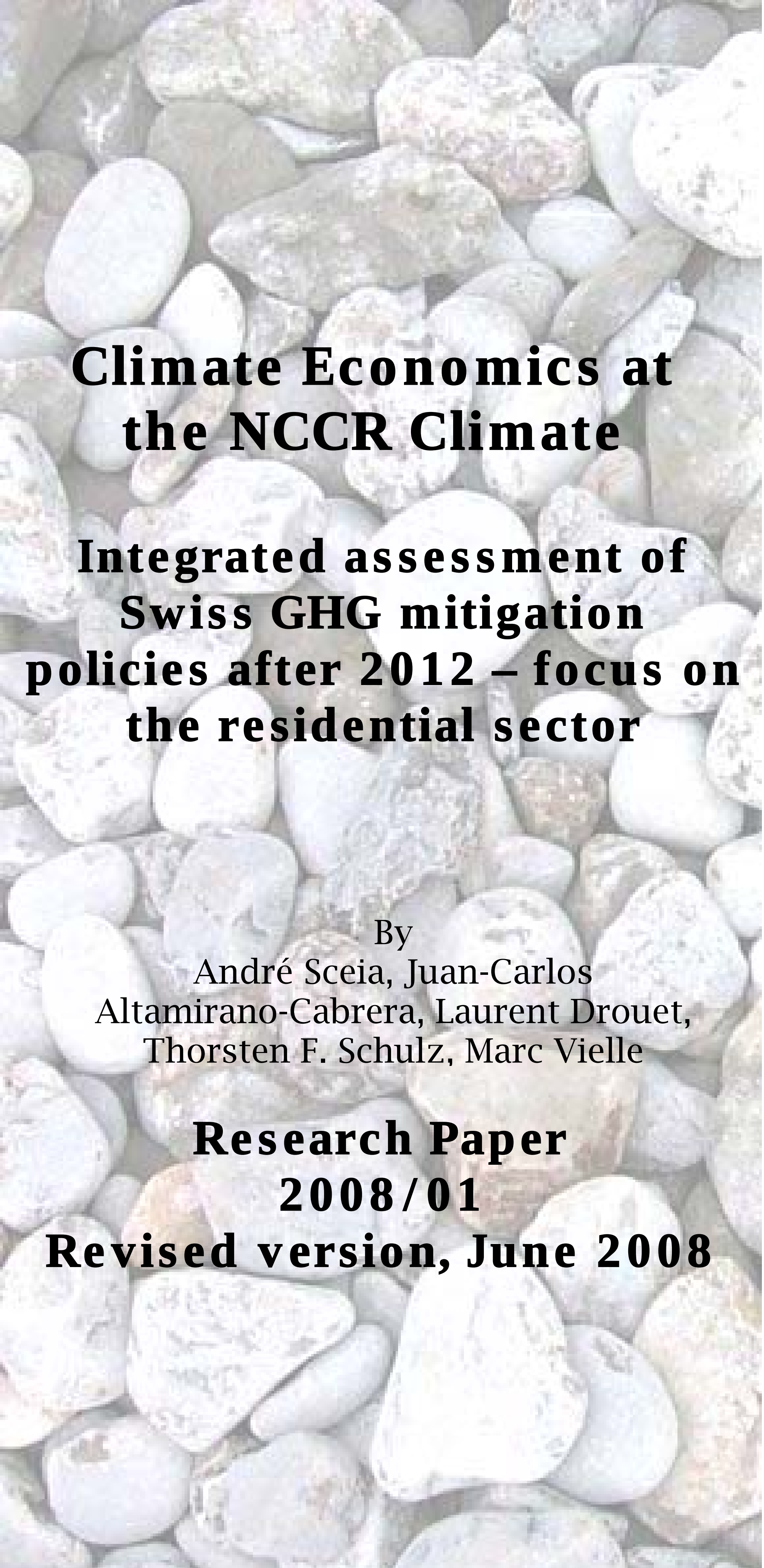

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Integrated assessment of Swiss GHG mitigation policies after 2012 – focus on the residential sector

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Integrated assessment of Swiss GHG mitigation policies after 2012 - focus on the residential sector

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Abstract

The residential sector presents a great potential for greenhouse gases (GHG) mitigation. We perform an integrated assessment of different mitigation policies for Switzerland focusing on the residential sector. We analyze the case of pure incentive taxes and technical regulations. For our analysis, we have coupled a general equilibrium model with a Swiss residential energy model. We find that a progressive GHG tax of more than 200 USD_{2000}/tCO_2eq is necessary to reach a target of 50% reduction of GHG emissions in 2050. Finally, we find that technical regulations do not provide additional abatement incentives.

JEL classification: Q54; C68; H23

Keywords: Swiss residential sector; Climate policy; Top-down and bottom-up

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1 Introduction

In many industrialized countries, the residential sector accounts for an important and increasing share of greenhouse gases (GHG) emissions. For instance, in 2005, the Swiss residential sector was responsible for 22.3% of total GHG emissions. These emissions are mainly due to the combustion of light fuel oil used for room and water heating. When we add the emissions from transport to those of the residential sector, they represent more than half of the total GHG emissions, a huge proportion when we consider that industry was only responsible for 21.6%. This Swiss specificity is mainly due to two factors. First, the major part of high energy goods are imported into Switzerland, indeed, the Swiss economy is more based on services than on heavy industry. Secondly, the electricity is produced at almost 95% from hydroelectric and nuclear powerplants. The residential sector presents some of the more interesting low hanging fruits with regard to GHG abatement. Energy saving investments like insulation will become increasingly profitable if energy prices keep on rising. Moreover, efficient technologies for space and water heating, e.g. heat pumps and solar, are available today for both houses and apartment buildings. With that in mind, it makes perfect sense for policy makers to target the residential sectors when devising climate policies.

The current Swiss climate policy will comply with the objectives fixed in the Kyoto Protocol, though they are not sufficient to meet the objectives of the current CO_2 Law that prescribes a further emissions reduction. The Law advocates for a reduction of 2.9 million tons of CO_2. According to current estimates, there will be an excess emissions of 0.5 million tons of CO_2 with respect to the objective fixed by the Law. Considering the post 2012 climate policy, in February 2008, the Swiss Federal Council decided to launch a revision of the CO_2 Law. It decided to follow similar targets as the European Union, i.e. at least 20% reduction of GHG by 2020 and 50% by 2050. A consultation procedure on this revision is planned in order to compare various envisaged instruments: a pure incentive tax (the revenue of which would be redistributed to households), a tax financing national or international abatement or adaptation measures as well as technical regulations.

The objective of this paper is to assess some of the instruments envisaged for the the revision of the Swiss CO_2 Law. We focus on the residential sector given its potential when it comes to GHG abatement. To attain our objective we devise a coupled model, combining a global economic model (GEMINI-E3) with a Swiss residential energy use model (MARKAL-CHRES). The benefit of coupling a top-down Computable General Equilibrium (CGE) with a bottom-up energy use models is twofold. On one hand, it allows to estimate the consequences of global or national policies on the Swiss economy and more specifically on the Swiss residential sector. On the other hand, the coupled model allows to test policies targeting the energy use in the Swiss residential sector and to asses their impact on the overall economy.

The coupling between top-down and bottom-up models has already been explored in the literature (see, among other, Manne and Richels (1992); Böhringer (1998); Pizer et al. (2003); Drouet et al. (2005); Schfer and Jacoby (2006); Löschel and Soria (2007); Wing (2006). We have nevertheless followed an approach relatively different from those used by these authors. In Pizer et al. (2003), Schfer and Jacoby (2006) and Löschel and Soria (2007) the coupling has been mainly carried out in the calibration phase of the modeling; bottom-up models were used to calibrate some of the parameters in the top-down models.

Different from them, we have linked the models in the simulation phase. In Böhringer (1998) and Wing (2006), technology details have been directly incorporated in a CGE model. In contrast, we have worked with existing bottom-up and top-down models and tried to keep them as close as possible from their original formulation. Therefore, both models have been kept separate, while linking them with a coupling module. Manne and Richels (1992) incorporated a reduced CGE model in a bottom-up model. In contrast, we tried to keep our CGE as complete as possible, allowing for a more complete and realistic interpretation of the results for the forthcoming consultation procedure on the future of the Swiss CO_2 law. Finally, until now, the only coupling paper specifically targeted to the Swiss residential sector is Drouet et al. (2005). They have devised an hybrid model where the residential sector is completely removed from the top-down model and it is replaced by an exogenous and separate bottom-up model.

This paper aims at further developing the coupling methodology, dynamically integrating the results from the bottom-up model into the top-down without touching the interactions between the residential sector and the rest of the economy. The coupling procedure we have implemented allows for estimating CO_2 or GHG taxes in response to national emission targets. Furthermore, it allows for enforcing technical regulations in the residential sector. Finally, the coupled model allows an integrated analysis of the implication of the policies on the Swiss and the global economy as well as on the Swiss residential sector. From our analysis, we find that in Switzerland, without emissions trading mechanisms, the rapid implementation of a progressive GHG tax reaching more than 200 USD per ton of CO_2 equivalent (USD/tCO_2eq) would be necessary in order to achieve a GHG abatement of 50% in 2050. With such levels of taxation, we also find that technical regulations do not bring additional incentives to abate emissions.

The paper is organized as follows: section 2 presents both GEMINI-E3 and MARKAL-CHRES models, section 3 explains how the baseline scenario of the models has been calibrated, section 4 presents the coupling procedure and a sensitivity analysis of the coupled model, section 5 presents the policy scenarios, section 6 the numerical results and section 7 concludes.

2 Models

2.1 GEMINI-E3

The complete GEMINI-E3 is a dynamic-recursive CGE model that represents the world economy in 28 regions (including Switzerland) and 18 sectors. It incorporates a highly detailed representation of indirect taxation (Bernard and Vielle, 1998). For this study, we use an aggregated version of the model in 6 regions, i.e. Switzerland (CHE), European Union (EUR), other European and Euro-asian countries (OEU), Japan (JAP), USA, Canada, Australia and New Zealand (OEC) and other countries, mainly developing countries (PVD). The model is formulated as a Mixed Complementarity Problem , which is solved using GAMS and the PATH solver (Ferris and Pang, 1997; Ferris and Munson, 2000). 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 have completed the data from the GTAP database with information on indirect taxation and government expenditures from the International Energy Agency (International Energy Agency, Quartely Statitics 2005, 2002a,b), the OECD (Organisation For Economic Co-operation and Development, 2005, 2003) and the International Monetary Fund (International Monetary Fund, 2004). For Switzerland, we used data from 2001 input-output table devised at the Swiss Federal Institute of Technology (ETH) Zürich (Nathani et al., 2006) which we transformed in the GEMINI-E3 format (Sceia et al., 2007). All the data on emissions and abatement costs for non CO_2 GHG come from the U.S. Environmental Protection Agency (United States Environmental Protection Agency, 2006). For a complete description of GEMINI-E3 see Bernard and Vielle (2008).

Various versions of the model have been used to analyze the implementation of economic instruments allowing for GHG emissions reductions in a second-best setting (Bernard and Vielle, 2000). The following studies are examples of various analyzes carried out with GEMINI-E3: assessment of the strategic allocation of GHG emission allowances in the enlarge EU market (Viguier et al., 2006), analysis of the behavior of Russia with regard to the ratification process of the Kyoto Protocol (Bernard et al., 2003), assessment the cost of implementation of the Kyoto protocol in Switzerland with and without international emissions trading (Bernard et al., 2005), or assessment of the effects of an increase of oil prices on global and 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 rates of interest and exchange rates). Terms of trade (i.e. transfers of real income between countries resulting from variations of relative prices of imports and exports) and "real" exchange rates can also be accurately modeled.

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 allow the calibration and the coupling of GEMINI-E3 with MARKAL-CHRES, we have replaced the Stone-Geary utility function by a nested constant elasticity of substitution (CES) function. The nesting structure is shown in Figure 1. The σ_x refer to the elasticity parameter of each node. The version of GEMINI-E3 we use for this research only uses petroleum products as input in the transportation energy nest.

Finally, in order to better match the actual Swiss taxation scheme, we have differentiated excise taxes for heating oil from those of petroleum products used as transportation fuels. In order to do so, we have introduces a base excise tax ($ExTax_{base}$), fixed at the level of the 2001 residential excise tax, and a supplementary excise tax ($ExTax_{sup}$) applied only in the transportation sector. Therefore, in the residential sector, we use a final consumption price equal to $PC = (PB + ExTax_{base}) \times (1 + vat)$, where PB is the production price and vat the rate of value added tax. In the transportation sector, we add the supplementary excise and therefore $PC_{trans} = PC + ExTax_{sup}(1 + vat)$. Which is equivalent to $PC_{trans} = (PB + ExTax_{base} + ExTax_{sup}) \times (1 + vat)$.

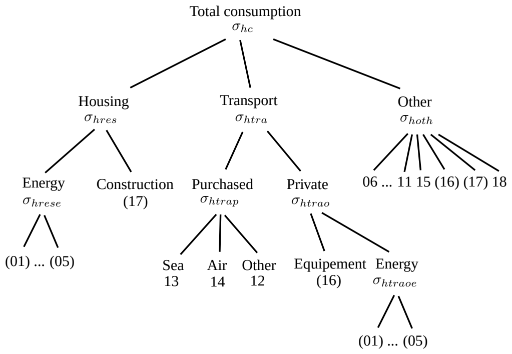


Figure 1: Structure of the households' nested CES utility function

2.2 MARKAL-CHRES

The MARKAL-CHRES is an energy model describing the Swiss residential energy system. It is based on the Swiss MARKAL model witch was recently taken over and further developed by researchers at the Paul Scherrer Institute (PSI) where is has been used, among other, to analyze the Swiss 2000W society initiative (Schulz et al., 2008). The MARKAL-CHRES is a subset of the complete Swiss model. It is restricted to technologies related to the residential sector and considers final energies as being imported with exogenous prices. The model contains 173 technologies using different energies sources, i.e. coal, oil, gas, electricity, wood, pellets and district heat.

The model base year (2000) is calibrated to the International Energy Agency (IEA) and Swiss General Energy statistics of the year 2000. The model has a time horizon of 50 years and it is divided into eleven time periods each with a duration of five years except the base year (2000, 2001–2005, 2006–2010, . . . , 2046–2050). The residential energy sector of the model includes 14 energy demand segments (see Table 1). The most important segments are the Room-Heating (RH) segments which represent more than 70% of final energy demand. We distinguish four different demand categories for RH: Single and Multi Family Houses as well as existing and new buildings. In the model we assume that dwellings constructed after the year 2000 are new buildings.

The model uses USD_{2000} as currency, therefore all monetary value are discounted to year 2000 values using a 1.5% discount rate.

One of the particularities of the MARKAL-CHRES model is to describe precisely a set of technologies which allow for energy savings in various processes. The idea behind those technologies is to take into account the reduction of energy demand which follows certain types of investment. For example, installing double windows increases isolation and therefore reduces heating demand.

For a more detailed description of the technologies used in the MARKAL-CHRES model, see Schulz (2007).

Table 1: 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

3 Baseline

3.1 Assumptions

In order to perform a first coupling attempt we have assumed that world energy prices are only slightly affected by changes in the energy use in Switzerland and are therefore kept fixed at the baseline levels in the MARKAL-CHRES. Moreover, the total households' consumption (energy and non energy), which could be used as a proxy for the useful energy demands in the the residential sector, does not greatly vary from the baseline to the counterfactual. Therefore, the useful energy demands in MARKAL-CHRES are kept constant.

Furthermore, in the MARKAL-CHRES model, population and economic estimates (e.g. GDP) together with construction estimations are used in order to estimate the Reference Energy Area (REA), i.e. the total useful surface of all heated rooms. The heating demands or useful energy used for heating (TJ/year) is equal to the Specific Room Heating Demand (MJ/m^{2}year) multiplied by REA (Mio m^2).

The Swiss Federal Office of Energy provides estimates of the REA until 2035. Values until 2050 are extrapolated. With regard to energy prices, we assume an annual increase of 1%.

In GEMINI-E3 population assumptions are based on United Nations medium scenario. The Swiss population is expected to grow until 2030 at a level of approximately 7.4 million people and then slowly decrease to reach 7.25 in 2050. Finally, according to the projections by SECO (2004), the annual average GDP growth rate is expected to be 1.2% from 2001 to 2020, and 0.6% from 2020 to 2050. We also use the projections from DOE (2006) for oil, gas and coal prices.

3.2 Aligning the baselines emissions

We import the fuel mix from MARKAL-CHRES in GEMINI-E3 in order to align the emissions in the residential sector between the two models. The annual variation of the total energy consumption in GEMINI-E3 Swiss residential sector is aligned to the variation of the total use of energy in MARKAL-CHRES. Moreover, the shares between the different energies are defined using the fuel mix. Furthermore, we set the growth of the technical progress in the private transport energy nest and of the general technical progress on the use of fossil fuels to 1.25% in order to have the total CO_2 emissions baseline decline by 13% between 2000 and 2035 as forecasted by OFEN (2007). Figure 2 shows the baseline CO_2 and other GHG emissions calculated by GEMINI-E3 using the fuel mix from MARKAL-CHRES. Emissions of other GHG are transformed into CO_2 equivalent (CO_2eq) for comparison and and summing requirements. They represent the amount of CO2 that would have the same global warming potential, when measured over a specified timescale. The natural decline of emissions is partly due to the availability of costless abatement measures, but also to the existing energy and climate policy instruments (R&D, fuel taxes, . . .).

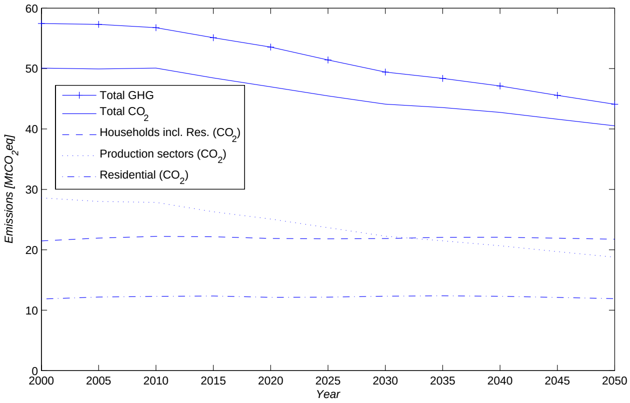


Figure 2: Baseline CO_2 and GHG emissions

4 Coupling

CGE models allow for an explicit representation of the economy and are based on sound micro-economic foundations. From highly aggregated formulations it is always possible to disaggregate some parts of the model but they, nevertheless, fail to depict precisely the evolution of substitution among technologies or the actual energy use, respecting the physical energy conservation principles. In that respect, bottom-up models perform much better. At the opposite, because bottom-up models focus mainly on rich technology representation and cost minimization objectives, they fail to represent the complex market interactions which are dealt with by top-down models.

With that in mind, we have used the MARKAL-CHRES model to calculate the fuel mixes in the residential sector and used them in GEMINI-E3 to calculate emissions as well as all other macroeconomic variables. In order to do so, the share parameters in the residential energy nest are defined using the values calculated by the MARKAL-CHRES and the elasticity σ_{hres} is set to 0. In other words, we use a Leontief formulation in the residential energy nest. When relative fuel prices change, the substitution for the housing sector are therefore computed by MARKAL-CHRES.

4.1 Coupling method

In this paper we use a simple dichotomic procedure, which is sufficient in the case of a single control variable, in our case the CO_2 or GHG taxes. Indeed, in our coupled model, emissions in the target year are monotonic decreasing with respect to the tax. This ensures that our simple coupling module finds the unique optimal tax for each abatement target.

The coupling module functions as follows: we first initialize the minimum and maximum bounds for the tax (t_{min} and t_{max}), the tax level (tax), the emission target ($\bar{e}$) and the initial emission calculated by GEMINI-E3 ($e = G(tax, fm)$). While the difference between emissions in the target year and the emission target is greater than a defined threshold ($|e - \bar{e}| > 0.01$) and while the tax variation between 2 runs in greater than another set threshold ($|tax_{-1} - tax| > 0.01$), we run MARKAL-CHRES to calculate the fuel mix ($fm = M(tax)$) and then GEMINI-E3 to calculate the total emissions in the target year ($e = G(tax, fm)$). If the total emissions are lower than the target we redefine the the upper bound of the tax ($t_{max} = tax$) else we redefine the lower bound ($t_{min} = tax$). We store the tax level for future comparisons ($tax_{-1} = tax$) and define the new tax ($tax = t_{min} + (t_{max} - t_{min})/2$).

fm is the fuel mix matrix in the residential sector calculated by MARKAL-CHRES and is defined as follows:

$$fm = \begin{pmatrix} fm_{coal,2000} & fm_{coal,2005} & \cdots & fm_{coal,2050} \\ fm_{gas,2000} & fm_{gas,2005} & \cdots & fm_{gas,2050} \\ fm_{petr,2000} & fm_{petr,2005} & \cdots & fm_{petr,2050} \\ fm_{elec,2000} & fm_{elec,2005} & \cdots & fm_{elec,2050} \end{pmatrix}.$$

$fm_{coal,t}$, $fm_{gas,t}$, $fm_{petr,t}$ and $fm_{elec,t}$ are respectively the energy consumptions of coal, gas, petroleum products and electricity in the year t.

Figure 3 presents this coupling schema, where the tax is the variable that allows to control both models, the residential fuel mix is the coupling variable ensuring that GEMINI-E3 calculates emissions on the basis of the MARKAL-CHRES simulations and the total emissions in the target year are the optimization variable ensuring that the coupled models converge to the target defined by policymakers.

4.2 Sensitivity analysis of the coupled model

Figure 4 shows the sensitivity of the model to various levels of taxation. The lines represent taxes of 0 (plain), 50 (dash-dot), 100 (plus), 150 (star) and 200 USD/tCO_2eq (circles);

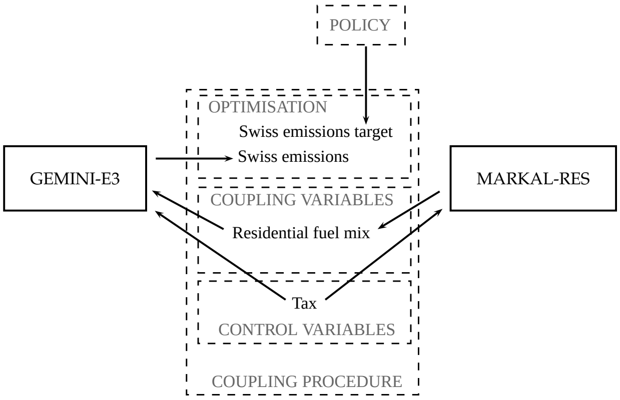


Figure 3: Coupling structure

colors are used to differentiate between the various types of emissions (see legend). The figure shows that both the total CO_2 and total GHG emission decline strongly when the progressive tax is set up to reach 150 USD/tCO_2eq by 2050. With such taxation levels, the residential sector, which presents high substitution potentials in this coupled framework, exhausts all its abatement potential as early as 2035. The figure also demonstrates that households private transportation , the other side of the households' emission, is quite inelastic. This is a consequence of having only petroleum products as source of energy for households private transportation as well as having incorporated the existing differentiation in the taxation of petroleum products according to their use. The CO_2 tax affects more the relative prices of heating oil than those of gasoline or diesel.

Figure 5 shows the additional abatement in 2020 and 2050 at various levels of tax for both the original GEMINI-E3 and the coupled model. It is interesting to notice that a pure CGE model like GEMINI-E3 allows for stronger abatement than the coupled model when it comes to relatively small taxes. Nevertheless, it is not able to model the substitution to future efficient but expensive technologies when taxes over 100 USD/tCO_2eq are introduced. Therefore, only the coupled model enables us to reach the high levels of abatement we are expecting in 2050 with realistic taxation levels. We observe in Figure 4 that the abatement possibilities in the residential sector tend to exhaust quickly when the tax level reaches 150 USD/tCO_2eq. As a consequence, in 2050, the total additional abatement tend to stabilize after having reached 16 [MtCO_2eq].

5 Policy scenarios

In February 2008, the Swiss Federal Council decided to launch a revision of the CO_2 law for the post 2012 climate policy. It decided to follow similar targets as the European Union, i.e. at least 20% reduction of GHG by 2020 relative to 1990 and 50% by 2050. A consultation procedure on this revision, envisaged for the summer of 2008, will allow to compare various instruments: a pure incentive tax which revenue is redistributed to households, a tax which revenue would be used to finance national or international abatement or adaptation measures

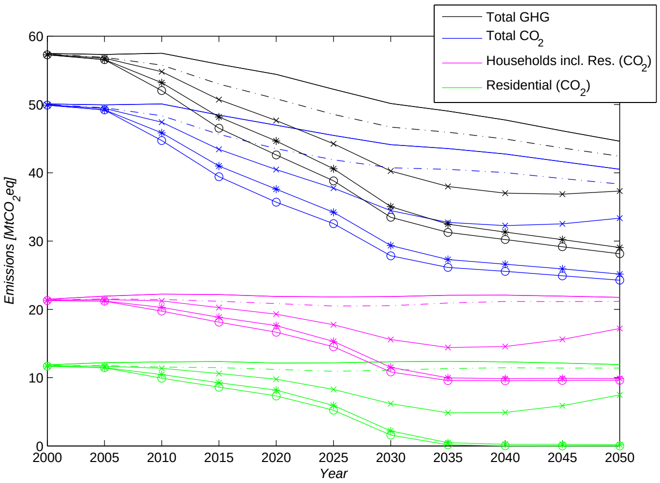


Figure 4: Sensitivity of the model to various levels of progressive taxes (0, 50, 100, 150 and 200 USD/tCO_2eq)

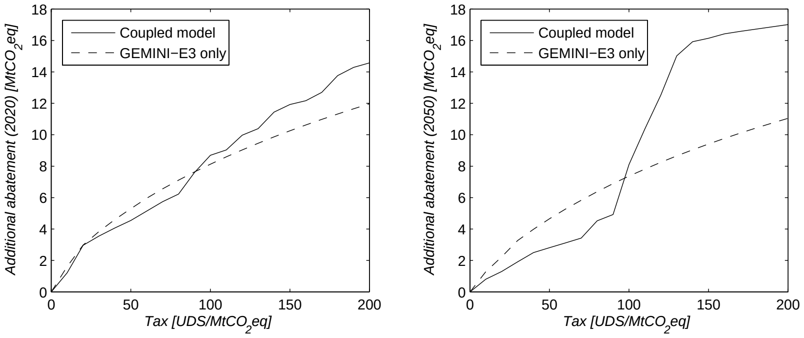


Figure 5: Comparison of GEMINI-E3 with the coupled model - Additional total abatement in 2020 (left) and 2050(right)

as well as technical regulations. Furthermore, it had decided in 2007 that the Swiss energy policy would be based on four pillars: the increase of energy efficiency, the promotion of renewable energy, the replacement and construction of electric power plants and the international energy policy. These four pillars are in line with the climate policy targets and they should also support action plans aiming at a reduction of the use of fossil fuels by 20% by 2020, an increase of 50% in the use of renewable energy by the same year and a limit of 5% on the growth of electricity consumption between 2010 and 2020. The action plans are base on measures aiming at increasing energy efficiency and promoting renewable energies.

In order to facilitate the transition between the current CO_2 Law, which targets only CO_2 emissions, and the future policies which will encompass all GHGs, we have decided to consider objectives for both CO_2 and all GHG emissions. Among the policy instrument and measures under consideration, we have selected those which either focus on the residential sector or have a wide impact on the economy. As a consequence, we have decided to analyze pure incentive GHG and CO_2 taxes as well as technical regulations enforced in the residential sector. We study the potential abatement and the consequences following the implementation of both instruments separately as well as jointly. In this study, the tax revenues of the so-called pure incentive taxes are redistributed to households through lump sum transfers. Further studies could analyze the influence of various redistribution schemas or specific uses of the tax revenue.

We test three scenarios. In the first scenario, we implement emission taxes applied across the whole Swiss economy, influencing both the production sectors and the households by changes in relative prices. We analyze two type of taxes, first a progressive tax that increases linearly up to the target year and, secondly, a uniform tax, which has a fixed value from 2008 till 2050. We also compare CO_2 taxes with a tax covering all GHG.

In the second scenario, we consider the implementation of technical regulation which aims at restricting the investments in technologies considered inefficient. For the purpose of this paper, we consider technical regulations only in the residential sector. We compare the energy efficiency of each technology with the average efficiency of all technologies allowing for satisfying the same final energy demand (see Table 1). Then, as of 2015, we restrict households' investments to those technologies having an energy efficiency superior or equal to the average. Technologies not using fossil fuels or electricity were not restricted, and in the case of residential heating, we do not consider heat pumps, neither in the calculation of the average efficiency nor in the list of restricted technologies. Examples of inefficient technologies falling in the restricted list are incandescent and halogen lamps.

Finally, the third scenario considers the joint use of both instruments. The next section presents the integrated assessment of those policies.

6 Results

In this section we present the results of the scenarios described above from the perspective of their environmental effectiveness as well as their consequences on the Swiss economy and on the residential sector in particular.

6.1 Pure incentive tax

The results in Table 2 show that the 20% emissions reduction of GHG emissions by 2020 requires a 97.9 USD/tCO_2eq progressive tax on all GHG gasses and the tax should reach 201.6 USD/tCO_2eq to allow a 50% abatement by 2050. The level of those taxes could obviously be reduced if the taxes were set uniformly across periods. Furthermore, when only CO_2 emissions are targeted, similar abatement levels require higher taxation levels, which could go up to almost 220 USD/tCO_2eq to abate by 50% in 2050. These results confirm that without emissions trading, achieving substantial abatement levels requires a significant level of taxation. In comparison, these levels of taxation are much higher than the CO_2 tax introduced in 2008 on heating and process fuels, which amounts to 12 CHF/tCO_2

and should grow to 36 CHF/tCO_2 in 2010.

In the case of a 50% abatement target, the model faces rigidities in private transportation where little substitution is possible even with distant horizons such as 2050. Modeling the transportation sector using an energy use model would allow for a better representation of the substitution possibilities and therefore would allow reaching similar targets with lower taxes. The figures in italic, the intermediate (2020) or final (2050) abatement levels associated with the taxes, show that the taxation levels set out to reach the 2020 target would not allow to reach the 2050 objectives. Similarly, taxes allowing to reach the 2050 targets are either insufficient, if implemented in a progressive way, or too restrictive, when implemented uniformly across the whole period. If both the 2020 and 2050 objectives need to be met, the tax could be implemented progressively but not linearly. The annual increase in the first phase (before 2020) should be stronger than in the second phase.

Table 2: Abatement and pure incentive taxes USD/tCO_2eq

	CO_2 tax		GHG tax	
Target	Progressive	Uniform	Progressive	Uniform
20% by 2020	105.47	93.21	97.86	89.45
% in 2050	*36.95*	*28.50*	*35.16*	*31.61*
50% by 2050	219.67	156.54	201.58	134.09
% in 2020	*17.64*	*27.30*	*17.22*	*24.79*

6.2 Technical regulations

We find that the use of technical regulations of the type we have described and limited to the residential sector alone has a limited impact on Swiss CO_2 and GHG emission. Figure 6 compares the baseline emissions with (lower line) and without (upper line) technical regulations in the residential sector. The impact of the technical regulations is slightly more important on CO_2 emissions than on total GHG emissions due to the targeting of the regulations on CO_2 intensive technologies. The maximum impact of the regulation is of about 2% around 2020, but only in the case where no taxes are implemented simultaneously. The next section shows how taxes further diminishes the usefulness of the technical regulations as we have implemented them in this paper.

Other measures than those we have modeled could have a greater impacts on emissions and would deserve further consideration. Among those, we can mention: financing a program promoting the energetic renovation of buildings, implementing technical regulations on vehicles, strengthening research on energy efficiency or accelerating technological transfer.

6.3 Joint use of technical regulations and taxes

When the coupled model takes into account the implementation of the technical regulations, the CO_2 and GHG taxes allowing for achieving the abatement target are not significantly different from those calculated without technical regulations. This is mainly due to the fact that the less efficient technologies are naturally abandoned by households since CO_2

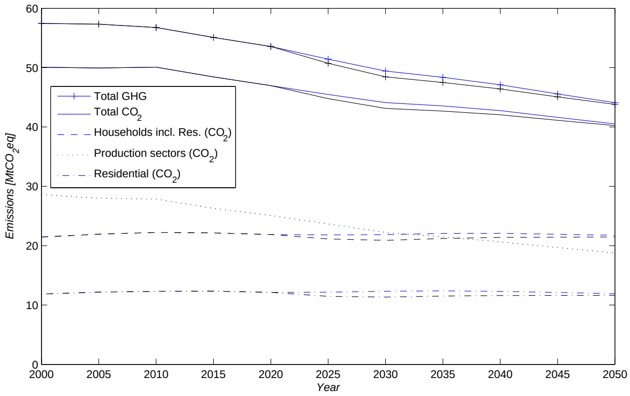


Figure 6: Impact of the technical regulations on the baseline CO_2 and GHG emissions

or GHG taxes further reduce their competitiveness. As a consequence, for the rest of the analysis we focus on the first scenario, witch, in our framework, allows to reach the emission targets without requiring additional technical regulations.

6.4 Impacts on the Swiss economy

Table 3 shows the impacts on GDP of the pure incentive taxes defined in Table 2. If technical regulations are combined with the taxes, we saw that the taxes only differ marginally from the case without regulations and the same applies for their impacts on the GDP. The figures show that the impact of emission taxes on the Swiss economy is limited and, in all cases, would reduce GDP growth by less than half a percent, even with taxes as high as 200 USD/tCO_2eq. Moreover, GHG taxes have a smaller impact on GDP than CO_2 taxes. The effects on GDP might be a little stronger, if we would force the CGE part of the model to mimic the increased spending in equipment as we can observe in the MARKAL-CHRES. Indeed, the tax has an incidence on the consumer investment strategy, he invests in less polluting but more expensive technologies.

Table 3: GDP variations without technical regulations (in %)

Gas	Target	Tax	2020	2050
GHG	20% by 2020	Progressive	-0.17	-0.21
		Uniform	-0.16	-0.17
	50% by 2050	Progressive	-0.11	-0.41
		Uniform	-0.24	-0.36
CO_2	20% by 2020	Progressive	-0.19	-0.26
		Uniform	-0.17	-0.18
	50% by 2050	Progressive	-0.12	-0.44
		Uniform	-0.28	-0.39

In our assessment, only uniform taxes set to meet the 2050 targets allow to meet both

2020 and 2050 targets. Progressive taxes have nevertheless a higher chance to be accepted since their cumulated impact on GDP is smaller. Figure 7 shows the impacts on the production sectors of a 219.7 USD/tCO_2 tax on CO_2 and a 201.6 USD/tCO_2eq tax on all GHGs. The only sector that strongly benefits from the introduction of the taxes is the electricity sector, due to the increased demand for electricity which is produced mainly CO_2 free in Switzerland. In the case that current nuclear power plants were replaced by combined cycle gas turbines, emission taxes would have to be higher and the electricity sector would not benefit as much from the introduction of the tax. The petroleum products sector is the most affected by the introduction of the taxes, together with other energy intensive sectors such as mineral products, agriculture and air transport. Not surprisingly, in our modeling framework, other transport (transport nec), which includes commercial road transport and rail, is not that much affected by the tax in view of the substitution between private and purchased transport.

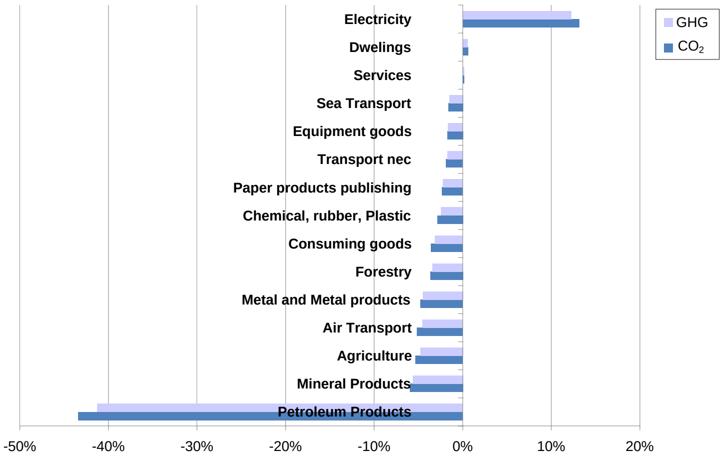


Figure 7: Variation of the production in 2050

Table 4 presents the contributions of households and economic sectors to CO_2 abatement as well as the contributions of the different greenhouse gases to total abatement. The major contribution to the CO_2 abatement effort is attributed to households with a share of 35%, followed by road and rail transport which accounts for 16.5% of the emissions reductions between 2001 and 2050. If we consider that in the baseline scenario a certain level of abatement is already achieved as a consequence of policies already adopted, the share of households in the additional abatement is as high as 74%. The share of households would be even higher if the private transportation would be coupled to a transportation energy use model, similarly as we do it for the residential sector. Except from fluorinated gases, which still increase despite the high levels of taxation mainly because of an increase in SF_6 (sulfur hexafluoride) emissions in electric power systems, all GHG contribute substantially to the overall abatement, in particular in the case of GHG taxation.

Finally, the estimations confirm our initial assumption stating that the prices of energy would only vary slightly compared to the baseline due to the limited impact of Swiss energy demand on world prices.

Table 4: Contributions to the change in emissions between 2000 and 2050 after progressive taxation

Sectors / Gases	GHG tax	CO_2 tax
Households	35.11	37.78
Transport nec	16.55	16.86
Services	8.64	8.92
Air Transport	4.90	5.06
Mineral Products	4.25	4.29
Consuming goods	3.25	3.29
Equipment goods	2.13	2.16
Petroleum Products	2.09	2.13
Paper products publishing	1.91	1.93
Metal and Metal products	1.86	1.87
Agriculture	1.09	1.10
Chemical, rubber, Plastic	0.99	1.01
Electricity	0.92	0.93
Forestry	0.34	0.34
Dwellings	0.00	0.00
Sea Transport	-0.04	-0.02
CO_2	83.97	87.66
CH_4	9.33	7.88
N_2O	7.25	6.62
Fluorinated gases	-0.55	-2.16

6.5 Impacts on the residential sector

As we saw earlier, the implementation of emissions taxes has strong consequences on the residential sector. The bottom-up part of the coupled model shows, as presented in Figure 8, that the residential sector reacts to the introduction of the taxes by a strong switch to electricity between 2020 and 2035. A uniform tax of 156.5 USD/tCO_2eq would even have an earlier and stronger impact and would even trigger an almost CO_2 free residential sector.

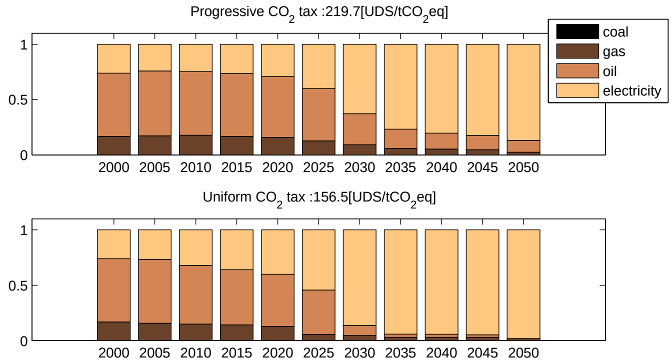
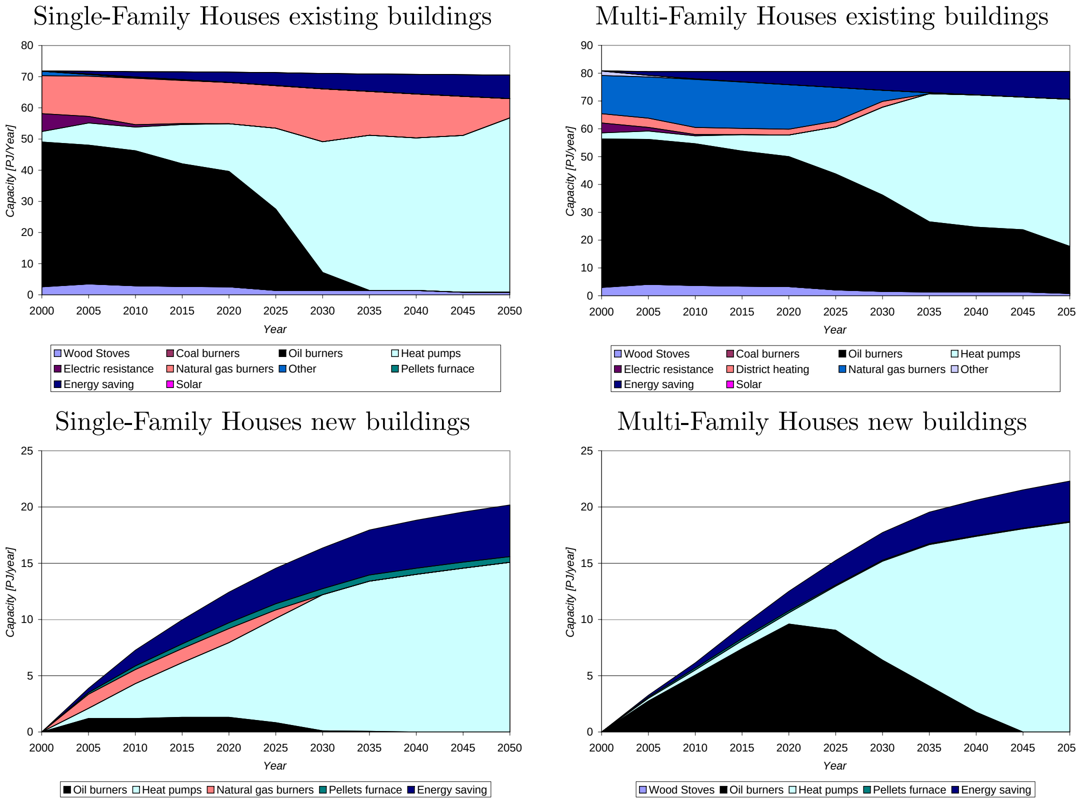


Figure 8: Residential fuel mix

Figure 9 presents the evolution of installed capacity of various room heating technologies following the implementation of a progressive GHG tax allowing to reach a 50% abatement by 2050. It clearly indicates that, in all building types, heat pumps will have a rapidly growing share and, as of 2030, be the dominant technology used for room heating. This is due to to the fact that heat pumps have a high energy efficiency and that they only consume electricity, which is, to a large extent in Switzerland, not produced from fossil fuels. Finally, the figure also show that an important part of the final energy demand is met by installing energy saving technologies, in particular in new single family houses where almost a fourth of the energy is saved by using appropriate insulation and other energy efficiency standards.


Single-Family Houses existing buildings

Multi-Family Houses existing buildings

Single-Family Houses new buildings

Multi-Family Houses new buildings

Figure 9: Installed capacity of room heating technologies

7 Conclusions

This paper provides a new integrated approach to analyze GHG mitigation policies in Switzerland which provides useful insights relevant for the forthcoming revision of the CO_2 law and the elaboration of the post 2012 climate policies. We have focused this analysis on the residential sector which is expected to play a major role in future GHG abatement.

We have studied the impacts of CO_2 and GHG taxes as well as technical regulation applied to the residential sector and shown that the latter would not be sufficient to achieve major emissions reductions and loose their *raison detre* when used in conjunction with emission taxes. This effect might be a little overestimated by the MARKAL-CHRES part of the coupled model, which assumes that consumers have a pure optimizing behavior which takes into account investment, maintenance and usage prices of all technologies. Furthermore, this study confirms that, in Switzerland, GHG taxes are more effective than CO_2 taxes, without further jeopardizing the production of the economic sectors. A progressive GHG tax reaching 201.6 USD/tCO_2eq in 2050 would yield a 50% reduction in GHG emissions relative to 1990 and would lower Swiss GDP growth by approximately 0.4%. Such a tax would imply, for example, that the prices of light fuel oil used in the residential sector would increase annually by 0.012 [USD_{2000}].

Finally, this paper also shows that with high emissions taxes, private transportation becomes the principal emitter of GHG. This is in line with with a recent proposal for a Swiss energy policy by ETHZ (2008), which states that emissions should be reduced to 1 tCO_2 per capita by 2100, a sufficient condition to render the planet CO_2 neutral if applied globally in a contraction and convergence framework, and that those emissions would only be restricted to the transportation sector. In the settings of this paper, the transportation sector remains a big emitter due to the rigidities in the model, which somehow reflects the lack of clean alternative technologies, but also to the fact that the price of petroleum products used for transport already includes high taxes and, therefore, the relative change in price is much lower than in the residential sector.

This research could be further developed by an analysis of the means that would allow for a CO_2 neutral Switzerland, as well as their consequences. As assumed by the Federal Council, this could be done investing a part of the tax revenue in the purchase of foreign CO_2 certificates. Having in mind that the marginal abatement costs in Switzerland are very high, the purchase of certificates would significantly lower the costs of abatement. Some amendments to our coupled model could enable a global or regional carbon market and, once abatement strategies in all regions would be defined, will allow the assessment of the price of CO_2 certificates. Once climate policies will be internationally introduced in the models, energy prices and demands will vary substantially. Our coupling framework would therefore also need to be slightly amended to allow feedbacks from the top-down to the bottom-up model. Furthermore, the variation of the investment costs following the implementation of the policies should be aligned between both models in order to render a more realistic framework with regard to the macroeconomic consequences of the investments in the residential sector. Finally, a more detailed modeling of the private transportation sector, possibly using another energy use model, would allow to take into account the realistic hypothesis that, before 2050, energies other that petroleum products could represent an important share in the private transportation fuel mix. These additional substitutions potentials would allow for reaching the emission targets with lower taxes than those presented in this paper.

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