An ex-post evaluation of the effectiveness of the Swiss CO_2 levy*

Final Report Module B

Marc Vielle and Philippe Thalmann

Laboratory of Environmental and Urban Economics
(leure.epfl.ch)

December 10, 2015

*We would like to thank Frédéric Babonneau for his research assistance on this project.

Contents

1 Introduction

In 2008, Switzerland introduced a CO_2 levy on heating and process fuels [13] at an initial rate of CHF 12 per ton of CO_2. It was gradually increased to 60 CHF by 2014. The aim of this pricing mechanism is to reduce Swiss CO_2 emissions in accordance with the commitment made in the Kyoto protocol (-8% over 2008-2012 relative to 1990). This study provides a counterfactual analysis of CO_2 emissions if no CO_2 levy had been implemented. We use a macroeconomic model called GEMINI-E3 to perform the analysis. Although it is not very common to use such model for back-casting, some countries have already implemented such protocols. This is the case for example of the US administration, which conducts regularly an ex-post estimation of the benefits and costs of the Clean Air Act [14]. Among the different tools that are used to do this analysis we find the EMPAX-CGE model. Also in Switzerland Ecoplan applied a historical simulation from 1990 to 2001 and from 2001 to 2008 with its model SwissAGE based on [10].

In the present project we analyze two main scenarios. First, a historical scenario that includes the CO_2 levy and the exemption regimes and replicates the historical development of the Swiss economy and in particular the resulting energy consumptions and CO_2 emissions for the period 2008-2013 including a forecast for the year 2014. The second scenario is a counterfactual scenario in which the CO_2 levy and exemption regimes are removed. We then compare the results of the two scenarios and thereby evaluate the impacts of the Swiss CO_2 levy.

The report is structured as follows: In Section 2 we introduce the GEMINI-E3 model used to simulate the historical scenarios with and without the CO_2 levy and the exemption regimes. Then, in Section 3 we present the design of the Swiss CO_2 levy and Section 4 explains how the model is calibrated on historical evolutions. Section 5 shows the estimated impacts of the CO_2 levy. The final section presents the conclusions of this study.

2 The GEMINI-E3 Model

GEMINI-E3[1][6] is a multi-country, multi-sector, recursive dynamic[2] computable general equilibrium (CGE) model comparable to other CGE models (EPPA, OECD-Env-Linkage, etc) built and implemented by other modeling teams and institutions, and sharing the same long experience in the design of this class of economic models. The standard model is based on the assumption of total flexibility in all markets, both macroeconomic markets such as the capital and the exchange markets (with the associated prices being the real rate of interest and the real exchange rate, which are then endogenous), and microeconomic or sector markets (goods, factors of production).

[1] All information about the model can be found at http://gemini-e3.epfl.ch/, including its complete description.

[2] Recursive dynamic CGE models are those that can be solved sequentially (one period at a time) and where the decisions about investment, consumption and production are based on the prices in the period of decision usually referred as myopic expectations in contrary to forward-looking dynamic model.

In the last 20 years, GEMINI-E3 has been extensively used to assess planned climate and energy strategies at global and regional levels, including:

- Assessment of the EU "Energy–Climate" Directive [9];
- Assessment of acceptable Swiss post-2012 climate policies [12];
- Study of possible fair negotiation outcomes at the forthcoming Conferences of the Parties of the UNFCCC [4];
- Estimation of the role of non-CO_2 gases in climate policy [8];
- Uncertainty analysis in climate policy assessment [3];
- Assessment of Russia's role in the Kyoto protocol [7];
- Climate change effects of high oil prices [15].

The current version is built on the Swiss input-output table 2008 [11] and the GTAP database 8 [5] for the other countries. The industrial classification used in this study comprises 18 sectors (Table 1). The model describes six energy goods and sectors: coal, oil, natural gas, petroleum products, electricity and heat supply. Considerable effort was spent for obtaining a good description of the main energy intensive industries and for identifying in each sector the share of firms that are allowed to participate in the Swiss emission trading scheme (ETS). Concerning the regions represented by the model, we use an aggregated version of GEMINI-E3 that describes only 5 countries/regions: Switzerland, European Union, United States of America, BRIC (Brazil, Russia, India and China) and the rest of the World.

Table 1: Industrial and regional classifications

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

2.1 Energy demand

Domestic energy demand is equal to the sum of energy consumed by firms as a production factor and energy consumed by households as a final good. The production structure of the industrial sectors is shown in Figure 1[3].

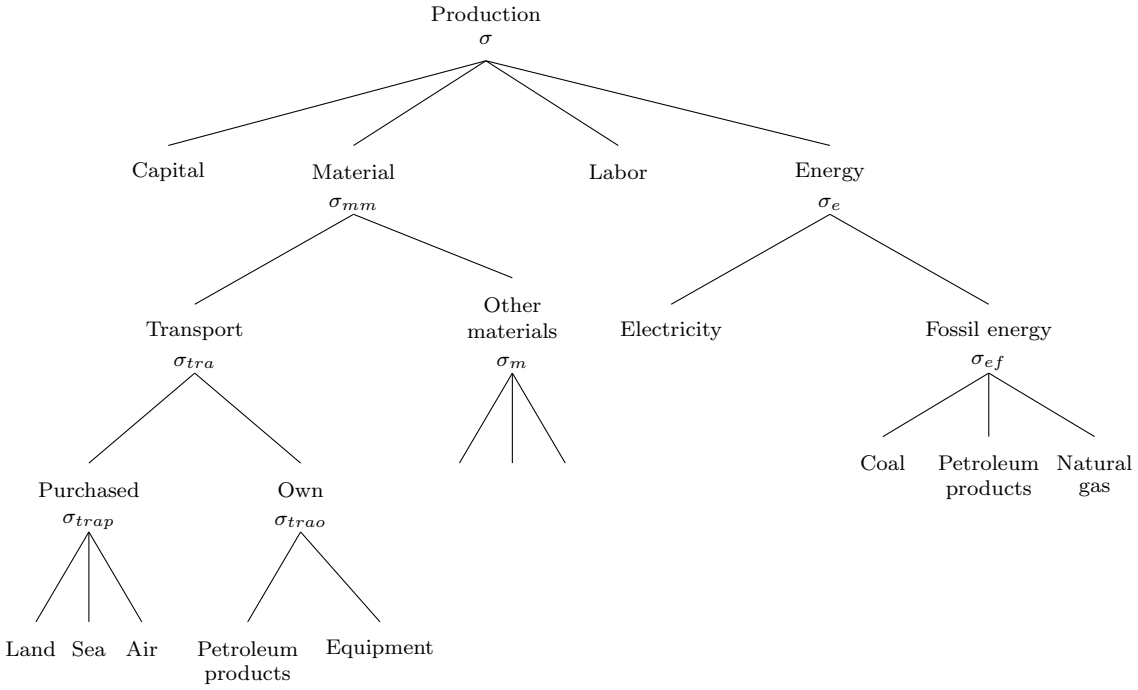

Figure 1: Nested CES production structure

Consumption choices are represented as resulting from the optimization choices of a single representative household. This household uses, in every period, its disposable income to purchase the bundle of goods that gives it greatest satisfaction (Figure 2). The choices will be affected by the relative prices of these goods. For instance, suppose transportation prices increase. That raises the relative price of transport compared to housing and other goods, so the household will buy less transport and more of these alternative goods. The intensity of this substitution depends on the amplitude of change of the relative prices and on the household's willingness or capacity to replace one good by another. This last determinant is measured by elasticities of substitution, the σ in Figure 2. In simulations, one starts from a statistically observed bundle of consumer goods and then lets changes in relative prices provoke deviations from this bundle through substitutions between alternative goods.

In addition to composing its bundle of consumer goods, the representative household is modelled as a kind of producer, in that it 'produces' some of the goods it consumes itself. It combines different modes of transportation (its own vehicle and public transport by land, sea or air) to create the transport services (or mobility) it enjoys. Similarly, the representative household combines capital (shelter) and energy (for heating and appliances)

[3]The elasticities of substitution (σ) used in this version of GEMINI-E3 are provided in Appendix 7.1.

to create the housing services it consumes. The household consumes more housing services by buying more shelter capital and more building related energy. These combinations are modelled in a similar fashion as for the production sectors, with elasticities of substitution being the main parameters. Thus, energy enters the household's choices indirectly, in the production of transport and housing services. In the latter the household can even choose how it obtains that energy, by combining purchases of electricity and fossil fuels.

When fossil fuels become more expensive, e.g. due to the CO_2 levy, the households replaces some fossil fuels by electricity (mostly heat pumps) and some energy by spending more for its shelter (insulation). Even though these substitutions mitigate the impact of higher fuel prices, housing still becomes more expensive, inducing the households to substitute it partly by other goods.

Private transport, one of the modes of transportation, is produced by the household by combining its vehicle with energy (gasoline or diesel). To consume more private transportation, it must use more cars and more petroleum products (remember there is one representative household standing for the full population, so the number of cars is really the ratio of cars to households). If the price of petroleum products increases relative to that of cars, the household will spend a little bit more on cars to choose models that are more fuel efficient (including electric cars). In addition, private transportation becomes relatively more expensive, inducing the households to replace some of it by public (purchased) transportation and other goods. Thus the number of cars decreases.

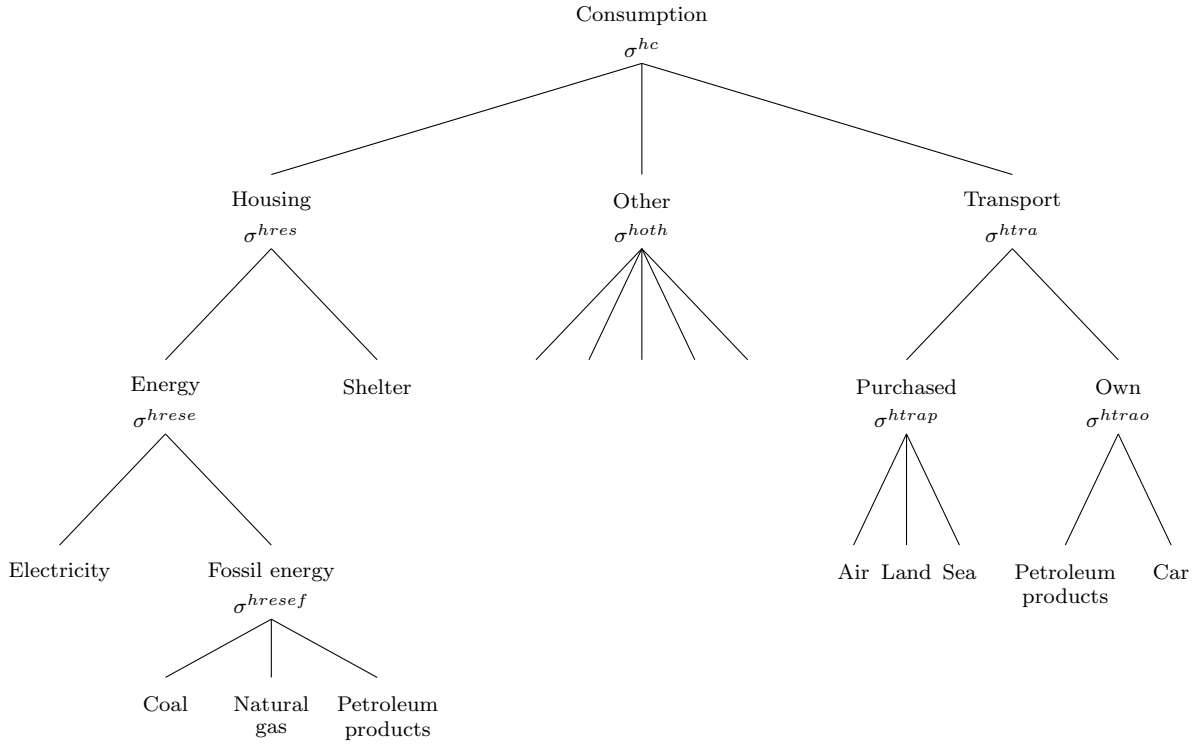

Figure 2: Nested CES consumption structure

2.2 Update of the GEMINI-E3 database

GEMINI-E3 is calibrated on the Swiss Input-Output table (SIOT) for the year 2008. The aim of this section is to describe the process of database building for a historical period (for the period 2008-2014) that will be used for the back-casting exercise. Data have been collected from various sources (mainly from national accounts and energy balances) and are related to GDP, industrial productions, CO_2 emissions, energy consumption by sector, energy taxation and energy prices.

The evolution of Swiss production accounts over the period 1998-2012 for the 18 sectors represented in GEMINI-E3 is based on the 2012 Swiss Federal Office of Energy SFOE (SFOE) statistics[4]. They have been adapted to the GEMINI-E3 data format according to the following methodology. First price inflation components were removed and all figures were calibrated on 2008 prices. The 18 GEMINI-E3 sectors were aggregated from sectors defined on the nomenclature NOGA 2002 (NOGA: nomenclature générale des activités économiques[5]) while SFOE statistics refer to NOGA 2008. Therefore, we used translation keys from NOGA 2008 to NOGA 2002 to aggregate sectors fitting the GEMINI-E3 nomenclature.

GEMINI-E3 has been calibrated to follow the Swiss GDP evolution from Swiss Federal Statistical Office statistics[6]. For the calibration exercise, we used percentage changes over previous year on the period 2005-2013 for the use of the disposable incomes (consumption and investments) of various actors.

After 2013, we extrapolate the trends computed over the period 2008-2013.

3 The Swiss CO_2 levy

The Swiss CO_2 levy has been introduced in 2008. It is applied on heating and process fuels, such as heating oil and natural gas consumed by firms and households. Oil products used for transportation (such as gasoline and diesel) are not affected by the CO_2 levy and are covered by other instruments[7]. Approximately two-thirds of the revenue from the levy is redistributed to the public and the economy independently of consumption. Approximately one-third of the revenue (max 300 million CHF/year) is invested in the buildings programme to promote energy-efficient renovations and renewable energies, while another CHF 25 million is invested in technology funds.

Figure 3 gives the evolution of the CO_2 levy on the period 2008-2014. It was introduced in January 2008 at an initial rate of CHF 12 per ton of CO_2 and left at that level for 2009. In January 2010, it was increased to CHF 36, because CO_2 emissions from heating and process fuels in 2008 were above the threshold triggering the increase. It was increased

[4] available at http://www.bfs.admin.ch/bfs/portal/fr/index/themen/04/02/02.html

[5] in English: general classification of economic activities.

[6] available at http://www.bfs.admin.ch/bfs/portal/fr/index/themen/04/02/01/key/bip_nach_verwendungsarten.html

[7] see http://www.bafu.admin.ch/klima/13877/14510/14511/index.html?lang=en

from CHF 36 to CHF 60 from 1 January 2014, when the revised CO_2 Act[8] allowed such an increase, because the intermediary target set for 2012 was not met.

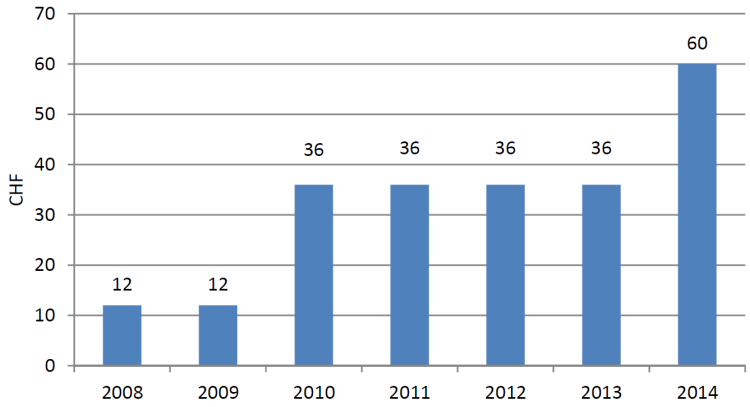

Figure 3: Swiss CO_2 levy in CHF

Energy-intensive companies can be exempted from the CO_2 levy. Before 2013, firms could be exempted from the CO_2 levy if they committed to reducing emissions in return. In 2013 the revised CO_2 Act defined a new instrument regarding energy-intensive industries with the implementation of a Swiss ETS. So a firm can be facing four different regimes: The CO_2 levy or three exempted cases (see Figure 4):

1. Firms with an installed capacity above 20 MW (activity according to Annex 6 of the CO_2 Ordinance) must participate in the ETS;
2. Firms with an installed capacity between 10 and 20 MW (and activity according to Annex 7 of the CO_2 Ordinance) can be exempted upon request and may voluntarily participate in ETS ("opt-in"); If they do not choose to opt-in, they have to commit to reduce their emissions;
3. Firms with an installed capacity below 10 MW (and activity according to Annex 7 of the CO_2 Ordinance) can be exempted upon request, but may not participate in ETS. But they have to commit to reduce their emissions.

Consequently, in each sector a firm could be facing four different carbon prices (i.e. the amount it would have to pay if it emitted one more ton of CO_2) according to its situation: the CO_2 levy, the ETS price, a cost of abatement related to its mandatory commitment or a price equal to 0 if the emissions of the sector are not covered by the CO_2 Act. The average CO_2 price in sector i would be :

$$CO_2\ price_i = (1-\alpha_i-\beta_i-\mu_i)\cdot CO2levy+\alpha_i\cdot PriceETS+\beta_i\cdot PriceNonETS+\mu_i\cdot 0 \quad (1)$$

where α_i is the share of ETS emissions in sector i, β_i is the share of emissions that are exempted from participating in the ETS and also exempted from the CO_2 levy, but

[8] https://www.admin.ch/opc/en/classified-compilation/20091310/index.html

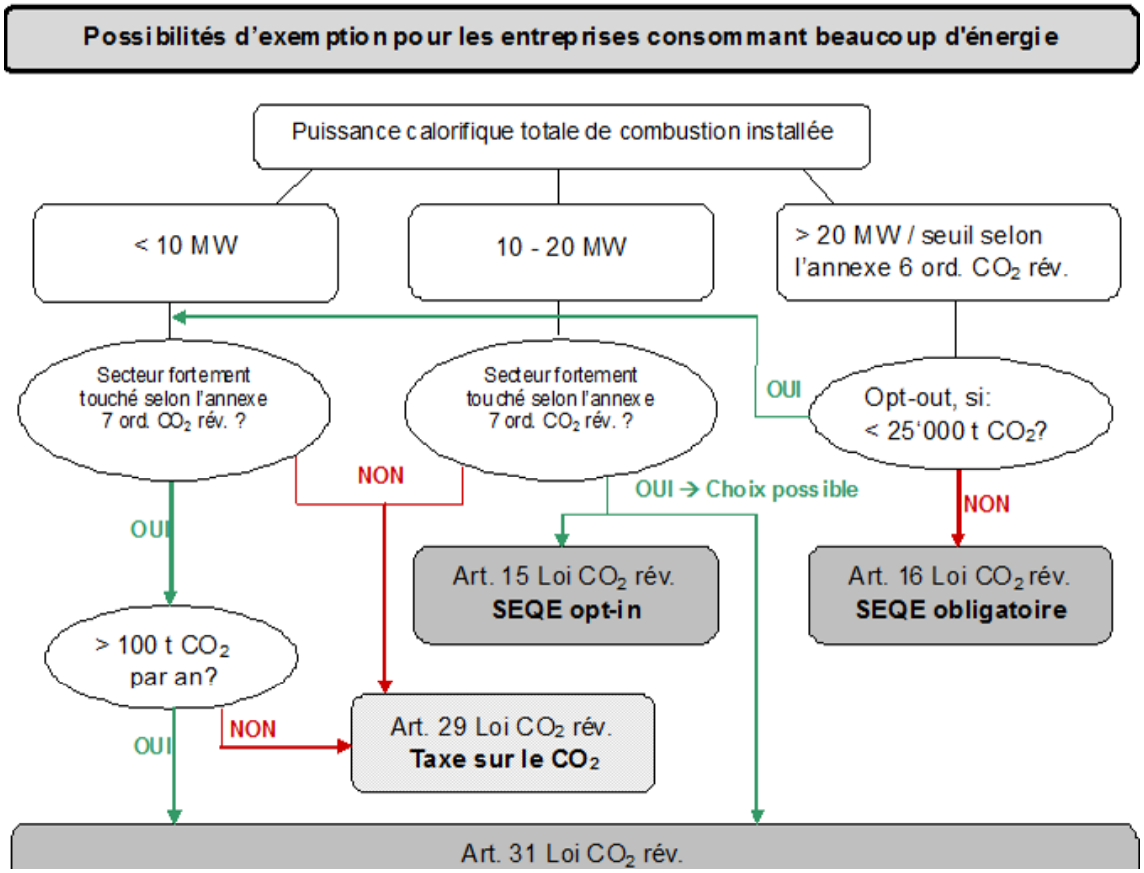

Figure 4: CO_2 levy exemption (Source: Federal Office for the Environment)

committed to reduce the emissions. $CO2levy$ is the CO_2 levy, $PriceETS$ is the ETS price and $PriceNonETS$ is the marginal abatement cost of firms that commit to mandatory abatement (also called in the literature the shadow CO_2 price). Finally, μ_i is equal to 1 if the emissions of the sector i are excluded from the CO_2 Act. That is the case for example of emissions from refineries until 2012, these emissions were included in the revised CO_2 Act in 2013 before 2013. For excluded emissions, the price is set to 0.

The marginal abatement cost of firms that commit to mandatory abatement is not known. Therefore, for numerical analyses we assume 3 different values for $PriceNonETS$:

1. First, we assume that $CO2levy$ and $PriceNonETS$ are equal. Indeed, if $PriceNonETS$ were superior to $CO2levy$ no firm would choose abatement measures that cost more than the CO_2 levy. Therefore, the CO_2 levy represents a ceiling on $PriceNonETS$;

2. We also simulate a scenario in which we assume that $PriceNonETS$ is equal to zero. The targets for CO_2 reduction commitments were set in a period of low energy prices. Their increase after 2000 would have induced energy efficiency improvements going beyond the commitments. Therefore, one could argue that for these exempted firms, the CO_2 Act provided no additional incentive regarding CO_2 abatement and the effective carbon price can be set to zero;

3. Finally, the last assumption retains an intermediate value where $PriceNonETS$ is equal to 50% of the $CO2levy$ level. This assumption will be retained in the reference case. Assumption 1. and 2. are used for sensitivity analyses.

We set the ETS price at 14.67 CHF per ton of CO_2 for the period 2013-2014. This corresponds to the average of the prices observed in the last three auctions in the Swiss ETS (i.e. (20+12+12)/3). For the period 2008-2012 the ETS price is set to zero.

Parameters α_i and β_i were computed from the Swiss emissions trading registry available online at the following address: https://www.emissionsregistry.admin.ch/crweb/public. We used details on the surrendered units for more than 400 Swiss firms. We associated to each firm a NOGA that represents the sector where the firm is conducting its main economic activity. The surrendered units by NOGA are presented in Table 2. In 2013, the CO_2 emissions from industrial processes (mainly those coming from the cement industry and chemical industry) were integrated in the CO_2 Act and therefore included in the Swiss ETS[9]. But the CO_2 emissions computed by GEMINI-E3 do not take into account the emissions coming from these processes. These emissions were therefore removed from the surrendered units by assuming that the allocations related to CO_2 emissions from energy combustion of these sectors follow their emissions between 2012 and 2013.

[9]See appendix 7.2 for the definition of GHG emissions that are included in the CO_2 Act.

Table 2: Surrendered units in tons of CO_2

NOGA	Sector definition	2008	2009	2010	2011	2012	2013
ETS							
10	Manufacture of food products						69'792
17	Manufacture of paper and paper products						181'412
19	Manufacture of coke and refined petroleum products						950'881
20	Manufacture of chemicals and chemical products						143'998
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations						140'258
23	Manufacture of other non-metallic mineral products						698'239
24	Manufacture of basic metals						188'729
35	Electricity, gas, steam and air-conditioning supply						473'221
52	Warehousing and support activities for transportation						30'600
Sum ETS							**2'877'131**
Non ETS							
01	Crop and animal production, hunting and related service activities	34'951	37'292	43'636	38'045	41'588	70'014
08	Other mining and quarrying	5'617	11'818	13'258	11'823	10'954	13'168
10	Manufacture of food products	404'624	385'498	386'792	364'651	432'637	262'403
11	Manufacture of beverages	29'925	27'481	27'110	24'685	24'333	20'650
12	Manufacture of tobacco products	9'702	10'827	10'342	9'541	9'259	10'431
13	Manufacture of textiles	37'832	32'337	31'675	32'283	31'370	32'205
15	Manufacture of leather and related products	3'643	3'485	4'748	8'716	10'396	3'651
16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	55'243	47'240	35'898	25'108	20'980	25'351
17	Manufacture of paper and paper products	209'582	198'048	211'506	217'956	209'802	36'741
18	Printing and reproduction of recorded media	5'701	5'593	5'725	3'021	3'076	2'859
19	Manufacture of coke and refined petroleum products	0	0	0	0	0	778
20	Manufacture of chemicals and chemical products	290'149	208'762	233'629	210'963	216'425	74'624
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	124'703	118'775	152'043	146'345	147'686	29'491
22	Manufacture of rubber and plastic products	36'010	40'381	36'126	37'271	35'665	38'477
23	Manufacture of other non-metallic mineral products	894'653	873'158	926'935	898'788	820'536	177'908
24	Manufacture of basic metals	237'228	187'780	220'847	228'619	242'424	59'194
25	Manufacture of fabricated metal products, except machinery and equipment	33'147	30'287	29'858	37'202	35'668	53'852
26	Manufacture of computer, electronic and optical products	2'558	2'428	2'622	18'112	10'011	12'229
27	Manufacture of electrical equipment	44'460	8'564	38'520	13'827	49'708	10'708
28	Manufacture of machinery and equipment n.e.c.	4'741	3'659	5'327	5'231	4'733	17'869
29	Manufacture of motor vehicles, trailers and semi-trailers	1'339	1'475	3'396	3'897	3'558	5'273
30	Manufacture of other transport equipment	0	0	0	0	0	1'449
31	Manufacture of furniture	1'966	1'492	1'597	1'723	1'647	2'979
32	Other manufacturing	0	0	0	0	0	748
35	Electricity, gas, steam and air-conditioning supply	130'462	116'100	141'165	161'572	120'079	35'983
37	Sewerage	7'476	7'617	5'465	3'756	4'739	21'763
38	Waste collection, treatment and disposal activities; materials recovery	324	68	16	17	17	961
41	Construction of buildings	3'932	4'833	6'925	8'598	7'876	6'560
42	Civil engineering	1'914	8'817	10'521	10'107	10'383	15'650
43	Specialised construction activities	0	1'438	1'415	1'434	1'256	7'030
46	Wholesale trade, except of motor vehicles and motorcycles	20'606	25'908	43'432	39'028	37'318	66'678
47	Retail trade, except of motor vehicles and motorcycles	14'056	15'342	23'982	13'571	14'329	11'182
49	Land transport and transport via pipelines	2'055	1'940	9'992	8'448	8'909	771
50	Water transport	4'574	3'925	3'831	3'797	3'649	2'940
52	Warehousing and support activities for transportation	0	0	0	0	0	871
55	Accommodation	7'603	7'369	9'049	7'324	7'043	33'871
62	Computer programming, consultancy and related activities	0	0	0	7'541	8'148	7'981
64	Financial service activities, except insurance and pension funding	4'465	7'858	8'286	10'039	7'789	33'827
65	Insurance, reinsurance and pension funding, except compulsory social security	4'003	3'810	4'261	4'872	4'686	5'021
66	Activities auxiliary to financial services and insurance activities	0	0	0	0	0	252
68	Real estate activities	181'770	148'349	114'201	49'066	904	875
70	Activities of head offices; management consultancy activities	12'828	15'786	13'831	13'326	13'888	41'369
71	Architectural and engineering activities; technical testing and analysis	0	0	0	0	0	3'153
81	Services to buildings and landscape activities	510	19'094	19'081	17'883	17'974	5'838
82	Office administrative, office support and other business support activities	257	7'647	7'892	9'116	11'005	10'829
84	Public administration and defence; compulsory social security	0	0	0	0	0	955
87	Residential care activities	0	0	276	140	106	0
93	Sports activities and amusement and recreation activities	3'892	3'685	3'394	3'357	3'248	3'303
94	Activities of membership organisations	283	294	286	264	263	60'718
96	Other personal service activities	6'877	8'284	8'860	9'844	8'882	12'539
	Non identified NOGA	0	0	0	0	0	1'420
Sum Non ETS		**2'875'661**	**2'644'544**	**2'857'751**	**2'720'907**	**2'654'947**	**1'355'392**
Sum ETS and non ETS		**2'875'661**	**2'644'544**	**2'857'751**	**2'720'907**	**2'654'947**	**4'232'523**
Total without Electricity, gas, steam and air-conditioning supply (35) and Manufacture of coke and refined petroleum products (19)		**2'745'199**	**2'528'444**	**2'716'586**	**2'559'335**	**2'534'868**	**2'770'240**

The table shows two distinct periods: 2008-2012 and 2013. During the first period, emissions that are exempted from the CO_2 levy decrease from 2.9 to 2.7 million tons of CO_2 (-8%), but after 2012 the exempted CO_2 emissions jump to 4.2 million tons of CO_2 with the introduction of new sources. Indeed with the revision of the CO_2 Act, more CO_2 sources were included: mainly refineries and electricity generation[10]. These emissions are included in the new Swiss emissions trading system that accounts for 2.9 million tons of CO_2[11], while the former system covered only 1.4 million tons of CO_2.

The surrendered units by NOGA are aggregated using the GEMINI-E3 classification. Next we compute the parameters α_i and β_i by dividing the surrendered units by the total emissions (computed by the model) for each sector. One further adjustment was necessary. In 2013, the sum of surrendered units concerning electricity and heat supply were slightly greater than the emissions computed by GEMINI-E3 for these two sectors. That can be explained by some statistical discrepancies between the two classifications. We assume that for these two sectors all emissions are not taxed by the CO_2 levy and are integrated mainly in the ETS in 2013. Tables 3 and 4 show the values of α and β per sector. In 2014, we assume that these parameters remain constant at their 2013 values.

Table 3: Share of non-ETS tax-exempted emissions (β)

	2008	2009	2010	2011	2012	2013
03 Natural gas	0%	0%	0%	0%	0%	0%
04 Petroleum products	0%	0%	0%	0%	0%	0%
05 Electricity	0%	0%	0%	0%	0%	0%
06 Services of public heat supply	40%	35%	41%	56%	41%	12%
07 Agriculture, Forestry and fishing	19%	19%	24%	23%	27%	46%
08 Chemical, rubber and plastic products	28%	24%	28%	28%	29%	11%
09 Other non-metallic mineral products	81%	80%	88%	94%	86%	18%
10 Basic metals	58%	46%	53%	59%	63%	15%
11 Food products, beverage and tobacco products	55%	50%	53%	54%	64%	39%
12 Pulp, paper, paper products, wood and wood products	41%	37%	40%	42%	42%	11%
13 Fabricated metal products, except machinery and equipment	11%	10%	11%	15%	15%	23%
14 Other Industries	9%	5%	9%	9%	13%	10%
15 Services	5%	5%	5%	4%	3%	7%
16 Land transport	1%	1%	5%	4%	4%	0%
17 Sea transport	39%	29%	31%	33%	31%	25%
18 Air transport	0%	0%	0%	0%	0%	0%
Total	21%	19%	21%	23%	22%	11%

4 The historical scenario

4.1 Methodology

The calibration of the GEMINI-E3 model on the historical economic development was achieved in two steps. First the international economic environment is calibrated to reproduce world energy prices and world GDP growth. The following variables were calibrated:

[10] The emissions from refineries and from electricity generation were exempted from 2008 until 2012.

[11] The 2.9 million cover only CO_2-emissions from energy combustion and from refineries. If we include process emissions, the ETS covers around 5.6 million tons of CO_2.

Table 4: Share of ETS emissions (α)

	2008	2009	2010	2011	2012	2013
03 Natural gas						0%
04 Petroleum products						93%
05 Electricity						100%
06 Services of public heat supply						88%
07 Agriculture, Forestry and fishing						0%
08 Chemical, rubber and plastic products						19%
09 Other non-metallic mineral products						72%
10 Basic metals						47%
11 Food products, beverage and tobacco products						9%
12 Pulp, paper, paper products, wood and wood products						32%
13 Fabricated metal products, except machinery and equipment						0%
14 Other Industries						0%
15 Services						1%
16 Land transport						0%
17 Sea transport						0%
18 Air transport						0%
Total						24%

Table 5: Share of emissions not included in the CO_2 law (μ)

	2008	2009	2010	2011	2012	2013
03 Natural gas						
04 Petroleum products	100%	100%	100%	100%	100%	
05 Electricity	100%	100%	100%	100%	100%	
06 Services of public heat supply						
07 Agriculture, Forestry and fishing						
08 Chemical, rubber and plastic products						
09 Other non-metallic mineral products						
10 Basic metals						
11 Food products, beverage and tobacco products						
12 Pulp, paper, paper products, wood and wood products						
13 Fabricated metal products, except machinery and equipment						
14 Other Industries						
15 Services						
16 Land transport						
17 Sea transport						
18 Air transport						

- The exchange rates are fixed exogenously and equal to the historical values;
- Energy commodities prices (i.e. crude oil, coal and natural gas) are calibrated on their historical values (see Figure 5) by adjusting a variable that represents the rents related to the fossil energy resources. The energy rent is the difference between the world price of the energy resource and its total cost of production;
- The annual GDP changes are calibrated on their historical variations for the 4 countries/regions by adjusting labor productivity, with special attention to Europe and USA, Switzerland's main trading partners.

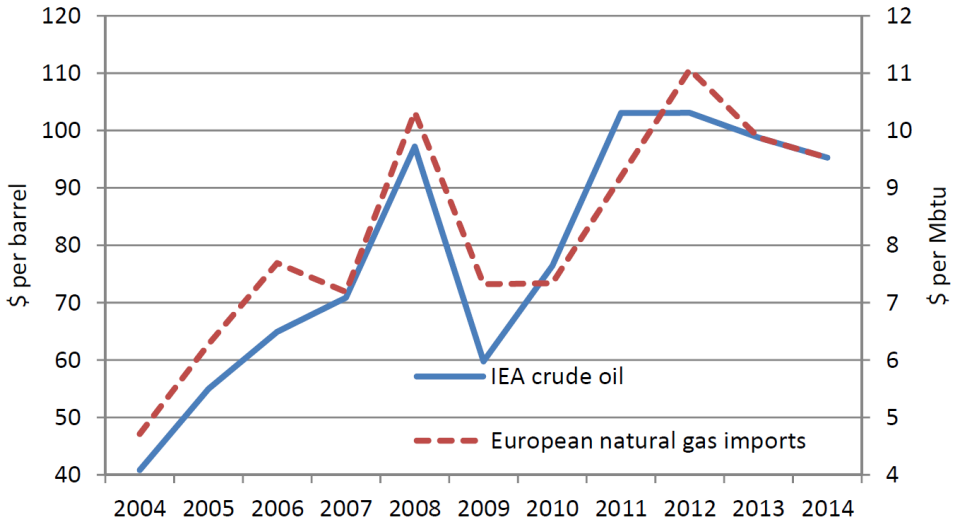

Figure 5: IEA crude oil import prices (left axis) and European natural gas import prices (right axis) in real terms (2008 prices)

The second step aims at reproducing in greater detail the development of the Swiss economy and its energy consumption. We have implemented the following protocol:

- The main economic aggregates (GDP, imports, exports, investment and consumption) are calibrated by adjusting labor productivity, the rate of saving and the CES parameters of the imports functions;
- Total energy consumption but also energy consumption by energy commodities are calibrated by the rate of autonomous energy efficiency improvement (AEEI) [2], and also through the rate of technical progresses associated to each commodity;
- We checked that the evolution of production for all sectors is close to its historical development;

We also implemented a carbon price as defined in section 3 and in equation (1).

The methodology used is the following. First we compute technical progresses (associated to labor and energy) in order to reproduce the economic trends between the two years 2008

and 2014. Then these technical progresses and other parameters are adjusted to reproduce as much as possible the yearly change between 2008 and 2014 of CO_2 emissions, GDP aggregates. In practice the aim is not to reproduce exactly these sets of variables, but more to reproduce their evolutions. Indeed some statistical discrepancies exist between the GEMINI-E3 database and the available statistical databases for several reasons. For example with the revision of the National accounts 2014, the values of the SIOT are not completely consistent with the revised national accounts. The new NOGA 2008 could not be properly linked with the one that was used to built the SIOT, because the definitions of the sectors are not exactly the same.

As a general rule, we assume that the model reproduces the past sufficiently accurate when the differences in absolute value between the run of the model and the historical values are less that 15%. However we apply more severe criteria (less than 5% difference on growth rate of macroeconomic aggregates) for aggregated variables like GDP and total CO_2 emissions.

4.2 Results

Table 6 shows the effective CO_2 prices that are implemented in each sector for the year 2013, based on the equation (1) and the parameters β and α given respectively in Tables 3 and 4. Figure 6 shows the evolution of Swiss GDP growth over the period 2009-2014. We observe that GEMINI-E3 reproduces it very accurately. Figure 7 presents the CO_2 emissions computed by GEMINI-E3 and reports the historical values for comparison purpose. We count CO_2 emissions from energy combustion excluding those coming from the energy sector which are not included in the CO_2 law up to 2012 (see appendix 7.2). Table 7 decomposes these CO_2 emissions by sector.

Table 6: Effective CO_2 prices by sector in 2013

	$PriceNonETS =$		
	zero	50% $CO2Levy$	$CO2Levy$
03 Natural gas	36	36	36
04 Petroleum products	16	16	16
05 Electricity	15	15	15
06 Services of public heat supply	13	15	17
07 Agriculture, Forestry and fishing	19	28	36
08 Chemical, rubber and plastic products	28	30	32
09 Other non-metallic mineral products	14	17	21
10 Basic metals	21	23	26
11 Food products, beverage and tobacco products	20	27	34
12 Pulp, paper, paper products and wood products	25	27	29
13 Fabricated metal products, except machinery and equipment	28	32	36
14 Other Industries	32	34	36
15 Services	33	35	36
16 Land transport	36	36	36
17 Sea transport	27	31	36
18 Air transport	36	36	36

Table 7: Swiss CO_2 emissions from energy combustion in Mt CO_2

	2008		2009		2010		2011		2012		2013	
	Historical values	Gemini-E3	Historical values	Gemini-E3	Historical values	Gemini-E3	Historical values	Gemini-E3	Historical values	Gemini-E3	Historical values	Gemini-E3
Energy	**3.8**	**3.4**	**3.7**	**3.4**	**3.8**	**3.5**	**3.6**	**3.4**	**3.6**	**3.3**	**3.6**	**3.4**
Conversion	1.9	1.5	1.8	1.5	1.9	1.5	1.7	1.4	1.7	1.4	1.8	1.4
Wastes	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	2.0	2.0	1.8	2.0
Industry	**5.9**	**5.9**	**5.6**	**5.9**	**5.7**	**5.7**	**5.3**	**5.3**	**5.3**	**5.1**	**5.4**	**5.2**
Transport	**16.5**	**15.7**	**16.3**	**16.3**	**16.2**	**16.0**	**16.1**	**16.0**	**16.2**	**16.1**	**16.1**	**16.2**
Interior airlines	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Road and railways	16.3	15.5	16.1	16.0	16.0	15.8	15.8	15.8	15.9	15.9	15.8	16.0
Households	11.2	10.7	11.1	11.3	11.1	11.1	10.9	11.1	10.8	11.2	10.6	11.3
Firms	5.1	4.8	5.0	4.8	4.9	4.8	4.9	4.7	5.2	4.7	5.2	4.7
Navigation	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other sectors	**16.0**	**17.2**	**15.5**	**16.9**	**16.7**	**17.6**	**13.6**	**14.4**	**14.8**	**15.2**	**15.7**	**15.6**
Agriculture	0.6	0.8	0.6	0.8	0.6	0.8	0.6	0.7	0.5	0.7	0.5	0.7
Services	4.9	5.6	4.8	5.9	5.1	5.8	4.2	4.8	4.6	4.9	4.9	5.0
Households	10.5	10.8	10.2	10.3	11.0	11.0	8.8	8.9	9.7	9.6	10.3	9.9
Army	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Total	**42.3**	**42.4**	**41.3**	**42.6**	**42.6**	**42.9**	**38.6**	**39.1**	**40.0**	**39.8**	**40.9**	**40.5**

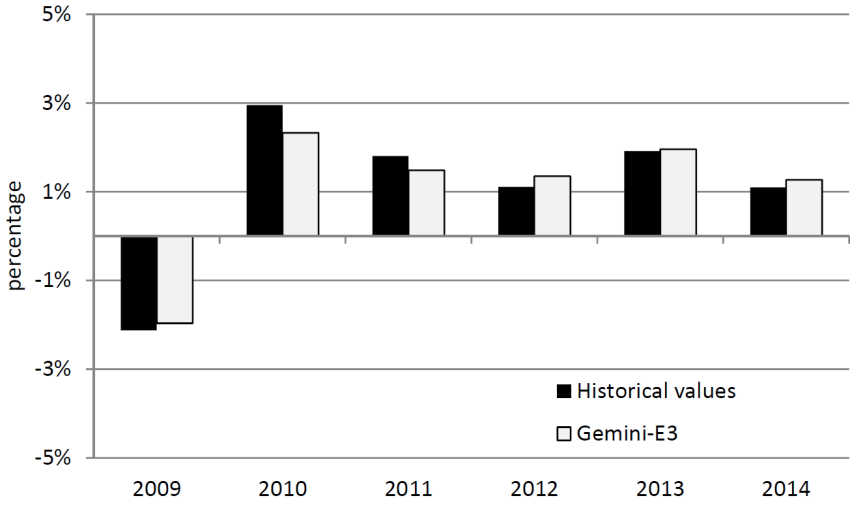

Figure 6: GDP growth

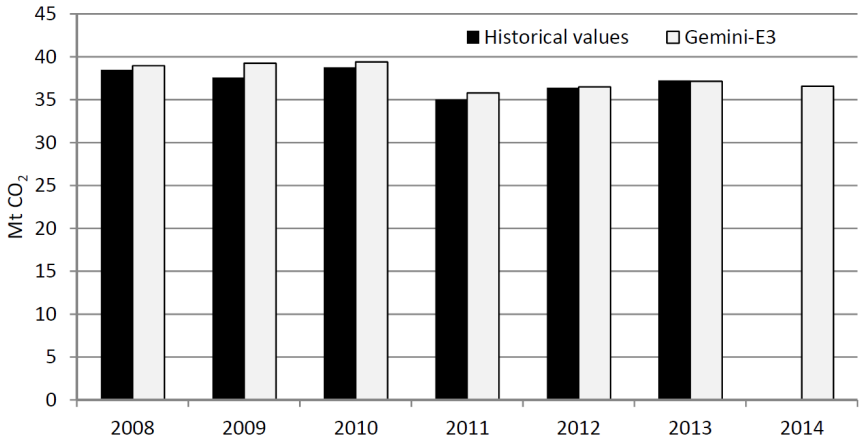

Figure 7: Swiss CO_2 emissions (CO_2 from energy combustion minus CO_2 from energy sector)

5 A counterfactual analysis

5.1 Reference case

In this section we run the model without the CO_2 prices (CO_2 levy, $PriceNonETS$ and ETS prices). Figure 8 compares the evolution of Swiss CO_2 emissions from 1990 to 2013 with and without the CO_2 prices. Table 8 shows the impact of the CO_2 levy in Mt of CO_2 and in % by sectors for the years 2008-2014. It compares the emissions computed by the model with CO_2 prices and the scenario where we remove all these carbon prices.

Table 8: Impact of the CO_2 prices on CO_2 emissions with $PriceNonETS$=0.5 × $CO2levy$

	2008		2009		2010		2011		2012		2013		2014		2008-2014	
	in Mt	in %	in Mt	in %	in Mt	in %	in Mt	in %	in Mt	in %	in Mt	in %	in Mt	in %	in Mt	in %
Energy	**0.0**	**-0.2%**	**0.0**	**-0.2%**	**0.0**	**-0.7%**	**0.0**	**-0.5%**	**0.0**	**-0.5%**	**0.0**	**-0.4%**	**0.0**	**-0.4%**	**-0.1**	**-0.4%**
Conversion	0.0	-0.4%	0.0	-0.6%	0.0	-1.5%	0.0	-1.1%	0.0	-1.2%	0.0	-0.9%	0.0	-1.0%	-0.1	-0.9%
Waste	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
Industry	**-0.1**	**-1.0%**	**-0.1**	**-1.5%**	**-0.2**	**-3.9%**	**-0.2**	**-3.4%**	**-0.2**	**-3.2%**	**-0.2**	**-3.3%**	**-0.3**	**-5.3%**	**-1.2**	**-3.0%**
Transport	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**-0.1%**	**0.0**	**-0.1%**	**0.0**	**-0.1%**	**0.0**	**-0.1%**	**0.0**	**-0.2%**	**-0.1**	**-0.1%**
Domestic airlines	0.0	0.0%	0.0	0.0%	0.0	-0.1%	0.0	-0.1%	0.0	-0.1%	0.0	0.0%	0.0	-0.1%	0.0	-0.1%
Road & railways	0.0	0.0%	0.0	0.0%	0.0	-0.1%	0.0	-0.1%	0.0	-0.1%	0.0	-0.1%	0.0	-0.2%	-0.1	-0.1%
Households	0.0	0.0%	0.0	0.0%	0.0	-0.1%	0.0	-0.1%	0.0	-0.1%	0.0	-0.1%	0.0	-0.2%	-0.1	-0.1%
Firms	0.0	-0.1%	0.0	-0.1%	0.0	-0.2%	0.0	-0.2%	0.0	-0.2%	0.0	-0.2%	0.0	-0.3%	-0.1	-0.2%
Navigation	0.0	-0.2%	0.0	-0.3%	0.0	-0.8%	0.0	-0.7%	0.0	-0.7%	0.0	-0.7%	0.0	-1.2%	0.0	-0.7%
Other sectors	**-0.1**	**-0.5%**	**-0.1**	**-0.8%**	**-0.4**	**-2.1%**	**-0.3**	**-1.9%**	**-0.3**	**-1.8%**	**-0.3**	**-1.9%**	**-0.5**	**-3.1%**	**-2.0**	**-1.7%**
Agriculture	0.0	-0.3%	0.0	-0.4%	0.0	-0.9%	0.0	-0.8%	0.0	-0.7%	0.0	-0.6%	0.0	-1.0%	0.0	-0.7%
Services	-0.1	-1.1%	-0.1	-1.6%	-0.3	-4.3%	-0.2	-3.9%	-0.2	-3.8%	-0.2	-3.8%	-0.3	-6.4%	-1.3	-3.5%
Households	0.0	-0.3%	0.0	-0.4%	-0.1	-1.0%	-0.1	-0.9%	-0.1	-0.9%	-0.1	-1.0%	-0.2	-1.6%	-0.6	-0.8%
Army	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**
Total	**-0.2**	**-0.4%**	**-0.2**	**-0.6%**	**-0.6**	**-1.5%**	**-0.5**	**-1.3%**	**-0.5**	**-1.2%**	**-0.5**	**-1.2%**	**-0.8**	**-2.0%**	**-3.4**	**-1.2%**
Total without emissions from Energy	**-0.2**	**-0.4%**	**-0.2**	**-0.6%**	**-0.6**	**-1.6%**	**-0.5**	**-1.3%**	**-0.5**	**-1.3%**	**-0.5**	**-1.3%**	**-0.8**	**-2.1%**	**-3.3**	**-1.2%**

Differences wrt the scenario where all CO_2 prices (CO_2 levy, ETS price and shadow price for non-ETS exempted firms) are equal to zero.

For example in 2010, the impact of the CO_2 prices is evaluated to 200'000 tonnes of CO_2 for the industry sector. The estimated cumulated impact on CO_2 emissions is equal to 3.3 Mt of CO_2 over 2008-2014. Figure 9 shows the yearly abatement from 2008 to 2014, Figure 10 gives the contribution of each sector to the cumulative abatement.

The industry contributes 36% of this abatement, the other sectors represent 60% (mainly services and households[12] whose contributions are respectively equal to 40% and 18%), the remaining 4% are done by the transport sector. Figure 11 gives the breakdown of industrial CO_2 abatement. The chemical industry represents 35% of the industrial abatement, followed by food products (14%) and pulp paper and wood industries (19%).

It is interesting to note that the services sector was the most important contributor to CO_2 abatement over the period 2008-2014. It emits approximately as much CO_2 from energy consumption as the industry sector, but since these emissions are much less concentrated in firms with international exposure, the services sector benefitted from nearly none of the exemptions granted to industrial firms. Households contributed relatively little to CO_2 abatement because transport fuels were exempted and because the effects of the Building Program were deliberately filtered out of these simulations.

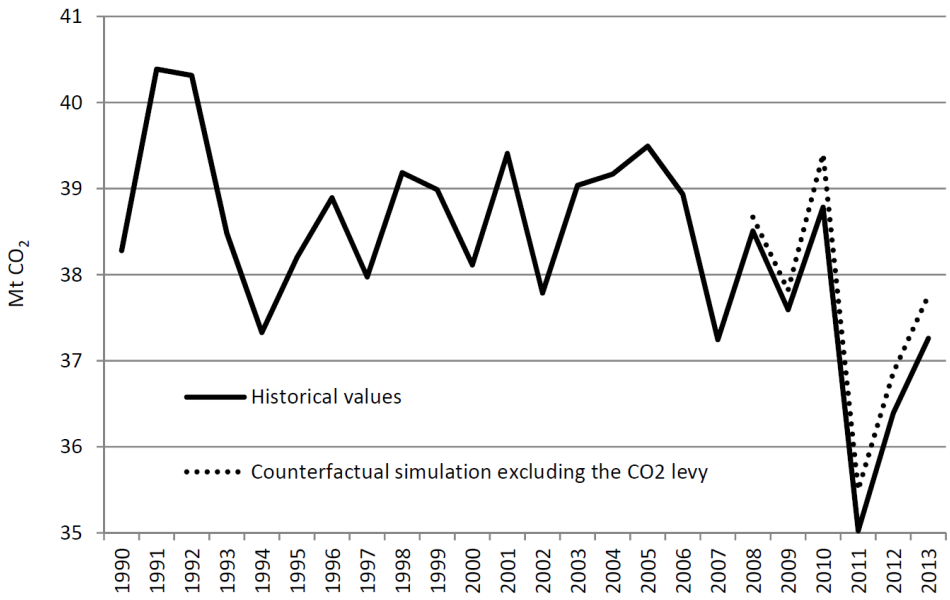

Figure 8: Historical CO_2 emissions (CO_2 from energy combustion minus CO_2 from energy sector) and the counterfactual scenario excluding CO_2 levy for the period 2008-2013

The abatement of CO_2 emissions is characterized by two peaks, one in 2010 and another one in 2014 (see Figure 9). Each of them follows the increase of the CO_2 levy (from 12 CHF to 36 CHF in January 2010 and from 36 CHF to 60 CHF in January 2014). After 2010, even if the CO_2 levy remains equal to 36 CHF up to 2013, the impact of the levy on energy prices is reduced by an increase of international energy prices in 2011 (see Figure 5) which explains the decrease of CO_2 abatement induced by the levy after 2010. It should also be noted that in 2013 the introduction of the Swiss CO_2 ETS moderates the impact

[12]excluding emissions from transportation purposes that are included in transport sector in Table 8.

of the CO_2 levy rise in industrial sectors, as we estimate that the CO_2 ETS price was equal to 14.67 CHF per ton of CO_2.

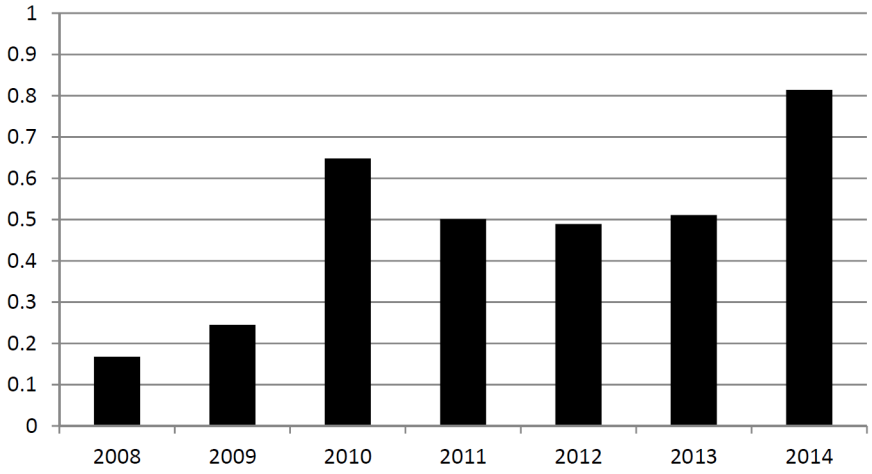

Figure 9: CO_2 emissions abatement in Mt CO_2 for the period 2008-2014

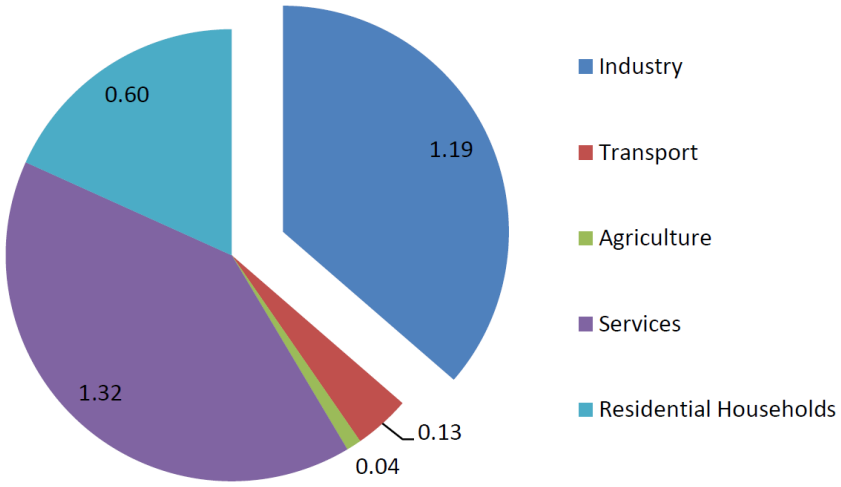

Figure 10: Sectorial breakdown of CO_2 emissions abatement in Mt CO_2 for the period 2008-2014 (see industrial breakdown in figure 11)

5.2 Sensitivity analysis

5.2.1 Non-ETS exempted emissions and their associated shadow price

In this subsection we analyse the impacts of alternative assumptions about the level of the $PriceNonETS$ because this implicit price of the abatement obligations imposed on firms exempted from the CO_2 levy is particularly difficult to estimate. In theory, these firms were supposed to abate as much as if they had faced the CO_2 levy, in which case they would

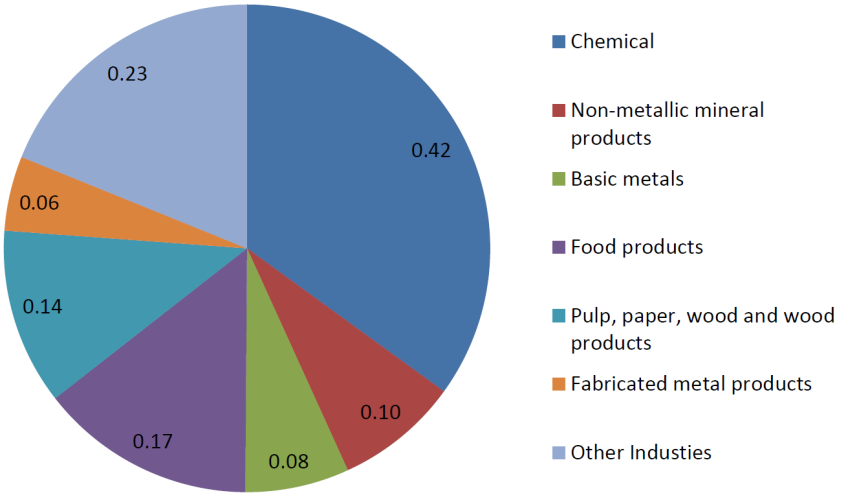

Figure 11: Industrial breakdown of CO_2 emissions abatement in Mt CO_2 for the period 2008-2014

have abated up to the point where the abatement of one more ton of CO_2 abatement would have cost as much as the CO_2 levy[13]. If that had been the case, $PriceNonETS$ would have been equal to the rate of the carbon levy. In reality, the abatement commitments were calculated in the early 2000 based on an assessment of the abatement that would have been profitable for these firms under current market conditions if they had to pay the CO_2 levy. When the levy was finally introduced and the commitments became binding, market conditions and mitigation options had changed so much that it was actually profitable for these firms to abate substantially more than what had been calculated. In effect, the commitments were not binding for most firms, which corresponds to a zero (marginal) cost of CO_2 emissions. Therefore we perform two new simulations where the CO_2 price for the firms that are exempted to CO_2 levy is respectively equal to the CO_2 levy or to zero. As can be seen in Figure 12, the effects on CO_2 emissions are limited and would result in a cumulated increase (decrease) of CO_2 emissions reductions equal to 0.26 (-0.27) Mt CO_2 corresponding to a variation of $\pm$ 8%. Tables 9 and 10 detail by sectors the impacts on CO_2 emissions of the two alternative assumptions about the $PriceNonETS$.

[13]The gain from the tax exemption is simply equal to the CO_2 levy that they do not have to pay on their residual CO_2 emissions.

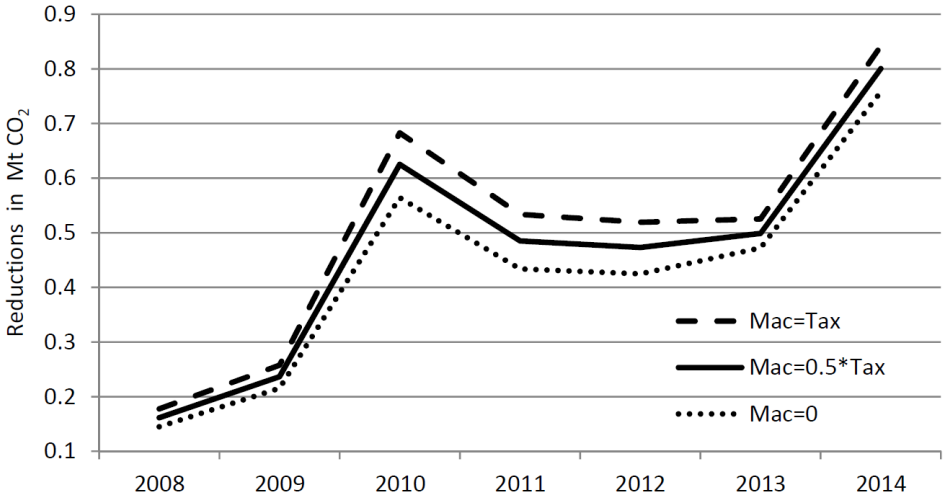

Figure 12: Impacts on CO_2 abatement of alternative assumptions about the stringency of commitments by non-ETS tax-exempted firms ($PriceNonETS$)

Table 9: Impact of the CO_2 levy on CO_2 emissions with $PriceNonETS$=0

	2008		2009		2010		2011		2012		2013		2014		2008-2014	
	in Mt	in %	in Mt	in %	in Mt	in %	in Mt	in %	in Mt	in %	in Mt	in %	in Mt	in %	in Mt	in %
Energy	**0.0**	**-0.1%**	**0.0**	**-0.2%**	**0.0**	**-0.5%**	**0.0**	**-0.3%**	**0.0**	**-0.4%**	**0.0**	**-0.3%**	**0.0**	**-0.4%**	**-0.1**	**-0.3%**
Conversion	0.0	-0.3%	0.0	-0.5%	0.0	-1.2%	0.0	-0.8%	0.0	-0.9%	0.0	-0.8%	0.0	-0.9%	-0.1	-0.8%
Waste	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
Industry	**0.0**	**-0.8%**	**-0.1**	**-1.2%**	**-0.2**	**-3.0%**	**-0.1**	**-2.6%**	**-0.1**	**-2.4%**	**-0.2**	**-3.0%**	**-0.3**	**-4.7%**	**-1.0**	**-2.5%**
Transport	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**-0.1%**	**0.0**	**-0.1%**	**0.0**	**-0.1%**	**0.0**	**-0.1%**	**0.0**	**-0.2%**	**-0.1**	**-0.1%**
Domestic airlines	0.0	0.0%	0.0	0.0%	0.0	-0.1%	0.0	-0.1%	0.0	-0.1%	0.0	0.0%	0.0	-0.1%	0.0	-0.1%
Road & railways	0.0	0.0%	0.0	0.0%	0.0	-0.1%	0.0	-0.1%	0.0	-0.1%	0.0	-0.1%	0.0	-0.2%	-0.1	-0.1%
Households	0.0	0.0%	0.0	0.0%	0.0	-0.1%	0.0	-0.1%	0.0	-0.1%	0.0	-0.1%	0.0	-0.2%	-0.1	-0.1%
Firms	0.0	0.0%	0.0	-0.1%	0.0	-0.2%	0.0	-0.2%	0.0	-0.2%	0.0	-0.2%	0.0	-0.3%	0.0	-0.2%
Navigation	0.0	-0.2%	0.0	-0.3%	0.0	-0.7%	0.0	-0.6%	0.0	-0.6%	0.0	-0.6%	0.0	-1.1%	0.0	-0.6%
Other sectors	**-0.1**	**-0.5%**	**-0.1**	**-0.8%**	**-0.4**	**-2.0%**	**-0.3**	**-1.9%**	**-0.3**	**-1.8%**	**-0.3**	**-1.8%**	**-0.5**	**-3.0%**	**-1.9**	**-1.7%**
Agriculture	0.0	-0.2%	0.0	-0.4%	0.0	-0.8%	0.0	-0.7%	0.0	-0.6%	0.0	-0.4%	0.0	-0.7%	0.0	-0.5%
Services	-0.1	-1.1%	-0.1	-1.6%	-0.25	-4.2%	-0.19	-3.8%	-0.2	-3.7%	-0.2	-3.7%	-0.3	-6.1%	-1.3	-3.4%
Households	0.0	-0.3%	0.0	-0.4%	-0.11	-1.0%	-0.08	-0.9%	-0.1	-0.9%	-0.1	-1.0%	-0.2	-1.6%	-0.6	-0.8%
Army	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**
Total	**-0.1**	**-0.4%**	**-0.2**	**-0.5%**	**-0.6**	**-1.3%**	**-0.4**	**-1.1%**	**-0.4**	**-1.1%**	**-0.5**	**-1.2%**	**-0.8**	**-1.9%**	**-3.1**	**-1.1%**
Total without emissions from Energy	**-0.1**	**-0.4%**	**-0.2**	**-0.5%**	**-0.6**	**-1.4%**	**-0.4**	**-1.2%**	**-0.4**	**-1.1%**	**-0.5**	**-1.3%**	**-0.8**	**-2.0%**	**-3.0**	**-1.1%**

Differences wrt the scenario where the CO_2 levy and the ETS price are equal to zero (reference case where the shadow price for non-ETS exempted firms is equal to zero).

Table 10: Impact of the CO_2 prices on CO_2 emissions with $PriceNonETS{=}CO2levy$

	2008		2009		2010		2011		2012		2013		2014		2008-2014	
	in Mt	in %	in Mt	in %	in Mt	in %	in Mt	in %	in Mt	in %	in Mt	in %	in Mt	in %	in Mt	in %
Energy	**0.0**	**-0.2%**	**0.0**	**-0.3%**	**0.0**	**-0.8%**	**0.0**	**-0.6%**	**0.0**	**-0.6%**	**0.0**	**-0.4%**	**0.0**	**-0.5%**	**-0.1**	**-0.5%**
Conversion	0.0	-0.5%	0.0	-0.7%	0.0	-1.8%	0.0	-1.4%	0.0	-1.4%	0.0	-1.0%	0.0	-1.2%	-0.1	-1.1%
Waste	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
Industry	**-0.1**	**-1.3%**	**-0.1**	**-1.8%**	**-0.3**	**-4.7%**	**-0.2**	**-4.2%**	**-0.2**	**-4.0%**	**-0.2**	**-3.6%**	**-0.3**	**-5.8%**	**-1.4**	**-3.6%**
Transport	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**-0.1%**	**0.0**	**-0.1%**	**0.0**	**-0.1%**	**0.0**	**-0.1%**	**0.0**	**-0.2%**	**-0.1**	**-0.1%**
Domestic airlines	0.0	0.0%	0.0	0.0%	0.0	-0.1%	0.0	-0.1%	0.0	-0.1%	0.0	0.0%	0.0	-0.1%	0.0	-0.1%
Road & railways	0.0	0.0%	0.0	0.0%	0.0	-0.1%	0.0	-0.1%	0.0	-0.1%	0.0	-0.1%	0.0	-0.2%	-0.1	-0.1%
Households	0.0	0.0%	0.0	0.0%	0.0	-0.1%	0.0	-0.1%	0.0	-0.1%	0.0	-0.1%	0.0	-0.2%	-0.1	-0.1%
Firms	0.0	-0.1%	0.0	-0.1%	0.0	-0.2%	0.0	-0.2%	0.0	-0.2%	0.0	-0.2%	0.0	-0.3%	-0.1	-0.2%
Navigation	0.0	-0.2%	0.0	-0.4%	0.0	-0.9%	0.0	-0.8%	0.0	-0.8%	0.0	-0.8%	0.0	-1.4%	0.0	-0.8%
Other sectors	**-0.1**	**-0.6%**	**-0.1**	**-0.8%**	**-0.4**	**-2.1%**	**-0.3**	**-1.9%**	**-0.3**	**-1.9%**	**-0.3**	**-1.9%**	**-0.5**	**-3.2%**	**-2.0**	**-1.7%**
Agriculture	0.0	-0.3%	0.0	-0.4%	0.0	-1.0%	0.0	-0.9%	0.0	-0.8%	0.0	-0.8%	0.0	-1.3%	0.0	-0.8%
Services	-0.1	-1.2%	-0.1	-1.7%	-0.3	-4.4%	-0.2	-3.9%	-0.2	-3.8%	-0.2	-4.0%	-0.3	-6.6%	-1.4	-3.6%
Households	0.0	-0.3%	0.0	-0.4%	-0.1	-1.0%	-0.1	-0.9%	-0.1	-0.9%	-0.1	-1.0%	-0.2	-1.6%	-0.6	-0.8%
Army	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**
Total	**-0.2**	**-0.4%**	**-0.3**	**-0.6%**	**-0.7**	**-1.6%**	**-0.6**	**-1.4%**	**-0.5**	**-1.3%**	**-0.5**	**-1.3%**	**-0.9**	**-2.1%**	**-3.7**	**-1.3%**
Total without emissions from Energy	**-0.2**	**-0.5%**	**-0.3**	**-0.7%**	**-0.7**	**-1.7%**	**-0.5**	**-1.5%**	**-0.5**	**-1.4%**	**-0.5**	**-1.4%**	**-0.8**	**-2.3%**	**-3.5**	**-1.3%**

Differences wrt the scenario where the CO_2 levy and the ETS price are equal to zero (reference case where the shadow price for non-ETS exempted firms is equal to the CO_2 levy).

5.2.2 CO_2 abatement by firms included in the Swiss ETS

We would like to determine the effectiveness of the ETS market, i.e. estimate how much CO_2 abatement was contributed by firms participating in the ETS market. The counterfactual is that these firms would have been entirely exempted from any obligation to reduce their CO_2 emissions or, alternatively, that the number of emission permits allocated to these firms exceeded their needs. Therefore, we simulate a scenario where we set the ETS price to zero while keeping the CO_2 levy and the $PriceNonETS$ at their historical values for the other firms. Table 9 shows the differences between CO_2 emissions in this scenario and those of the historical scenario. Before 2013 there are none, as the Swiss ETS was only implemented in 2013. For the years 2013-2014, the cumulative emissions reductions by ETS firms that can be attributed to the ETS regime are only 45,000 tons of CO_2[14]. This is of course the consequence of a very low ETS price in these two years, which reflects the abundance of permits allocated to these firms.

[14] without taking into account emissions from the energy sector.

Table 11: Impact of the ETS price on CO_2 emissions (Scenario with $PriceETS$=0)

	2008		2009		2010		2011		2012		2013		2014		2008-2014	
	in Mt	in %	in Mt	in %	in Mt	in %	in Mt	in %	in Mt	in %	in Mt	in %	in Mt	in %	in Mt	in %
Energy	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**-0.01**	**-0.3%**	**-0.01**	**-0.3%**	**-0.02**	**-0.1%**
Conversion	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	-0.01	-0.6%	-0.01	-0.7%	-0.02	-0.2%
Waste	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%
Industry	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**-0.02**	**-0.4%**	**-0.02**	**-0.4%**	**-0.04**	**-0.1%**
Transport	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.00**	**0.0%**	**0.00**	**0.0%**	**0.00**	**0.0%**
Domestic airlines	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%
Road & railways	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%
Households	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%
Firms	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%
Navigation	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%
Other sectors	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.00**	**0.0%**	**0.00**	**0.0%**	**0.00**	**0.0%**
Agriculture	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%
Services	0.0	0.0%	0.0	0.0%	0.00	0.0%	0.00	0.0%	0.0	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%
Households	0.0	0.0%	0.0	0.0%	0.00	0.0%	0.00	0.0%	0.0	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%
Army	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.00**	**0.0%**	**0.00**	**0.0%**	**0.00**	**0.0%**
Total	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**-0.03**	**-0.1%**	**-0.03**	**-0.1%**	**-0.06**	**0.0%**
Total without emissions from Energy	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**0.0**	**0.0%**	**-0.02**	**-0.1%**	**-0.02**	**-0.1%**	**-0.05**	**0.0%**

Differences between historical emissions and those of a scenario where the ETS price is equal to zero.

6 Conclusion

In this part of the report we used a computable general equilibrium model to quantify the impacts of the CO_2 levy and the associated carbon prices on Swiss CO_2 emissions for the period 2008-2014. We used the CGE model GEMINI-E3 to simulate two scenarios, with and without the CO_2 prices. The comparison of these two scenarios shows that the cumulative reduction in CO_2 emissions (i.e. the sum of all reductions over the entire period corresponding to 2008-2014) attributable to these CO_2 prices was equal to 3.3 Mt of CO_2, or about 1.2% of the estimated emissions without these CO_2 prices. Figure 13 disaggregates this total reduction between sectors and regulatory regimes. It shows that the services sector contributed more reduction than industry and that the exemption regimes were very favourable indeed. The exemption regimes from the CO_2 levy complicated the analysis, calling for hypotheses about the stringency of the regimes imposed on tax exempted firms. We subjected these hypotheses to sensitivity analyses. They showed that the uncertainty stemming from these exemption regimes is moderate. It adds a margin of error of $\pm$ 8% to the total calculated CO_2 reduction. Finally we must recall that these are estimations of the effects of the CO_2 levy and its exemptions regimes alone. Thus, the revenues of the CO_2 levy were modelled as being entirely refunded to firms and households. In reality, a substantial part of these revenues were used to promote building refurbishments and the use of renewable energy sources, which of course induced additional abatement. For example, the annual CO_2 reduction attributable to the Building Program (parts A and B) in 2013 has been evaluated at 121,000 tons of CO_2 [1]. This figure can be compared to the 500,000 tons of CO_2 reductions we estimated as an effect of the CO_2 levy and associated carbon prices for the same year.

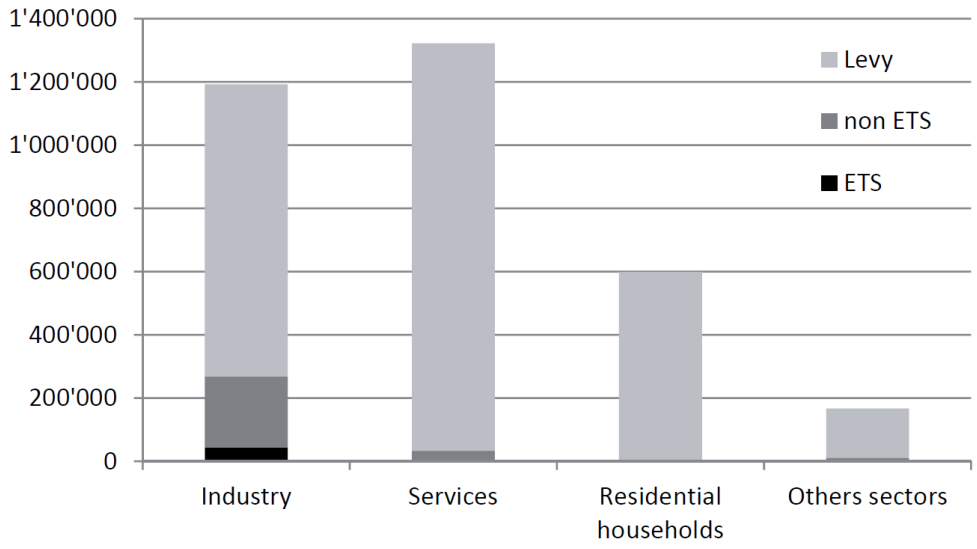

Figure 13: Cumulative abatement by regimes and sectors over the period 2008-2014 in tons of CO_2

References

[1] Le programme bâtiments en 2013 - rapport annuel. Technical report, 2013. 27

[2] Christian Azar and Hadi Dowlatabadi. A review of technical change in assessment of climate policy. *Annual Review of Energy and the Environment*, 24(1):513–544, 1999. 14

[3] Frédéric Babonneau, Alain Haurie, Richard Loulou, and Marc Vielle. Combining stochastic optimization and monte carlo simulation to deal with uncertainties in climate policy assessment. *Environmental Modeling & Assessment*, 17(1-2):51–76, 2012. ISSN 1420-2026. 4

[4] Frédéric Babonneau, Alain Haurie, and Marc Vielle. A robust meta-game for climate negotiations. *Computational Management Science*, 10(4):299–329, 2013. ISSN 1619-697X. 4

[5] Badri Narayanan, Angel Aguiar, and Robert McDougall, editors. *Global Trade, Assistance, and Production: The GTAP 8 Data Base*. Center for Global Trade Analysis, Purdue University, 2012. 4

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

[7] A. Bernard, S. Paltsev, J.M. Reilly, M. Vielle, and L. Viguier. Russia's Role in the Kyoto Protocol. Report 98, MIT Joint Program on the Science and Policy of Global Change, Cambridge MA, June 2003. 4

[8] A. Bernard, M. Vielle, and L. Viguier. Burden Sharing Within a Multi-Gas Strategy. *Energy Journal*, Multigas Mitigation and Climate Policy, Special Issue #3:289–304, 2006. 4

[9] Alain Bernard and Marc Vielle. Assessment of european union transition scenarios with a special focus on the issue of carbon leakage. *Energy Economics*, 31, Supplement 2(0):S274 – S284, 2009. ISSN 0140-9883. 4

[10] P.B. Dixon and M.T. Rimmer. *Dynamic General Equilibrium Modelling for Forecasting and Policy, Volume 256 of Contributions to Economic Analysis*. Elsevier Science B.V., 2002. 3

[11] C. Nathani, D. Sutter, R. van Nieuwkoop, M. Peter, S. Kraner, M. Holzhey, H. Rütter, and R. Zandonella. Energy related disaggregation of the Swiss Input-Output Table. Technical report, SFOE, EWG Publication, Bern, 2011. 4

[12] André Sceia, Juan-Carlos Altamirano-Cabrera, Marc Vielle, and Nicolas Weidmann. Assessment of acceptable swiss post-2012 climate policies. *Swiss Journal of Economics and Statistics (SJES)*, 148(II):347–380, 2012. 4

[13] Swiss Confederation. *Switzerland's Sixth National Communication and First Biennial Report under the UNFCCC*. 2013. 3

[14] US Environmental Protection Agency. The benefits and costs of the clean air act from 1990 to 2020. Technical report, 2011. 3

[15] M. Vielle and L. Viguier. On the Climate Change Effects of High Oil Prices. *Energy Policy*, 35(2):844–849, February 2007. 4

7 Appendix

7.1 Elasticities used in this version of GEMINI-E3

The elasticities used in GEMINI-E3 are guess-estimated, based on a review of the literature and discussion with our research partners at Ecoplan. In this study, we retain a set of low elasticities (with respect to the standard values that are usually used in GEMINI-E3) because we conduct a short-term analysis of the CO_2 levy. These elasticities are shown in Tables 12 and 13, the labels refer to the ones that are used in Figures 1 and 2.

Table 12: Elasticities in nested CES production structure

	σ	σ_e	σ_{ef}	σ_{mm}	σ_m	σ_{tra}	σ_{trap}	σ_{trao}
01 Coal	0.1	0.1	0.1	0.2	0.2	0.3	0.1	0.2
02 Oil	0.1	0.1	0.1	0.2	0.2	0.3	0.1	0.2
03 Natural gas	0.1	0.1	0.2	0.2	0.2	0.3	0.1	0.2
04 Petroleum products	0.1	0.1	0.1	0.2	0.2	0.3	0.1	0.2
06 Services of public heat supply	0.4	0.3	0.4	0.2	0.2	0.3	0.1	0.2
07 Agriculture, forestry and fishing	0.4	0.3	0.4	0.2	0.2	0.3	0.1	0.2
08 Chemical, rubber and plastic products	0.4	0.3	0.4	0.2	0.2	0.3	0.1	0.2
09 Other non-metallic mineral products	0.4	0.3	0.4	0.2	0.2	0.3	0.1	0.2
10 Basic metals	0.4	0.3	0.4	0.2	0.2	0.3	0.1	0.2
11 Food products, beverage and tobacco products	0.4	0.3	0.4	0.2	0.2	0.3	0.1	0.2
12 Pulp, paper, paper products, etc	0.4	0.3	0.4	0.2	0.2	0.3	0.1	0.2
13 Fabricated metal products, except machinery and equipment	0.4	0.3	0.4	0.2	0.2	0.3	0.1	0.2
14 Other Industries	0.4	0.3	0.4	0.2	0.2	0.3	0.1	0.2
15 Services	0.4	0.3	0.4	0.2	0.2	0.3	0.1	0.2
16 Land transport	0.4	0.3	0.2	0.2	0.2	0.3	0.1	0.2
17 Sea transport	0.4	0.3	0.2	0.2	0.2	0.3	0.1	0.2
18 Air transport	0.4	0.3	0.2	0.2	0.2	0.3	0.1	0.2

Table 13: Elasticities in nested CES consumption structure

σ^{hc}	0.2
σ^{hres}	0.05
σ^{hoth}	0.2
σ^{htra}	0.4
σ^{hrese}	0.2
σ^{hresef}	0.4
σ^{htrap}	0.1
σ^{htrao}	0.2

7.2 Definition of emissions included in the Swiss CO_2 law

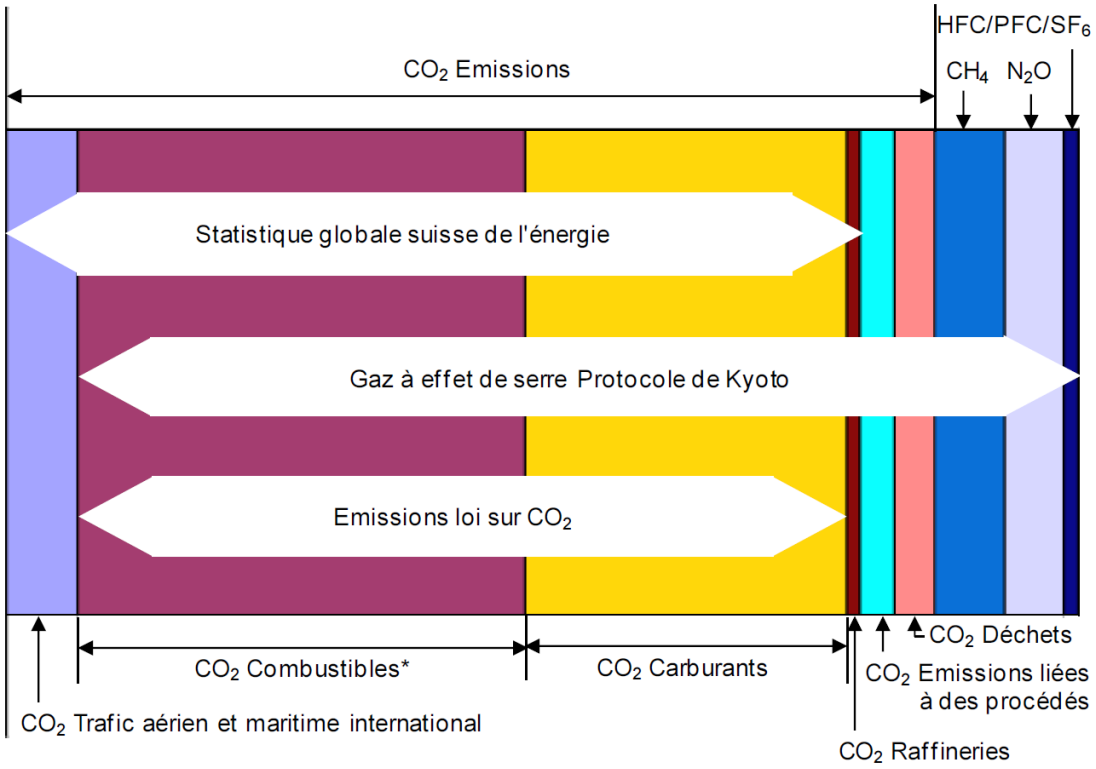

Figure 14: Definition of emissions included in the CO_2 Law up to 2012 (Source: Federal Office for the Environment)

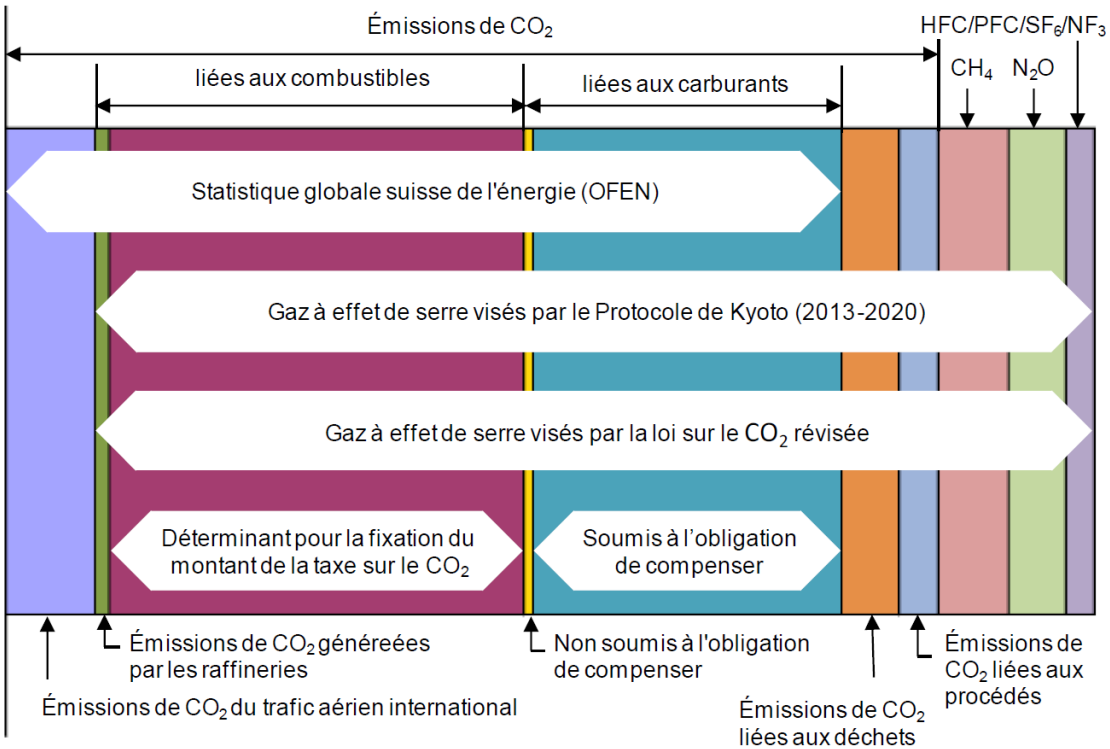

Figure 15: Definition of emissions included in the CO_2 Law after 2012 (Source: Federal Office for the Environment)