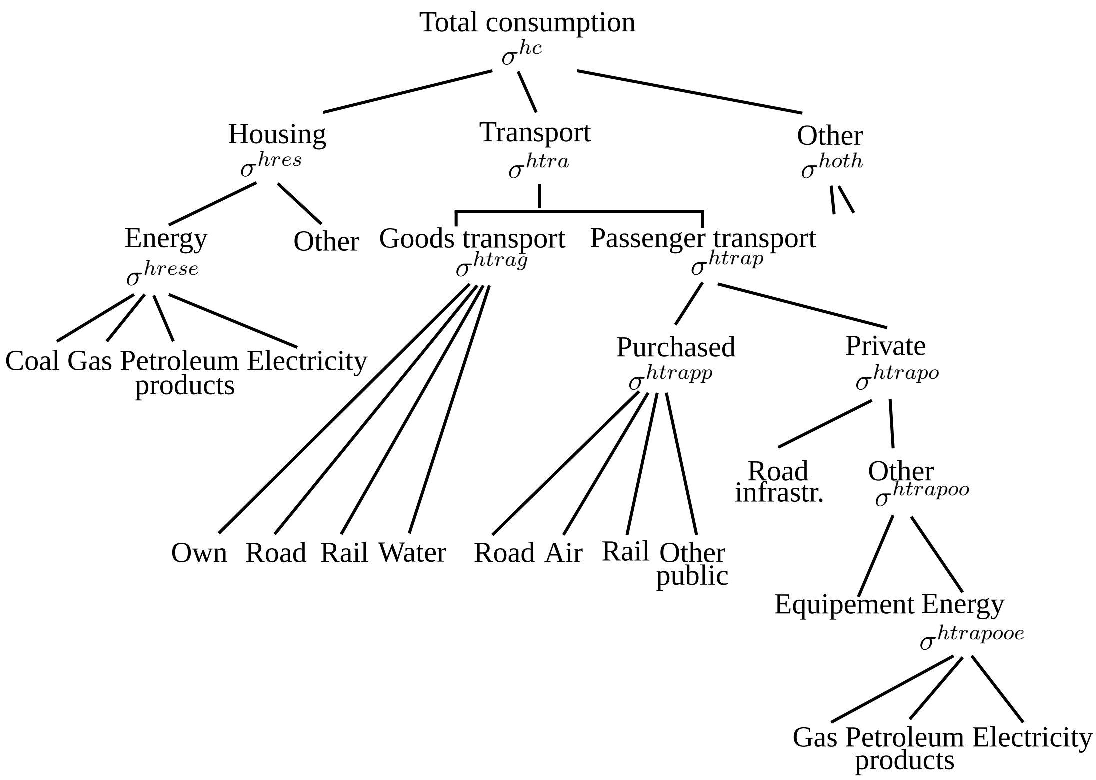


Figure 2.2: Structure of the households' nested CES utility function

The consumption of the transportation aggregated good ($HCTRA$) equals:

$$HCTRA_{CHE} \cdot {\theta_{CHE}^{hct}}^{t} = HCT_{CHE} \cdot \lambda_{CHE}^{hct} \cdot \alpha_{CHE}^{hct} \cdot \left[\frac{PCT_{CHE}}{PCTRA_r \cdot \lambda_{CHE}^{hct} \cdot {\theta_{CHE}^{hct}}^{t}} \right]^{\sigma_{CHE}^{hc}}, \tag{2.19}$$

where θ_r^{hct} is the technical progress of the transport nest, HCT the total aggregated consumption, PCT the price of the aggregated consumption and $PCTRA$ the price of the transport aggregated good.

The consumption of the aggregated goods transport ($HCTRAG$) and aggregated passenger transport ($HCTRAP$) are calculated as:

$$HCTRAG_{CHE} \cdot {\theta_{CHE}^{htrag}}^{t} = HCTRA_{CHE} \cdot \lambda_{CHE}^{htra} \cdot \alpha_{CHE}^{htra} \cdot \left[\frac{PCTRA_{CHE}}{PCTRAG_{CHE} \cdot \lambda_{CHE}^{htra} \cdot {\theta_{CHE}^{htrag}}^{t}} \right]^{\sigma_{CHE}^{htra}}, \tag{2.20}$$

$$HCTRAP_{CHE} \cdot {\theta_{CHE}^{htrag}}^{t} = HCTRA_{CHE} \cdot \lambda_{CHE}^{htra} \cdot (1 - \alpha_{CHE}^{htra}) \cdot \left[\frac{PCTRA_{CHE}}{PCTRAP_{CHE} \cdot \lambda_{CHE}^{htra} \cdot {\theta_{CHE}^{htrag}}^{t}} \right]^{\sigma_{CHE}^{htra}}, \tag{2.21}$$

where θ_{CHE}^{htrag} is the technical progress of the goods transport nest, θ_{CHE}^{htrap} the technical progresses of the passenger transport nest, and $PCTRAG_{CHE}$ is the price of the goods transport aggregated good and $PCTRAG_{CHE}$ the price of the passenger transport aggregated good. The aggregated goods transport is disaggregated into the consumption of the various sectors assumed to undertake only goods transport, i.e. 13, 12c, 12f, 12g and 12h, using the following formula.

$$HC_{iCHE} = HCTRAG_{CHE} \cdot \lambda_{CHE}^{htrag} \cdot \alpha_{C}^{htrag} HE \cdot \left[\frac{PCTRAG_{CHE}}{PC_{iCHE} \cdot \lambda_{CHE}^{htrag}} \right]^{\sigma_{CHE}^{htrag}}, \forall i = 13, 12c, 12f, 12g, 12h, \tag{2.22}$$

The aggregated passenger transport is separated into purchased and own passenger transport:

$$HCTRAPP_{CHE} \cdot {\theta_{CHE}^{htrag}}^{t} = HCTRAP_{CHE} \cdot \lambda_{CHE}^{htrag} \cdot \alpha_{CHE}^{htrag} \cdot \left[\frac{PCTRAP_{CHE}}{PCTRAPP_{CHE} \cdot \lambda_{CHE}^{htrag} \cdot {\theta_{CHE}^{htrag}}^{t}} \right]^{\sigma_{CHE}^{htrag}}, \tag{2.23}$$

$$HCTRAPO_{CHE} \cdot {\theta_{CHE}^{htrag}}^{t} = HCTRA_{CHE} \cdot \lambda_{CHE}^{htrag} \cdot (1 - \alpha_{CHE}^{htrag}) \cdot \left[\frac{PCTRAP_{CHE}}{PCTRAPO_{CHE} \cdot \lambda_{CHE}^{htrag} \cdot {\theta_{CHE}^{htrag}}^{t}} \right]^{\sigma_{CHE}^{htrag}}, \tag{2.24}$$

with $PCTRAPP_{CHE}$ and $PCTRAPO_{CHE}$ the prices of the aggregated purchased passenger transport and own passenger transport goods. The latter is disaggregated into the consumption of the various sectors assumed to undertake solely passenger transport, i.e. 14, 12b, 12d and 12e.

$$HC_{i\,CHE} = HCTRAPP_{CHE} \cdot \lambda_{CHE}^{htrapp} \cdot \alpha_{i\,CHE}^{htrapp} \cdot \left[\frac{PCTRAPP_{CHE}}{PC_{i\,CHE} \cdot \lambda_{CHE}^{htrapp}}\right]^{\sigma_{CHE}^{htrapp}}, \forall i = 14, 12b, 12d, 12e, \tag{2.25}$$

The other purchased transport is then further disaggregated in line with the following formulas:

$$HC_{17d,CHE} \cdot {\theta_r^{17d}}^{CHE} = HCTRAPO_{CHE} \cdot \lambda_{CHE}^{htrapo} \cdot (\alpha_{CHE}^{htrapo}) \cdot \left[\frac{PCTRAPO_{CHE}}{PC_{17d\,CHE} \cdot \lambda_r^{hptrapo} \cdot {\theta_{CHE}^{17d}}^{t}}\right]^{\sigma_{CHE}^{htrapo}}, \tag{2.26}$$

$$HCTRAPOO_{CHE} \cdot {\theta_{CHE}^{htrapoo}}^{t} = HCTRAPO_{CHE} \cdot \lambda_{CHE}^{htrapo} \cdot (1 - \alpha_{CHE}^{htrapo}) \cdot \left[\frac{PCTRAPO_{CHE}}{PCTRAPOO_{CHE} \cdot \lambda_{CHE}^{htrapo} \cdot {\theta_{CHE}^{htrapoo}}^{t}}\right]^{\sigma_{CHE}^{htrapo}}, \tag{2.27}$$

$$HC_{16,CHE}^{tra} \cdot {\theta_r^{tra16}}^{CHE} = HCTRAPOO_{CHE} \cdot \lambda_{CHE}^{htrapoo} \cdot (\alpha_{CHE}^{htrapoo}) \cdot \left[\frac{PCTRAPOO_{CHE}}{PC_{16\,CHE} \cdot \lambda_r^{hptrapoo} \cdot {\theta_{CHE}^{tra16}}^{t}}\right]^{\sigma_{CHE}^{htrapoo}}, \tag{2.28}$$

$$HCTRAPOE_{CHE} \cdot {\theta_{CHE}^{htrapoo}}^{t} = HCTRAPOO_{CHE} \cdot \lambda_{CHE}^{htrapoo} \cdot (1 - \alpha_{CHE}^{htrapoo}) \cdot \left[\frac{PCTRAPOO_{CHE}}{PCTRAPOE_{CHE} \cdot \lambda_{CHE}^{htrapoo} \cdot {\theta_{CHE}^{htrapoe}}^{t}}\right]^{\sigma_{CHE}^{htrapoo}}, \tag{2.29}$$

Moreover, the households transportation consumption of energies ($HC_{i\,CHE}^{tra}$) is calculated as:

$$HC^{tra}_{i\,CHE} = HCTRAPOE_{CHE} \cdot \lambda^{htrapooe}_{CHE} \cdot \alpha^{htrapooe}_{i\,r} \cdot \left[\frac{PCTRAPOE_r}{PC_{i\,CHE} \cdot \lambda^{htrapooe}_{CHE}}\right]^{\sigma^{htrapooe}_{CHE}}, \forall i = 1, \ldots, 5, \quad (2.30)$$

Furthermore, the transportation nest accounts for only a part of the consumption of energy goods as well as services. In order to have the total final consumption in those sectors, we use the following formulas:

$$HC_{i\,r} = HC^{res}_{i\,r} + HC^{tra}_{i\,r}, \forall i = 1, \ldots, 5, \quad (2.31)$$

$$HC_{16\,CHE} = HC^{tra}_{16\,r} + HC^{oth}_{16\,r}. \quad (2.32)$$

Finally, prices are calculated using the same parameters, in line with standard nested CES functions.

2.2.2 MARKAL-CHTRA & MARKAL-CHRES

MARKAL models are perfect-foresight bottom-up energy-system models that provide a detailed representation of energy supply and end-use technologies under a set of assumptions about demand projections, technology data specifications and resource potential (Loulou et al., 2004). The backbone of the MARKAL modeling approach is the so-called Reference Energy System (RES). The RES represents currently available and possible future energy technologies and energy carriers. From the RES, the optimization model chooses the least-cost combination of energy technologies and flows for a given time horizon and given end-use energy demands.

The MARKAL-CHRES and MARKAL-CHTRA are energy models describing the Swiss residential energy system and the Swiss transportation energy system. They are based on the Swiss MARKAL model developed at the Paul Scherrer Institute (PSI) and previously used to analyze the Swiss 2000 Watt Society project (Schulz et al., 2008), among others. MARKAL-CHRES and MARKAL-CHTRA are subsets of the complete Swiss model, being restricted to technologies related to the residential and transportation sectors and treating final energy as being imported with exogenous prices. The models contain respectively 173 and 184 technologies using different energy sources (coal, oil, diesel, gasoline, gas, electricity, wood, pellets and district heat). Resource costs and potentials as well as technology costs, potentials and characteristics vary over time.

Base year (2000) energy demand in MARKAL-CHRES is calibrated to the data of the International Energy Agency (IEA) and Swiss statistics. The model has a time horizon of 50 years until 2050, divided into eleven time steps each with a duration of five years (except the base year). Both MARKAL-CHRES and MARKAL-CHTRA include 14 energy demand segments (see appendix A table A.3 and A.4). For a more detailed description of the technologies used in the MARKAL models, see Schulz (2007).

2.2.3 Coupling

Compared to previous studies (Sceia et al., 2008, 2009), the coupling procedure allowing for linking the models has been amended to allow GEMINI-E3 to calculate taxes according to given emissions profiles. The models are run alternatively while the coupling variables are exchanged between the models, as shown in figure 2.3, until a defined threshold on the variation of the taxes is reached. The coupling procedure also takes into account a residential program which is paid for by a part of the revenue of the CO_2 tax on heating fuels. An additional optimization allows to estimate a discount on the cost of energy saving technologies which is used to model the building program in which the government helps home owners to refurbish their houses or buildings.

Through the exchange of the coupling variables, the coupling procedure ensures the link between the three models. The coupling variables are the fuel mixes of both residential and transportation sectors, the investments in those sectors, the energy prices, taxes and the transport demands.

As in Sceia et al. (2009), the prices of energies from GEMINI-E3 are used to control the price variations in the MARKAL models. Moreover, the fuel mixes and investments simulated by the MARKAL models are used to control the energy uses and spending in equipment and services in GEMINI-E3. On top of that, in order to allow for an adequate modeling of the substitution between the various transport sectors, the demand segments in the MARKAL-CHTRA model could not be assumed to be independent as in the case of the residential sector. Indeed, if it is reasonable to assume that, in Switzerland, the demand of the residential energy services was not significantly affected by the introduction of climate policies, the same does not hold in the transportation sectors in view of the possible modal shift. Therefore, the evolution of the production of the various transportation sectors in GEMINI-E3 is used to control the variation of the transport demand segments in MARKAL-CHTRA.

In view of the different structures of GEMINI-E3 and MARKAL, in particular for the transport sector, we had to define the links between the GEMINI-E3 sectors and the MARKAL-CHTRA demand segments (see table 2.2).

Similarly, the energy demand segments used in the MARKAL-CHTRA models do not match the energy sectors defined in GEMINI-E3 and therefore a correspondence

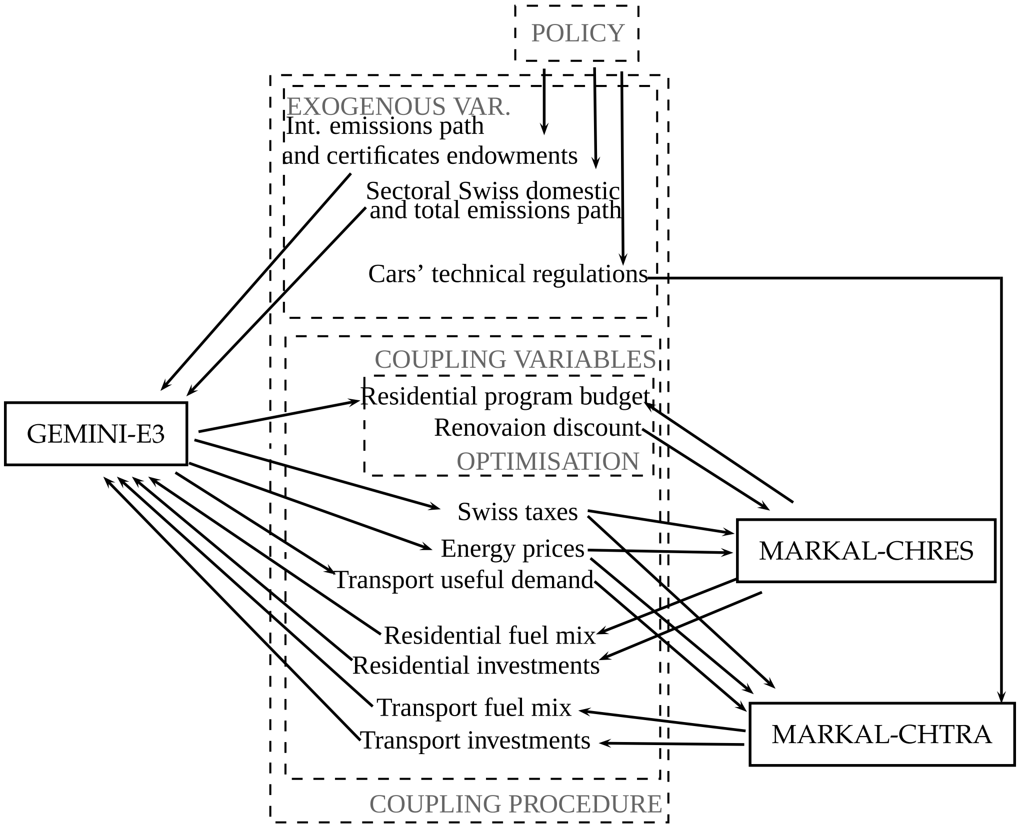


Figure 2.3: Coupling schema

has to be established (see table 2.3).

Table 2.2: Transportation sectors and links to the MARKAL-CHTRA segments

Code	GEMINI-E3 Sector	MARKAL demand segments
12a	Rail infrastructure	
12b	Rail passenger transport	Rail-Passengers
12c	Rail goods transport	Rail-Freight
12d	Other public transport	
13	Water transport	Domestic Internal Navigation, International Navigation
17b	Water transport infrastructure	
17c	Air transport infrastructure	
14	Air transport	Domestic Aviation, International Aviation
17d	Road infrastructure	
12e	Road commercial passenger transport	Road Bus
12f	Road goods transport	Road Medium Trucks
12g	Road goods own transport	Road Medium Trucks
12h	Pipeline	
17e	Other transport help, support and intermediaries	
HC	Households	Road Auto, Road Two Wheels

Table 2.3: Fuels links

MARKAL-CHTRA		GEMINI-E3
AVG	Aviation Gasoline	04 Refined Petroleum
COA	Coal	01 Coal
DST	Diesel	04 Refined Petroleum
ELC	Electricity	05 Electricity
ETH	Ethanol	06 Agriculture[a]
GSL	Gasoline	04 Refined Petroleum
HDN	Hydrogen[b]	–
HFO	Heavy Fuel Oil	04 Refined Petroleum
JTK	Jet Kerosene	04 Refined Petroleum
LPG	Liquified Petroleum Gas	04 Refined Petroleum
MET	Methanol	03 Natural Gas
NGA	Natural Gas	03 Natural Gas

[a] This link holds for the energy prices but, in view of time constraints, the CES functions in the energy nests of GEMINI-E3 do not allow for the use of agricultural products like ethanol as an energy. As a consequence and since the ethanol share is and remains marginal, we have added the ethanol share to the electricity sector, in order not to affect the Swiss CO_2 emissions.

[b] Not used in this version of the model

2.3 Baseline simulation

The GEMINI-E3 model with the disaggregated transportation sectors once linked to the MARKAL-CHRES and MARKAL-CHTRA models and calibrated with the new Swiss GDP and population figures, calculates a baseline scenario until 2050 but for this study we focus and present only data up to 2020. Table 2.4 presents the average annual GDP and population growth assumed for each regions until 2020. For Switzerland, the GDP growth rates are in line with the Secretariat of Economic Affairs (SECO) estimates, whereas for other regions, they mainly follow forecasts from Energy Information Administration (2008).

Table 2.4: Baseline annual GDP and population growth per decade

	GDP		Population	
	2010	2020	2010	2020
CHE	1.26%	1.58%	0.74%	0.50%
EUR	2.28%	2.06%	0.22%	0.06%
OEC	2.92%	2.68%	0.95%	0.81%
JAP	1.90%	0.98%	0.11%	-0.14%
OEU	6.67%	4.14%	-0.25%	-0.24%
DCS	6.22%	5.04%	1.40%	1.21%
World	3.48%	3.08%	1.18%	1.03%

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/bbl until 2020. For Switzerland, the calibration of the model with regard to the heating fuels emissions is made assuming that temperatures will correspond to the average over the years 1970-1992. It goes without saying that higher oil prices or higher temperatures would reduce the baseline emissions.

In this baseline scenario, the world GHG emissions reach a little more than 70 $GtCO_2eq$ by 2050, which is in line with the forecast in OECD (2008). Table 2.5 presents the detailed emissions for each region until 2020.

Table 2.6 presents the variations of the Swiss baseline emissions for the transport, residential and ETS sectors 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 heating fuels, i.e. those from the residential sector and those from the other sectors. The model does not make the distinction between the emissions from domestic and international air transport as in GEMINI-E3 both sectors are aggregated. Data on the variation of the other GHG are also presented in detail. The emission data are not fully in line with those in Ecoplan (2009) as

Table 2.5: Baseline GHG and CO_2 emissions ($MtCO_2eq$)

GHG Emissions	2001	2013	2015	2020
CHE	53.1	50.2	49.9	48.9
EUR	4777	5086	5139	5255
OEC	8294	9016	9246	9504
JAP	1247	1255	1258	1235
OEU	3428	4643	4832	5001
DCS	15553	23601	25224	26955
World	33352	43652	45748	47998

CO_2 Emissions	2001	2013	2015	2020
CHE	45.7	42.8	42.5	41.4
EUR	3873	4198	3706	4353
OEC	6858	7435	7501	7759
JAP	1147	1146	1138	1115
OEU	2574	3610	3706	3876
DCS	9343	15657	16245	17976
World	23841	32089	32870	35120

the sectoral model disaggregation differs slightly. Figure 2.4 shows the baseline CO_2 emissions from transport, heating fuels and ETS sectors, as well as those of the other GHG.

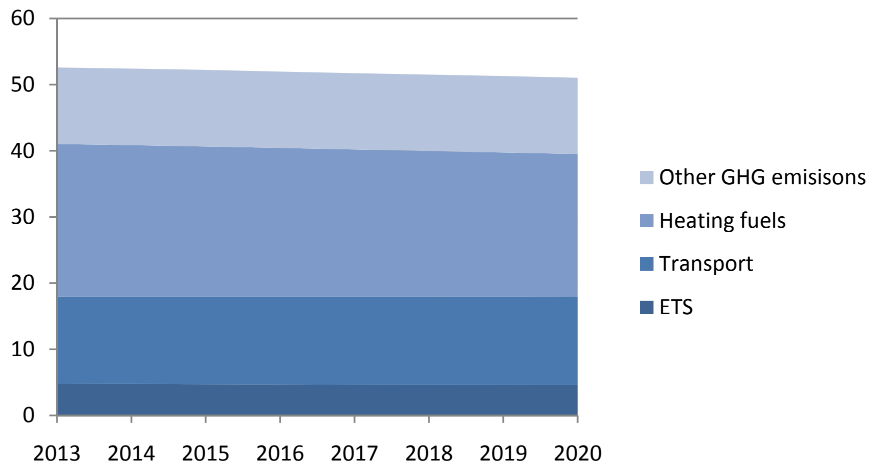


Figure 2.4: Baseline emissions path in Switzerland ($MtCO_2eq$)

Table 2.6: Variation of the baseline GHG emissions compared to 1990

	1990[a]	2013	2015	2020
Transport	*12.3*	7%	8%	9%
- Households	*8.4*	11%	12%	15%
- Transport sectors	*3.9*	-2%	-2%	-4%
Residential	*11.3*	-16%	-18%	-22%
ETS Sectors	*5.4*	-12%	-14%	-16%
Other sectors	*15.6*	-1%	-2%	-6%
- Air transport (Nat. + Int.)	*4.3*	-5%	-5%	-6%
- Other	*11.2*	1%	-1%	-6%
Domestic CO_2	*44.6*	-4%	-5%	-7%
Domestic CO_2 (wo Air transport)	*40.2*	-4%	-5%	-7%
- *Heating fuels*	*22.5*	-8%	-9%	-14%
Other GHG	*8.2*	-10%	-9%	-9%
- *CH_4*	*4.3*	-22%	-24%	-24%
- *$N_2 0$*	*3.6*	-20%	-24%	-24%
- *Fluorinated Gases*	*0.2*	377%	476%	476%
Domestic GHG	*52.8*	-5%	-5%	-7%
Domestic GHG (wo Air transport)	*48.4*	-5%	-5%	-8%

[a] in $MtCO_2eq$

With regard to the emissions in the ETS sectors, it is important to mention that, contrary to the FOEN proposal, we do not account for the the so-called geogenic CO_2 emissions related to the cement production. Indeed, we cannot model accurately the emissions due to the cement production activities, as they are part of the mineral products aggregated sector (08).

Among all the economic variables simulated by GEMINI-E3, it is also interesting to consider the production of all sectors as well as the final consumption. Table 2.7 presents the baseline production and final consumption figures for 2001, 2013 and 2020 for all sectors and products, including the newly disaggregated transportation sectors and products.

Table 2.7: Baseline annual production and final consumption in Mio. CHF_{2008}

	Production			Final consumption		
Sectors[a]	2001	2013	2020	2001	2013	2020
01	0	0	0	0	0	0
02	0	0	0	0	0	0
03	485	521	449	395	513	475
04	1640	2370	2116	2758	3122	3075
05	13359	14079	14563	1978	1807	1680
06	7307	7207	7382	2245	2617	2838
07	536	607	630	47	55	60
08	3866	3859	3848	339	386	419
09	28921	30127	31028	2944	3359	3658
10	2874	2323	2166	25	26	27
11	9673	10330	11093	1751	2022	2218
13	228	256	253	78	91	99
14	3439	3782	3832	2019	2343	2547
15	22898	23657	24854	17678	20139	21847
16	65185	66818	72136	8879	10032	10900
18	33861	41177	46687	28554	34713	39292
12a	1538	1774	1944	0	0	0
12b	2609	2850	2911	1291	1522	1679
12c	906	954	942	0	0	0
12d	2225	2416	2439	1391	1635	1791
12e	615	675	683	418	494	541
12f	2686	2866	2884	408	478	521
12g	2092	2263	2300	104	123	135
12h	107	80	67	0	0	0
17a	251693	301548	338982	100197	117870	130646
17b	13	15	17	0	0	0
17c	242	303	347	0	0	0
17d	4398	5414	6166	2270	2730	3059
17e	6715	8461	9781	517	587	647
Total	470111	536734	590500	176287	206662	228156

[a] The name of sectors corresponding to the codes can be found in tables A.1 and 2.1.

2.4 Policy scenarios

2.4.1 Swiss scenarios

We consider two world scenarios, a first one with limited international agreements, where only a low abatement would be achieved world wide, and a second one with an international agreement, where stronger abatement would be agreed upon among all world nations. The equivalent levels of international abatement are defined in section 2.4.2.

The envisaged Swiss post-Kyoto policies described in detail in table 2.8, 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.

Table 2.8: Swiss emissions reduction targets (% of 1990 emissions)

	Scenario 1		Scenario 2	
	2020	2050	2020	2050
ETS[a]	-1.75 % p.a.		-2.9 % p.a.	
Max. Certif.	40%		50%	
Transport[b]	25%	75%	40%	100%
Technical regulations on cars	target on average emissions of new cars[c]			
Heating fuels[b]	25%	50%	35%	80%
Residential program (2010-2020)	200 Mio CHF p.a. [d]			
Max. of certificates[b](% of 1990 GHG)	9%	25%	14%	36%

[a] Starts in 2013 on the basis of the average emissions in the period 2008-2012
[b] The values of the objectives increase linearly over the periods 2010-2020 and 2020-2050.
[c] Modeled as a ban on *standard* cars as of 2015
[d] Modeled as a discount on refurbishment costs (energy saving technologies)

First, the energy intensive sectors (04, 05, 08, 09, 10 and 11) will participate in an emission trading system (ETS) similar to the EU-ETS. 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 CDM market but also EUAs on the EU-ETS if the ETS and EU-ETS would be linked. As we have only one international carbon market, we cannot make the distinction between the two[4]. Thirdly, it is envisaged that 80% of the allowances would be distributed at first according to the grand-fathering principle and only progressively the auctioned share would grow to 70% in 2020. We assume that 100% of the allowances are auctioned since 2013. Fourthly, we only consider emissions related to the use of fossil fuels, i.e. geogenic CO_2 emissions are not counted.

Secondly, the importers of transportation fuels will be required to offset a part of the 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. Furthermore, the total amount of foreign certificates that can be purchased is bounded, taking into account that the ETS sectors have the priority in the purchase mechanism. It is also envisaged that if the limit on the purchase of foreign certificates is reached, a CO_2 tax would be introduced on transportation fuels to ensure that the abatement targets are reached. In view of the lack of data with regard to the differentiation of the consumption of petroleum products in the various economic sectors and taking into account that a specific sector for own goods transportation has been created, we have considered that only households and all transportation sectors are users of transportation fuels whereas all other sectors only use heating fuels. Therefore, a small discrepancy arises from miss-counting the fuel used for own passenger transport in those sectors.

Thirdly, the users of heating fuels other than those taking part in the ETS will face a tax which aims at specific abatement for them. The revenue of this tax is affected up to one third of its values or maximum 200 Mio. CHF to a building program, and the rest is redistributed to households through a lump sum transfer[5]. Finally, air transport is not subject to any constraint.

In addition to the various targets, two specific programs will also contribute to the overall Swiss abatement effort. First, a residential program, financed through a part of the revenue of the tax on heating fuels, will promote the refurbishment of residential building. We have modeled this through the introduction of a discount on the so-called energy saving technologies, simulating cost reductions for home owners in their refurbishment process amounting to 200 Mio. CHF per year. Secondly, newly registered cars have in average to comply with an emission target value. Importers of cars will have to pay a penalty if the average CO2 emissions of their sold and registered car fleet is above the required emission target value. Our transport model not having sufficient details with regard to the types of cars, we have modeled this as a restriction on the available technologies in the car market as of 2015, i.e. not allowing for the purchase

[4] A specific version of GEMINI-E3 has been developed to analyze the EU-ETS (Bernard and Vielle, 2009).

[5] The FOEN proposal envisages that the revenue is redistribute to both households and economic sectors, but in our framework, i.e. a single representative household that owns the capital, and assuming that companies would return the money to the capital owner, a simple lump sum transfer is equivalent.

of the most inefficient cars.

Car regulations

The post-Kyoto policies under consideration also envisage an average emission target value for the CO2 emissions of new passenger cars. Despite the technological richness of the MARKAL-CHTRA model, the descriptions of the available and future vehicles does not go into sufficient details such as to model this aspect of the policy. Instead, as of 2015, we have implemented a technical restriction on the purchase of the diesel and gasoline personal cars with the lowest efficiency. This leaves the following choices to the consumers: standard gas internal combustion engines (ICE) cars, efficient gas, diesel and gasoline cars, as well as hybrid cars using gas, diesel and gasoline.

Figure 2.5 shows the impact of this technical restriction on the emissions from transport. As MARKAL models are perfect foresight models, due to anticipations, the restrictions have an effect before their implementation and, already in 2013, approximatively one half million tons of CO_2 are avoided. The abatement exceeds 1.1 $MtCO_2$ by 2020[6].

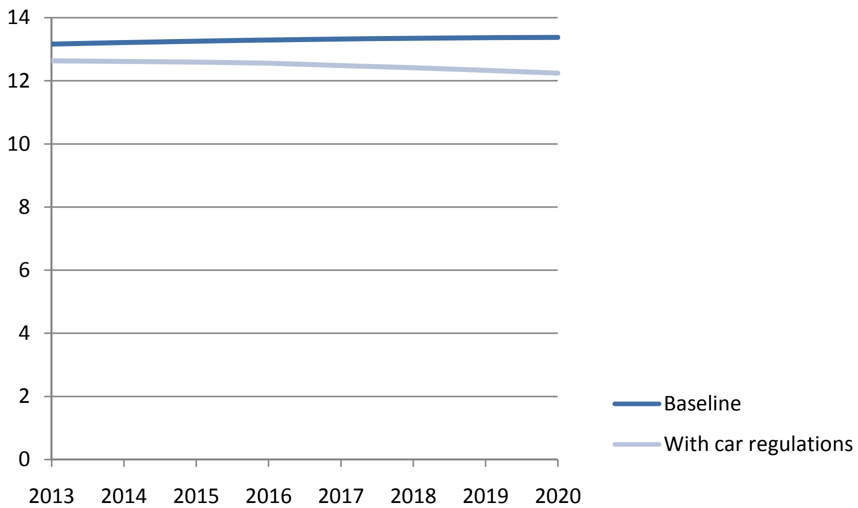


Figure 2.5: Swiss emissions from transport with and without technical regulations on cars ($MtCO_2eq$)

[6] FOEN estimated the benefits of this program to approximately 1.5 $MtCO_2$

Building program

The use of a hybrid model with a bottom-up residential sector allows for modeling endogenously the building program. Indeed, we have implemented a discount on the so-called energy saving technologies (e.g. insulation) in MARKAL-CHRES ensuring that households would increase the installation of these technologies. The discount is calculated so that the difference between the real costs of the installation and the costs borne by the households after discounts equal to the 200 Mio. CHF available for the building program. Provided that energy saving technologies would be approximately 40% cheaper for the final users, the MARKAL-CHRES model calculates that the additional installations would save up to 300'000 tCO_2 in the residential sector. This is well below the estimated 2.2 $MtCO_2$ per year estimated by SFOE.

This modeling of the building program does not consider the measures aimed at fuel switching. Extending the discount to cleaner technologies other than the energy saving ones might have triggered a stronger effect.

2.4.2 International scenarios

Climate policies will only be efficient in the long run if major agreements are found to limit emissions globally. If 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, it remains true that, without appropriate coordinated action of emerging nations, any efforts by the developed countries would be vain.

In this study we consider two cases, where two different international agreements would be achieved. The proposed target for the "low" and "high" scenarios for 2020 and 2050 are presented in table 2.9. The "low" scenario is used to analyze the first Swiss scenario, where weak international agreement would be reached, whereas the "high" scenario is used for the second Swiss scenario, where all countries would more actively participate in the global effort. The high scenario is based on the Energy Modeling Forum 23 optimistic scenario where DCS would have binding target as of 2030.

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. We also avoid that the overall effect of the policies is jeopardized by carbon leakage by capping the emissions of those not participating in the agreements to their baseline emissions.

Table 2.9: International emissions reduction targets (% of 2001 emissions)

Target year	2020		2050	
Scenario	Low	High	Low	High
CHE	22	32	50	73
EUR	20	30	50	75
OEC	20	30	50	80
JAP	20	30	50	80
OEU	-[a]	10	30	50
DCS	-[a]	-[a]	-[a]	25[b]

[a] baseline emissions
[b] % of 2030 emissions

2.5 Results

2.5.1 Scenario 1

Tables 2.10 and 2.11 present respectively the taxes that allow to achieve the objectives of scenario 1 and the detailed emission abatements in the various parts of the Swiss economy. As expected, the levy collected on transport fuels is small in view of the low price of foreign CO_2 certificates. The additional heating fuel tax (on top of the actual 36 CHF per tone of CO_2) is significant as it would have to reach approximately 213 CHF_{2008} by 2020 to reach the 25% abatement despite the technical possibilities offered by MARKAL-CHRES and the residential program. The price of the allowances in the ETS market remains rather low because the baseline abatement in those sectors is quite pronounced already, leaving small additional abatement needed to meet the target, which can be achieved at rather low costs.

Table 2.10: Swiss environmental taxes and prices of certificates/allowances in scenario 1 (CHF_{2008}/tCO_2eq)

	2013	2015	2020
Transport CO_2 levy	0.07	0.25	1.15
Heating fuels tax	57.51	91.43	212.94
ETS allowance price	1.26	3.20	12.29
World certificate price	1.26	2.10	2.41

The figures relative to abatement of the emissions due to heating fuels and those from the residential sector (see table 2.11) suggest that modeling the use of heating fuels in commercial buildings with an energy-systems model, as it is the case in the residential sector, would lower the estimation of the heating fuels tax. Indeed, it seems reasonable to assume that technologies available for residential buildings can to a large extent be also 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 residential program which triggers an abatement in the residential sector of 0.3 $MtCO_2$, the effect of the tax on the other sectors (-8%) seems too limited when compared to the reductions in the residential sector (-44%).

Table 2.11: Variation of the Swiss GHG emissions compared to 1990 in scenario 1

	1990[a]	2013	2015	2020
Transport	*12.3*	0%	1%	1%
- *Households*	*8.4*	1%	2%	4%
- *Transport sectors*	*3.9*	-2%	-2%	-5%
Residential	*11.3*	-26%	-32%	-44%
ETS Sectors	*5.4*	-13%	-15%	-20%
Other sectors	*15.6*	-1%	-2%	-7%
- *Air transport*	*4.3*	-3%	-3%	-5%
- *Other*	*11.2*	0%	-2%	-8%
Domestic CO_2	*44.6*	-9%	-10%	-16%
Domestic CO_2 (wo Air transport)	*40.2*	-9%	-11%	-17%
- *Heating fuels*	*22.5*	-13%	-17%	-26%
Other GHG	*8.2*	-10%	-10%	-10%
- CH_4	*4.3*	-23%	-23%	-25%
- $N_2 0$	*3.6*	-22%	-22%	-25%
- *Fluorinated Gases*	*0.2*	406%	406%	475%
Domestic GHG	*52.8*	-9%	-10%	-15%
Domestic GHG (wo Air transport)	*48.4*	-9%	-11%	-16%
Total GHG	*52.8*	-10%	-13%	-21%
Total GHG (wo Air transport)	*48.4*	-11%	-14%	-23%

[a] in $MtCO_2eq$

Both the transport and the ETS sectors can purchase foreign emission certificates within the predefined limits. Table 2.12 shows that in the first scenario the ETS sectors do not really need to purchase emissions abroad 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 at the same time, the introduction of the regulations on cars triggers a domestic abatement that can be observed when comparing tables 2.6 and 2.11. More information on the effect of the regulations on passenger cars can be found in section 2.4.1. The purchase cap for foreign emission certificates is not reached, indicating that the policies ensure sufficient domestic abatement without having to impose an additional tax on transport fuels.

Table 2.12: Swiss purchase of certificates in scenario 1 ($MtCO_2eq$)

	2013	2015	2020
Transport	0.7	1.4	3.2
ETS	0.0	0.0	0.1
Total	0.7	1.5	3.4
Purchase cap	2.1	2.8	4.8
%1990 GHG emissions	4%	5%	9%

Table 2.13 presents the impacts of scenario 1 on GDP and welfare (households' surplus) as well as the decomposition of the welfare into the gains and losses of the terms of trade (GTT), the trade of emissions permits and the deadweight loss of taxation (DWL)[7]. The welfare components are presented as a percentage of total consumption (HC). In the first scenario, the impact of the climate policies on GDP remains reasonable (0.26% in 2020). The welfare impacts are nevertheless non-negligible as they are above a half percentage point as of 2013. Despite the limited purchase of permits and positive GTT, the DWL is sufficiently important to affect welfare significantly. These results are quite different from what we observed in previous studies, where a uniform tax was applied across the whole Swiss economy, which equalized marginal costs an thus had a lesser impact on welfare.

Table 2.13: Economic impacts of scenario 1 in Switzerland

	2013	2015	2020
GDP volume (% baseline)	-0.09%	-0.14%	-0.26%
Households' Surplus (%HC)	-0.52%	-0.58%	-0.56%
GTT (%HC)	0.04%	0.04%	0.12%
Trade of permits (%HC)	0.00%	0.00%	0.00%
Deadweight Loss (%HC)	-0.55%	-0.62%	-0.68%

Table 2.14 presents the variation of the production and consumption with regard to the baseline. As expected, the overall impact of climate policies is negative on both production and consumption. Nevertheless, some sectors are more affected than others and some even benefit from the policies. The most affected sectors are the refined petroleum (04) and coal (01) sectors, for which final consumption is reduced respectively by 25 and 13% by 2020. Such structural changes are obviously the aim of climate policies. In Switzerland, coal is marginal and totaly imported but the production of refined petroleum products is quite strongly affected as it decreases by more than 8%. In this scenario, gas (03) turns out to be a viable alternative to petroleum products as its

[7]See annex B for more detail on the calculation of the welfare components.

consumption increases strongly as does its production. The electricity sector (05) also strongly benefits from the policies and sees its production increase by almost 3% in 2020. As expected, most transport sectors (12a. . . 12h, 13, 14 and 17b. . . 17e) are negatively affected in scenario 1. Nevertheless, the rail sectors and the passenger transport sectors are less affected. Furthermore, pipeline transport (12h) is also increasing as it benefits from the increase in gas production and consumption. Except in the energy sectors, the variations are nevertheless limited.

Each scenario having a specific international framework, it is interesting to look at some international results and compare them with Switzerland. Table 2.15 presents the welfare effect per region together with the net trade of permits. The first scenario assumes that no or week international agreements are reached and as a consequence 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 emission certificates and have a positive welfare effect. It is worth noticing that Switzerland, which is the only region where the tax is not uniform across sectors and not on all GHGs, suffers a greater welfare loss than any other region.

Table 2.14: Variations of production and final consumption in scenario 1 in Switzerland (% of baseline)

	Production			Final consumption		
Sectors[a]	2013	2015	2020	2013	2015	2020
01				-4.6%	-6.7%	-12.6%
02						
03	1.0%	1.4%	3.9%	16.1%	20.0%	47.5%
04	-3.5%	-3.9%	-8.2%	-13.7%	-16.8%	-25.4%
05	0.6%	1.4%	2.9%	0.7%	1.5%	0.9%
06	-0.6%	-1.1%	-2.1%	-0.5%	-0.6%	-0.7%
07	-0.5%	-0.8%	-1.5%	-0.5%	-0.6%	-0.6%
08	-0.2%	-0.3%	-0.4%	-0.4%	-0.5%	-0.4%
09	0.0%	0.0%	-0.1%	-0.4%	-0.5%	-0.4%
10	0.2%	0.2%	0.3%	-0.4%	-0.5%	-0.5%
11	-0.1%	-0.2%	-0.2%	-0.4%	-0.5%	-0.4%
13	-1.0%	-1.0%	-1.5%	-0.8%	-0.8%	-0.4%
14	0.2%	0.1%	-0.3%	0.6%	0.4%	-0.3%
15	-0.5%	-0.7%	-1.2%	-0.4%	-0.5%	-0.5%
16	0.5%	0.3%	-0.3%	4.4%	3.9%	1.4%
18	-0.4%	-0.4%	-0.3%	-0.4%	-0.4%	-0.4%
12a	0.1%	0.1%	-0.1%			
12b	0.3%	0.3%	0.0%	0.7%	0.5%	-0.1%
12c	-0.3%	-0.3%	-0.6%			
12d	0.4%	0.3%	-0.1%	0.7%	0.5%	-0.1%
12e	0.3%	0.2%	-0.2%	0.5%	0.3%	-0.3%
12f	-0.1%	-0.1%	-0.3%	-0.7%	-0.8%	-0.5%
12g	-0.1%	-0.1%	-0.2%	-0.7%	-0.7%	-0.5%
12h	1.3%	1.9%	5.5%			
17a	-0.1%	-0.1%	-0.1%	-0.3%	-0.4%	-0.3%
17b	-1.0%	-1.0%	-1.5%			
17c	0.2%	0.1%	-0.2%			
17d	-0.4%	-0.4%	-0.4%	-0.7%	-0.7%	-0.7%
17e	0.0%	0.0%	-0.2%	-0.4%	-0.5%	-0.5%
Total	0.0%	-0.1%	-0.2%	-0.2%	-0.2%	-0.3%

[a] The name of sectors corresponding to the codes can be found in tables A.1 and 2.1.

Table 2.15: International welfare and permit trading in scenario 1

	Households' Surplus (%HC)			Net trade of permits ($MtCO_2eq$)		
	2013	2015	2020	2013	2015	2020
CHE	-0.5%	-0.6%	-0.6%	-0.7	-1.5	-3.4
OEU	0.0%	0.1%	0.2%	228	304	480
JAP	0.0%	0.0%	0.0%	-77	-111	-199
EUR	0.0%	0.0%	-0.1%	-422	-645	-1212
OEC	0.0%	0.0%	-0.1%	-739	-1148	-2292
DCS	0.0%	0.0%	0.1%	1010	1602	3225

The MARKAL-CHRES part of the models allows to analyze the technical implications of the scenarios more in detail. Figure 2.6 presents the evolution of the residential energy uses by type of energy in the first scenario. It is interesting to notice that the emission reductions in the residential sectors are not only due to an increase of the share of renewable energies and electricity but also to a general reduction in the total use of energy. This is mainly due to an extended use of energy saving technologies and heat pumps.

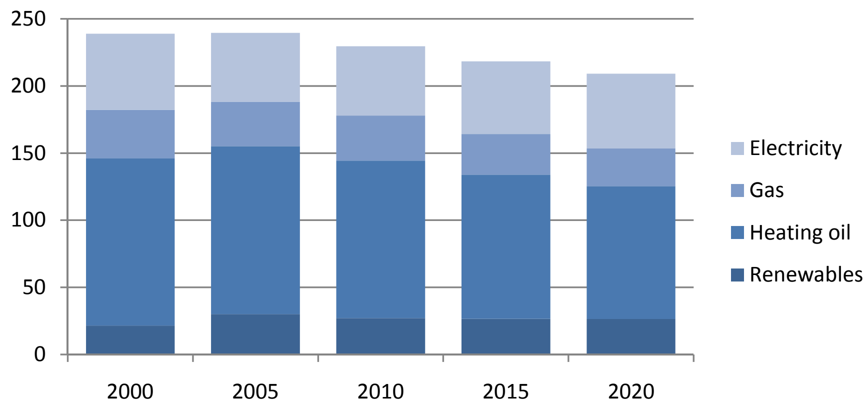


Figure 2.6: Scenario 1 - Fuels usage in the residential sector (PJ)

In the transport sector, the limited levy does not have strong effects on the park of vehicles. The car regulations are responsible for most of the differences with the baseline scenario. Figure 2.7 shows the progressive replacement of a part of the gasoline cars by diesel, gas and hybrid cars.

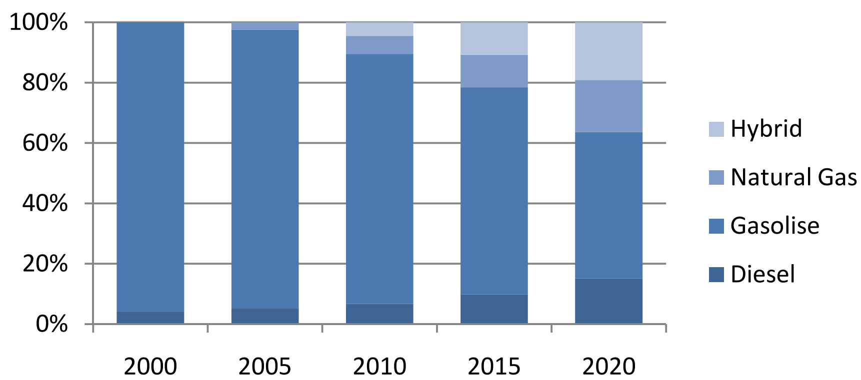


Figure 2.7: Scenario 1 - Types of passenger cars (%)

2.5.2 Scenario 2

Tables 2.16 and 2.17 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 four 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 0.3 cents per liter. The heating fuels tax additional to the 36 CHF per tone of CO_2 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 residential program a tax reaching almost 470 CHF_{2008} would be necessary. This result is inline with previous studies (e.g. Sceia et al., 2008), which showed that a progressive tax reaching 100 USD would be sufficient to achieve significant abatement by 2050 but short term abatement could not be achieved without higher taxes. As in the first scenario, the price of allowances in the ETS market remains rather low, in view of the limited abatement compared to the baseline and because of the possibility to undertake 50% of this abatement abroad through the purchase of cheap emission certificates. The international emissions certificates remain at a low price because in this scenario as in the previous one, developing countries are not subject to emissions reductions until 2030.

Table 2.16: Swiss environmental taxes and prices of certificates/allowances in scenario 2 (CHF_{2008}/tCO_2eq)

	2013	2015	2020
Transport CO_2 levy	0.39	1.09	4.52
Heating fuels tax	74.35	153.08	467.85
ETS allowance price	3.89	10.10	27.86
World certificate price	3.50	5.50	11.14

Regarding the purchase of emission certificates from the transport and the ETS sectors, table 2.18 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 5 tCO_2eq in 2020 and represents approximately 10% of 1990 emissions. As in the previous scenario the domestic abatement in the transport sector should be attributed to the regulations on passenger cars rather than to the small increase of transportation fuels' prices.

Table 2.19 presents the impacts of scenario 2 on GDP and the decomposition of welfare. The impact of the climate policies on the GDP varies from a tenth to a third of a percentage point. As in the previous scenarios, the welfare impacts are more substantial as the DWL almost reaches one percent of households consumption and the

Table 2.17: Variation of the Swiss GHG emissions compared to 1990 in scenario 2

	1990[a]	2013	2015	2020
Transport	*12.3*	0%	1%	1%
- *Households*	*8.4*	1%	2%	4%
- *Transport sectors*	*3.9*	-2%	-3%	-6%
Residential	*11.3*	-33%	-40%	-57%
ETS Sectors	*5.4*	-13%	-16%	-23%
Other sectors	*15.6*	-1%	-4%	-12%
- *Air transport*	*4.3*	-3%	-3%	-5%
- *Other*	*11.2*	-1%	-4%	-14%
Domestic CO_2	*44.6*	-10%	-13%	-21%
Domestic CO_2 (wo Air transport)	*40.2*	-11%	-14%	-23%
- *Heating fuels*	*22.5*	-17%	-22%	-36%
Other GHG	*8.2*	-10%	-10%	-12%
- CH_4	*4.3*	-24%	-24%	-27%
- $N_2 0$	*3.6*	-22%	-22%	-27%
- *Fluorinated Gases*	*0.2*	407%	407%	475%
Domestic GHG	*52.8*	-10%	-13%	-20%
Domestic GHG (wo Air transport)	*48.4*	-11%	-14%	-21%
Total GHG	*52.8*	-13%	-18%	-30%
Total GHG (wo Air transport)	*48.4*	-14%	-19%	-32%

[a] in $MtCO_2eq$

slight gains of the terms of trade are not sufficient to offset it. Again, it is interesting to mention that this might be due to the differentiation of the tax across the Swiss economy, which does not allow to equalize the marginal costs, and does not seem to be compensated by potential gains in the terms of trade. In view of the low prices of foreign emission certificates, their purchase almost does not affect the Swiss welfare.

Table 2.20 presents the variation of the production and consumption between the baseline and the second scenario. As expected the overall impact of climate policies on both production and consumption is negative but only slightly stronger than in the previous scenario. The strongest effect is on the petroleum products sector, which is significantly affected (-12% of production), mainly because of a strong decrease in final consumption (-31%). When comparing with the previous scenario, one can observe that with higher taxes, the switch which previously was taking place from petroleum products to gas, now turns toward electricity. Therefore, the electricity sector is the major beneficiary in this scenario and increases its production by 2.6 to 2.9%. In the first scenario, the policy does not have such strong effects in the first years, only 0.6% as in 2013, but in 2020 the variation of electricity production is similar. Again, the air

Table 2.18: Swiss purchase of certificates in scenario 2 ($MtCO_2eq$)

	2013	2015	2020
Transport	1.4	2.5	5.0
ETS	0.0	0.1	0.4
Total	1.4	2.6	5.4
Purchase cap	3.0	4.3	7.4
%1990 GHG emissions	6%	8%	14%

Table 2.19: Economic impacts of scenario 2 in Switzerland

	2013	2015	2020
GDP volume (% baseline)	-0.09%	-0.16%	-0.33%
Households' Surplus (%HC)	-0.55%	-0.63%	-0.71%
GTT (%HC)	0.07%	0.08%	0.23%
Trade of permits (%HC)	0.00%	0.00%	-0.01%
Deadweight Loss (%HC)	-0.62%	-0.71%	-0.93%

transport sector is very slightly affected as it does not face any carbon price.

The second scenario assumes a different international framework, with 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 remains the only region selling emission certificates and enjoying welfare gains.

Table 2.21 shows that Switzerland is more affected than other regions, except for OEU which is extremely sensitive to climate policies in view of its energy and energy intensive goods exports. Again, this is partly explained by the fact that Switzerland's policies do not target all GHGs and that different parts of the economy face different carbon prices.

Table 2.20: Variations of production and final consumption in scenario 2 in Switzerland (% of baseline)

	Production			Final consumption		
Sectors[a]	2013	2015	2020	2013	2015	2020
01				-4.9%	-9.2%	-19.6%
02						
03	-0.6%	-0.3%	0.4%	0.3%	3.3%	18.2%
04	-4.5%	-5.3%	-11.9%	-16.2%	-20.6%	-31.1%
05	2.6%	2.7%	2.9%	8.7%	7.4%	4.7%
06	-0.7%	-1.4%	-3.8%	-0.5%	-0.7%	-1.1%
07	-0.7%	-1.3%	-3.2%	-0.4%	-0.6%	-0.7%
08	-0.4%	-0.5%	-0.8%	-0.4%	-0.5%	-0.5%
09	-0.1%	-0.2%	-0.2%	-0.4%	-0.5%	-0.4%
10	0.2%	0.3%	0.1%	-0.4%	-0.5%	-0.5%
11	-0.2%	-0.3%	-0.4%	-0.4%	-0.5%	-0.4%
13	-1.3%	-1.4%	-2.3%	-0.8%	-0.8%	-0.4%
14	0.2%	0.1%	-0.3%	0.5%	0.4%	-0.3%
15	-0.6%	-1.0%	-2.2%	-0.4%	-0.5%	-0.6%
16	0.3%	0.0%	-0.9%	4.4%	3.9%	1.3%
18	-0.4%	-0.4%	-0.3%	-0.5%	-0.5%	-0.3%
12a	0.1%	0.0%	-0.2%			
12b	0.3%	0.2%	0.0%	0.6%	0.5%	-0.1%
12c	-0.4%	-0.5%	-0.9%			
12d	0.4%	0.3%	0.0%	0.7%	0.5%	-0.1%
12e	0.3%	0.2%	-0.2%	0.4%	0.3%	-0.3%
12f	-0.2%	-0.2%	-0.5%	-0.7%	-0.8%	-0.6%
12g	-0.1%	-0.1%	-0.3%	-0.8%	-0.8%	-0.5%
12h	-0.8%	-0.5%	0.3%			
17a	-0.1%	-0.1%	-0.1%	-0.3%	-0.3%	0.0%
17b	-1.3%	-1.4%	-2.3%			
17c	0.1%	0.1%	-0.2%			
17d	-0.4%	-0.4%	-0.6%	-0.8%	-0.8%	-0.9%
17e	-0.1%	-0.1%	-0.3%	-0.4%	-0.5%	-0.6%
Total	0.0%	-0.1%	-0.3%	-0.1%	-0.2%	-0.3%

[a] The name of sectors corresponding to the codes can be found in tables A.1 and 2.1.

Table 2.21: International welfare and permit trading in scenario 2

	Households' Surplus (%HC)			Net trade of permits ($MtCO_2eq$)		
	2013	2015	2020	2013	2015	2020
CHE	-0.6%	-0.6%	-0.7%	-1.4	-2.6	-5.4
OEU	-0.2%	-0.3%	-1.0%	-413	-614	-1085
JAP	0.0%	0.0%	-0.1%	-112	-162	-285
EUR	0.0%	0.0%	-0.2%	-535	-809	-1495
OEC	0.0%	-0.1%	-0.2%	-913	-1398	-2690
DCS	0.0%	0.1%	0.4%	1974	2986	5560

Figure 2.8 presents the evolution of the residential energy uses by type of energy in the second scenario. Similarly to the first scenario, the reduction of emissions is partly due to a strong decrease of the total use of energy. Furthermore, in this scenario, the high heating fuel tax not only triggers a decrease of the share of heating oil but also significantly reduces the use of natural gas. The share of fossil fuels goes from two thirds in 2000 to approximately half in 2020.

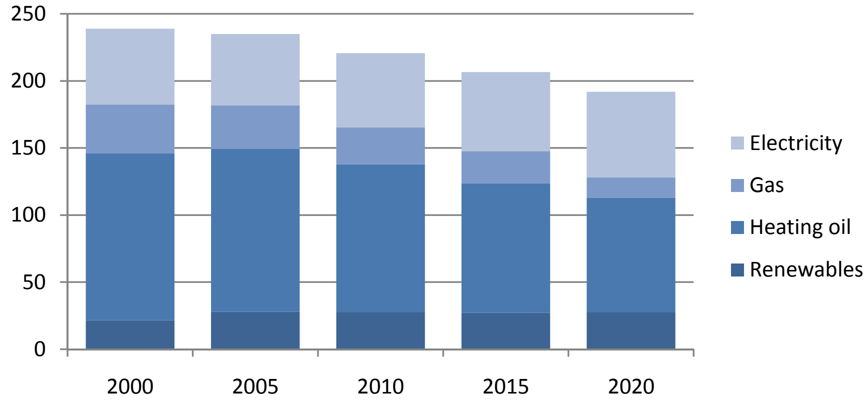


Figure 2.8: Scenario 2 - Fuels usage in the residential sector (PJ)

In scenarios 1 and 2, the limited transport levy has very similar impacts on the composition of the personal cars fleet.

2.5.3 Alternative scenarios

In view of the substantial difference between the effect of the 200 Mio. CHF residential programs estimated by SFOE (2.2 $MtCO_2$) and the estimation calculated by the MARKAL-CHRES model alone (0.3 $MtCO_2$), we have simulated two alternative scenarios, 1bis and 2bis, which mimic the original scenario in every point except for the modeling of the residential program. Indeed, the alternative scenarios take the residential program as exogenous and implement an artificial reduction of the emissions for the residential sector. The reduction increases linearly to reach the estimated 2.2 $MtCO_2$ in 2020.

If the effect of the building program is exogenously incorporated in the model, i.e. increasing linearly the emissions target up to 2.2 $MtCO_2$ in 2020, the picture gets quite different. Indeed, in an alternative scenario 1bis, where the modeling of the residential program is replaced by an artificial abatement of 2.2 $MtCO_2$, the tax required to achieve the target in 2020 is approximately 60 CHF_{2008}/tCO_2eq (see table 2.22). Consequently, the impact on GDP is also reduced from -0.26% to -0.21% and the deadweight loss goes from -0.68% to -0.59%. In an alternate scenario 2 including the same modifications, the tax is approximately divided by two and reaches 214 CHF_{2008}/tCO_2eq in 2020. The GDP would also be less affected, losing only 0.26% compared to the baseline, and the deadweight loss would reach about -0.7% of total final consumption.

Table 2.22: Heating fuel tax with exogenous building program (CHF_{2008}/tCO_2eq)

	2013	2015	2020
Scenario 1	43.2	51.6	59.2
Scenario 2	61.4	93.7	214.0

Tables 2.23 and 2.24 present respectively the economic impacts as well as the variation of production and consumption for scenario 1bis. Tables 2.25 and 2.26 present the same information for scenario 2bis.

Table 2.23: Economic impacts of scenario 1bis in Switzerland

	2013	2015	2020
GDP volume (% baseline)	-0.08%	-0.12%	-0.21%
Households' Surplus (%HC)	-0.54%	-0.59%	-0.56%
GTT (%HC)	0.00%	-0.01%	0.03%
Sales of permits	0.00%	0.00%	0.00%
Deadweight Loss (%HC)	-0.53%	-0.58%	-0.59%

Table 2.24: Variations of production and final consumption in scenario 1bis in Switzerland (% of baseline)

	Production			Final consumption		
Sectors[a]	2013	2015	2020	2013	2015	2020
01				-4.4%	-4.9%	-5.5%
02						
03	2.1%	2.8%	5.8%	27.7%	35.1%	69.4%
04	-2.9%	-3.0%	-4.4%	-11.5%	-13.1%	-18.3%
05	-0.3%	0.6%	2.8%	-3.5%	-3.0%	-0.7%
06	-0.5%	-0.7%	-0.7%	-0.5%	-0.6%	-0.6%
07	-0.3%	-0.4%	-0.2%	-0.5%	-0.6%	-0.5%
08	0.0%	-0.1%	-0.1%	-0.5%	-0.6%	-0.5%
09	0.2%	0.2%	0.2%	-0.5%	-0.5%	-0.5%
10	0.4%	0.4%	0.5%	-0.5%	-0.6%	-0.6%
11	0.0%	0.0%	-0.1%	-0.5%	-0.5%	-0.5%
13	-0.8%	-0.8%	-0.9%	-0.8%	-0.8%	-0.5%
14	0.2%	0.1%	-0.3%	0.5%	0.3%	-0.4%
15	-0.4%	-0.5%	-0.5%	-0.5%	-0.6%	-0.6%
16	0.6%	0.6%	0.1%	4.3%	3.8%	1.2%
18	-0.4%	-0.4%	-0.4%	-0.4%	-0.5%	-0.5%
12a	0.1%	0.1%	-0.1%			
12b	0.3%	0.3%	-0.1%	0.6%	0.5%	-0.2%
12c	-0.1%	-0.1%	-0.2%			
12d	0.4%	0.3%	-0.1%	0.6%	0.4%	-0.3%
12e	0.4%	0.2%	-0.2%	0.4%	0.3%	-0.3%
12f	0.0%	0.0%	-0.1%	-0.8%	-0.8%	-0.6%
12g	0.0%	-0.1%	-0.1%	-0.8%	-0.8%	-0.5%
12h	2.8%	4.0%	8.6%			
17a	-0.1%	-0.1%	-0.1%	-0.4%	-0.5%	-0.5%
17b	-0.9%	-0.8%	-0.9%			
17c	0.2%	0.1%	-0.2%			
17d	-0.3%	-0.3%	-0.3%	-0.7%	-0.7%	-0.6%
17e	0.0%	0.0%	-0.1%	-0.5%	-0.5%	-0.5%
Total	0.0%	0.0%	-0.1%	-0.2%	-0.3%	-0.4%

[a] The name of sectors corresponding to the codes can be found in tables A.1 and 2.1.

Table 2.25: Economic impacts of scenario 2bis in Switzerland

	2013	2015	2020
GDP volume (% baseline)	-0.09%	-0.14%	-0.26%
Households' Surplus (%HC)	-0.54%	-0.61%	-0.62%
GTT (%HC)	0.03%	0.04%	0.11%
Sales of permits	0.00%	0.00%	-0.01%
Deadweight Loss (%HC)	-0.57%	-0.64%	-0.72%

Table 2.26: Variations of production and final consumption in scenario 2bis in Switzerland (% of baseline)

	Production			Final consumption		
Sectors[a]	2013	2015	2020	2013	2015	2020
01				-5.0%	-7.0%	-13.1%
02						
03	0.4%	1.0%	3.4%	11.6%	15.8%	43.5%
04	-3.6%	-4.1%	-8.3%	-13.9%	-17.0%	-25.2%
05	1.0%	1.8%	3.2%	2.6%	3.7%	3.1%
06	-0.6%	-1.0%	-1.8%	-0.5%	-0.7%	-0.8%
07	-0.6%	-0.8%	-1.5%	-0.5%	-0.6%	-0.6%
08	-0.2%	-0.3%	-0.5%	-0.4%	-0.5%	-0.5%
09	0.0%	0.0%	0.1%	-0.4%	-0.5%	-0.5%
10	0.3%	0.4%	0.5%	-0.5%	-0.6%	-0.6%
11	-0.1%	-0.2%	-0.3%	-0.4%	-0.5%	-0.5%
13	-1.1%	-1.1%	-1.6%	-0.8%	-0.8%	-0.4%
14	0.2%	0.1%	-0.3%	0.5%	0.3%	-0.4%
15	-0.5%	-0.8%	-1.3%	-0.5%	-0.6%	-0.6%
16	0.4%	0.2%	-0.4%	4.4%	3.8%	1.3%
18	-0.4%	-0.4%	-0.3%	-0.5%	-0.5%	-0.4%
12a	0.1%	0.1%	-0.1%			
12b	0.3%	0.3%	0.0%	0.6%	0.5%	-0.1%
12c	-0.3%	-0.3%	-0.5%			
12d	0.4%	0.3%	-0.1%	0.7%	0.5%	-0.2%
12e	0.3%	0.2%	-0.2%	0.5%	0.3%	-0.3%
12f	-0.1%	-0.1%	-0.3%	-0.8%	-0.8%	-0.6%
12g	-0.1%	-0.1%	-0.2%	-0.8%	-0.8%	-0.5%
12h	0.5%	1.3%	4.8%			
17a	-0.1%	-0.1%	-0.1%	-0.3%	-0.4%	-0.3%
17b	-1.1%	-1.1%	-1.6%			
17c	0.2%	0.1%	-0.2%			
17d	-0.4%	-0.4%	-0.4%	-0.7%	-0.7%	-0.7%
17e	0.0%	-0.1%	-0.2%	-0.5%	-0.5%	-0.5%
Total	0.0%	-0.1%	-0.2%	-0.2%	-0.2%	-0.3%

[a] The name of sectors corresponding to the codes can be found in tables A.1 and 2.1.

2.6 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 for the modeling of the numerous aspects of the future climate policies, which can be of both technical and economic nature. In order to fully model and analyze the transport sectors in particular, extensive work has been carried out to disaggregate the Swiss transport sectors within our CGE model.

Our coupled model simulates all the different policy instruments that are envisaged in Switzerland for the post-Kyoto period endogenously (see section 2.4.1 and table 2.8 for details) and therefore allows to analyze 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, GDP is only affected by a quarter percentage point in 2020. The various instruments would nevertheless trigger a loss of welfare of more than half a percent. In the second scenario, these figures increase slightly to 0.33% and over 0.7% respectively. These value would be even lower if the model would take into account induced technical progress and first-mover advantages. Both scenarios trigger an important switch away from petroleum products. In the first case, this turns out to be very beneficial to the gas sector, whereas in the second scenario, a doubling of the tax on heating fuels pushes further toward the use of electricity which is almost carbon free in Switzerland. 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 would be possible without jeopardizing the domestic emissions targets.

When comparing the Swiss results with those of other regions, which face a single price of carbon that equalizes internationally the marginal costs of GHG emissions abatements, we see that Switzerland is more affected, in particular with regard to the loss of welfare. Indeed, differentiated carbon prices and the exclusion of GHG other than CO2 from the scope of the policies is not efficient and results in higher costs.

Another important aspect pinpointed by this study is the influence of the residential program on the results. If modeled endogenously as a discount on refurbishing costs, the residential program has a relatively limited effect (0.3 $MtCO_2$) compared with the estimations laid down by the FOEN in the terms of reference of this study (2.2 $MtCO_2$). This has very significative implications on the levels of the heating fuel tax as well as on the economic consequences of the policies.

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 very low, allowing for cheap offsetting of Swiss emissions, mainly in the transport sector. The scenarios take into account that the chances that international agreements would impose significant abatement on developing countries before 2020 are rather low. If this would happen, the price of emission certificates could increase sharply and affect significantly the Swiss welfare as Swiss policies are highly dependent on the purchase of certificates in the transport sector.

Appendix A

Characteristics of the models

Table A.1 presents the regional and sectoral dimensions of GEMINI-E3, as well as the sectoral aggregation used in this paper. For additional information regarding the GEMINI-E3 model, such as the list of GHG emissions calculated by the model, see Bernard and Vielle (2008). Table A.2 presented the values of the elasticity parameters in both production and consumption functions. Tables A.3 and A.4 show the useful demands in MARKAL-CHRES.

Table A.1: Dimensions of the complete and aggregated GEMINI-E3 Model

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

Table A.2: GEMINI-E3 Elasticities

Production function			Consumption function		
				Value	
Parameter	Sector	Value	Parameter	CHE	other regions
all regions			σ^{hc}	0.20	0.50
σ	All	0.30	σ^{hres}	0.00	0.80
σ^{pf}	01	0.40	σ^{htra}	0.10	0.50
	02, 03	0.20	σ^{hoth}	0.30	0.30
	04	0.10	σ^{hrese}	0.00	
σ^{pp}	All	0.10	σ^{htrag}	0.80	-
σ^{e}	01 to 05	0.10	σ^{htrap}	0.50	0.50
	06,07,12,13,14	0.20	σ^{htrapp}	0.50	-
	Others	0.40	σ^{htrapo}	0.30	-
σ^{fe}	01 to 04	0.10	$\sigma^{htrapoo}$	0.30	-
	05	1.50	$\sigma^{htrapooe}$	0.00	-
	06 to 11 & 15 to 18	0.90	σ^{htrao}	-	0.30
	Others	0.30	σ^{htraoe}	-	0.80
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			

Table A.3: MARKAL-CHRES Demand segments

RC1	Cooling
RCD	Cloth Drying
RCW	Cloth Washing
RDW	Dish Washing
REA	Other Electric
RH1	Room-Heating Single-Family Houses (SFH) existing building
RH2	Room-Heating SFH new building
RH3	Room-Heating Multi-Family Houses (MFH) existing buildings
RH4	Room-Heating MFH new buildings
RHW	Hot Water
RK1	Cooking
RL1	Lighting
RRF	Refrigeration

Table A.4: MARKAL-CHTRA Demand segments

TAD	Domestic Aviation
TAI	International Aviation
TRB	Road Bus
TRC	Road Commercial Trucks
TRE	Road Three Wheels
TRH	Road Heavy Trucks
TRL	Road Light Vehicle
TRM	Road Medium Trucks
TRT	Road Auto
TRW	Road Two Wheels
TTF	Rail-Freight
TTP	Rail-Passengers
TWD	Domestic Internal Navigation
TWI	International Navigation

Appendix B

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 et al. (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 B.1 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[1].

[1] 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 B.1: Measurement and components of welfare

$S = R - \triangle CVI$
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
$GTT = \sum Exp_0 \triangle Pexp - \sum Imp_0 \triangle Pimp$

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