CER-ETH
Center of Economic Research at ETH Zurich

How rich is the 2000 Watt Society?

Impact of Energy Conservation Policy Measures on Innovation, Investment and Long-term Development of the Swiss Economy

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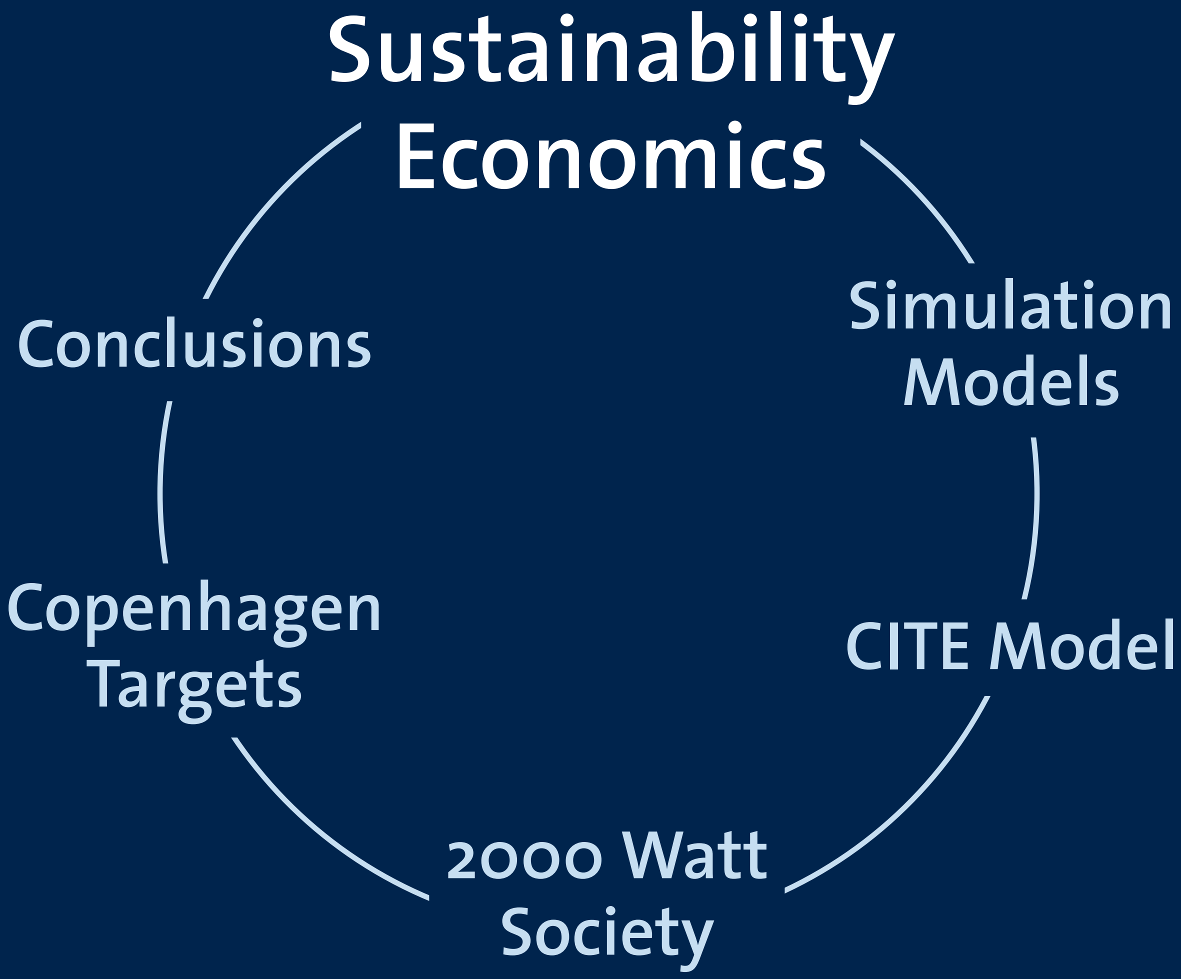
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Long-run perspectives

Over the past two centuries, the Swiss economy has experienced an unprecedented increase in living standards. At the same time, the stock of various natural resources has declined and environmental conditions have changed substantially. Today, the pollution of the atmosphere is considered a major risk for future development at the global level. Predictions show that, without climate policy, worldwide greenhouse gas emissions would rise by 45 percent until 2030, which would cause an increase in the global average temperature of up to six degrees Celsius on average by the end of the century. According to the Stern Review,[1] the global warming could entail losses equivalent to more than ten percent of global income in the long run. Not only climate change but also the limitation of oil reserves make it necessary to reduce and gradually replace the use of today's dominant fossil energy sources. Fossil fuels will be used to facilitate the transition phase of the global energy system in the 21st century; but during transition, emphasis should be placed on an efficient decarbonisation of the economy.

Sustainable future

There are several targets for policies aiming at long-run development: increasing living standards, protecting crucial natural resources, and reducing the risks associated with economic and ecological crises. These aims can be conveniently summarized under the heading of "sustainability." On a sustainable path, the global energy system needs to be compatible with the natural environment.

An urgent goal is to stabilize greenhouse gas concentration in the atmosphere at a level that prevents dangerous anthropogenic interference with the climate system. At the climate summit in Copenhagen, the conference of the parties (COP 15) took note of the Copenhagen Accord, which aims to keep the increase in global temperature at below two degrees Celsius. To reach this goal, CO_2 reductions for industrialized countries should be in a range of -25 percent to -40 percent until 2020, and -80 percent to -95 percent until 2050, compared to their level in 1990. For the very long run, calculations show that a target of around one ton CO_2 emissions per capita and a primary energy use between 2000 and 3500 Watt per capita, depending on the use of renewable energies, would deliver a sustainable outcome.[2]

The vision of a 2000-Watt society was developed at ETH Zurich and has been promoted by the ETH board. The energy use of 2000 Watt per capita amounts to about one third of today's per capita energy demand in Europe. It is not meant as an exact quantity target but rather as a vision of a modern low-energy society, which aims at enabling a balance between industrialized and developing countries in the long run.[3] The 2000-Watt society has entered the political arena as one of the future scenarios in the plans of the Swiss Office of Energy (scenario IV of the energy perspectives)[4] , and with the vote in the City of Zurich in 2008, where the long-run targets of 2000 Watt and one ton CO_2 emissions per capita were approved by the voters (with a 76 % majority). While the technical feasibility has already been the focus of extensive inquiries,[5] the

[1]Stern (2007) [2]Energy Science Center (2008). [3]Novatlantis is currently implementing elements of the 2000-Watt society on a project level in Basel, Zurich, and Geneva. [4]Bundesamt für Energie (2007) [5]Jochem (2004)

present study focuses on the economic consequences of the transition to 2000 Watt per capita. Moreover, we calculate the economic effects of the two degrees Celsius target of the Copenhagen accord.

Economic models

The development of human well-being can only be adequately analyzed by using economic models. To evaluate the sustainability of a low energy and low carbon society as well as the optimum transition to this state, economic analysis and numerical simulation models are indispensable. In a similar way, economics can show how to evaluate costs and benefits of carbon and energy policies. The major benefit of long-run carbon policies lies in reducing the probability of large damages due to climate change. The involved costs are related to the induced change in economic activities and - especially - long-run growth. Specifically, costs and benefits of political measures need to be evaluated with the help of quantitative models that adequately account for the input of energy and aim at forecasting development in the long run. This is crucial because the targeted massive reduction of an input like fossil energy use poses a challenge that has not often been faced in economic history. It makes it mandatory to understand the complex mechanisms of a dynamic multi-sector market economy.

One cannot gain any insight into the dynamic consequences of the different policies unless something concrete is known about the properties of feasible development paths. In order to obtain this knowledge, the different paths have to be predicted by theory. Specifically, the theory of economic growth and associated numerical simulations play an important role for a better understanding of the basic dynamics. They are used to quantitatively predict economic development and, in addition, to indicate how the development process can be guided into a desired direction.

With regard to the future of Swiss energy use, the different scenarios of the so-called "energy perspectives" (“Energieperspektiven”) up to 2035 of the Swiss Federal Office of Energy are an excellent guideline for the policy discussion. The energy perspectives list options for planning a long-term and sustainable energy policy that meets the principal requirements of supply security, protection of the environment, economic viability and social acceptance. The current study is mainly inspired by scenario IV, which depicts the major elements for the transition of the Swiss economy to a 2000 Watt society, i.e. a state with an energy use of 2 kW per capita.

More with less?

Can a decrease of energy use ever be beneficial for an economy? "Conventional" thinking suggests that lower energy use causes a loss in income and economic growth. Indeed, the oil price jumps of 1973-74, 1978-80, 1989-90 and 2004-08 were all followed by a worldwide recession. But, on the other hand, it is interesting to note that - at least in the rich countries - the simple correlation between energy use and growth is actually negative. Various countries with low energy use and high energy prices have performed well economically, while many low-energy-price countries persistently show low growth rates. Thus, we have to take care that our intuition is not relying too much on the short-run business cycle, but rather on the more important long-run effects.

It is true that, in a static economy, less input means less output. But this is not the real issue. For the longer run, two effects are important.

First, output level and output growth are determined by different mechanisms. Economic output is given by the quantities of inputs and their productivity. Economic growth, however, is driven by the accumulation of capital, where capital comes in different forms, e.g. physical, human, knowledge, and social capital. We note that the input of energy is not free but costly, meaning that lower energy expenditures allow for higher expenditures for other inputs like capital; in the same way, lower energy spending allows for intensified development of new technologies. Thus overall, lower energy use might decrease economic activities or it might foster capital accumulation and long-run growth; it depends on the general economic conditions.

Second, we are obviously not living in a perfect world. Why else would we think of welfare-improving policies? Given our topic we have to consider the market failure associated with climate change, i.e. induced economic and social costs that are not reflected in market prices. This failure of the market system has even been called the "greatest market failure the world has seen".[6] To put the right prices on carbon emissions unambiguously increases welfare. While pollution is a so-called "negative" externality harming the markets, the opposite holds for learning effects, which are often associated with innovation and capital accumulation. A higher investment rate can promote growth not only by directly adding to the existing capital stock, but also indirectly by increasing the knowledge stock in the economy (via so-called "positive" externalities).

We conclude that to obtain more growth with less energy is neither impossible nor guaranteed: it depends on the mechanics and the behavior of the economy. This is why we need detailed models to make accurate predictions. Moreover, one has to make sure that the costs of climate policies are viewed in the right perspective. In particular, they have to be compared to the right benchmark, which has to include the damages of global warming. More precisely, “business as usual” is no longer a growth rate of around two percent per year, but a long-term path where income is affected by climate change.

May we be skeptical?

Successful energy and climate policies require substantial information from different fields of science. It cannot be provided without uncertainty. Therefore, we may always keep a skeptical attitude. But this is not equivalent to ignoring the problems associated with climate change and exhaustible natural resources. Yet, some denialist views can still be observed in public discussions and in the business community.

It is advisable to take the results from climate and energy science seriously and to include all aspects of risk in the analysis. From there we have to derive the best possible reactions of markets and politics. The focus should be on the cost-effectiveness of climate policies and international climate treaties. This is exactly where the present study aims to make a contribution. Of course, purely economic indicators such as costs

[6] Stern (2007)

and benefits are not the only criteria to be considered in policy evaluation. Nevertheless, they permit a well-founded assessment of crucial facts for decision making.

Market economies are only efficient when all costs are reflected in market prices, which does not apply in the case of climate change. Correcting the prices in order to include all costs improves social welfare. Efficient markets make the necessary adjustments at the lowest possible costs. Thus, if we believe in the efficiency of markets, we should be careful when calling adjustments to ecological constraints expensive, undesirable or even impossible. Public opinion now seems to support the view that adaptation to undamped climate change is likely to be very expensive, which enhances the need for mitigation of climate change. By calculating the costs of climate and energy policies, this study contributes to a deeper understanding of the relevant issues and mechanisms, which should help formulate responsible individual, corporate, and political actions.

When aiming at a low carbon society we could also be skeptical about whether the necessary changes of human behavior will be sufficient and fast enough. The French publisher de Girardin once rightfully said that "everybody talks of progress but nobody wants to leave the routine" ("tout le monde parle de progrès, et personne ne sort de la routine"). Moreover, many wish to have something like a "guaranteed future", which does not exist at anytime. Importantly, the future does not become more certain with political inaction. Quite the opposite is expected to hold true: the more accurate our efforts are today, the lower the risks for the future. The present study cannot remove all our doubts about the future and the behavior of mankind, but it should widen our scope of how to realistically think about future development.

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First generation models

The first generation of numerical energy models was based on the assumption of exogenous growth and an autonomous improvement of energy efficiency. It ignored interconnections between technological change and policy measures. Changes in energy prices due to political actions simply resulted in substitution of other factors for energy, leaving the rate of growth in energy efficiency unchanged. In these models, the increase of energy efficiency was defined by a so-called "autonomous energy efficiency index", which was a heuristic measure of all non-price driven enhancements in energy technology, including structural change in the economy and sector-specific technological change. It was a separate coefficient in the production or cost functions and represented either factor-augmenting or price-diminishing technical change. The main difficulty with applying this index is to identify the difference in the influence of technical progress and of long-term price effects. For this reason, we have replaced the index by endogenous growth mechanisms.

Induced Innovation

The empirical evidence for the effects of energy price changes on innovation is relatively univocal and builds on the "Hicks" induced innovation hypothesis." Hicks (1932) proposed a theory stating that changes in relative factor prices result in innovations that reduce the demand for the relatively expensive factor. Thus, with an increase in energy prices, a dynamic substitution effect is added to the better-understood static cost effects. Popp (2001) confirms the hypothesis empirically and finds that the overall effects of an input price change are derived by two thirds from factor substitution and one third from induced innovation. Also, Newell et al. (1999) find that increasing energy prices have an observable effect on the types of products offered in stores. Likewise, Popp (2002) finds further evidence of a positive impact of energy prices on innovation activities. Consequently, energy policy has dynamic effects on output and welfare, in addition to the usual static effects. Especially when looking at the long or even very long run, as has become usual in the current energy and climate debate, the dynamic effects dominate and certainly have an impact on policy conclusions.

Modelling growth

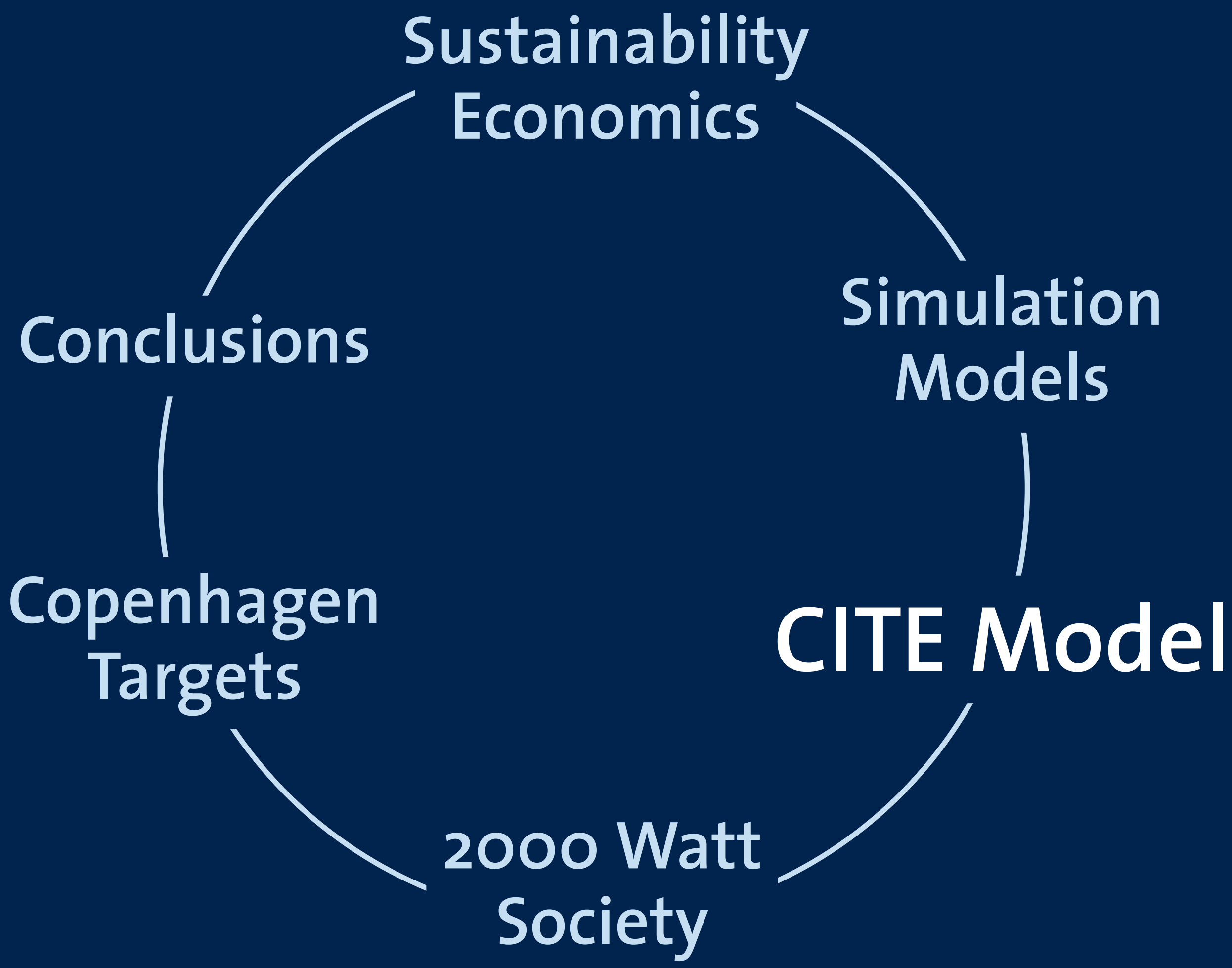
Since the seminal work of Solow (1956), economists consider capital accumulation and technology as the main drivers of growth. The recent strand of "new growth theory" is based on the assumption that technological innovation is an economic activity just as any other activity in the economy. Profit-maximizing agents optimize innovative investments according to profit incentives. Endogenous growth theory builds on a "Schumpeterian" innovation approach, reflecting that profit incentives account for a major part of technological change. In addition, it has been observed that learning is a major driving force of technological change, as it improves the relation of cost and performance of technologies. A learning curve describes the declining cost of a technology as a function of cumulative capacity, which can be seen as an approximation for accumulated experience.

A class of models that embody endogenous growth mechanisms include investments in research and are inspired by macroeconomic models of endogenous growth; the seminal contributions are Romer (1990) and Grossman & Helpman (1991). In these models, the change of input quantities have both static and dynamic effects in the economy.

Policy effects

Theoretical reasoning suggests that dynamic effects of policy, i.e. effects changing the growth rate of an economy, are potentially very powerful (Baldwin 1992). Moreover, compared to the level effect, growth effects can work in the opposite direction. For example, a growth effect might alleviate or possibly even revert a negative static effect. Whether this happens or not depends on the impact of policy on capital productivity. Provided that this productivity is increased, additional capital accumulation guides the economy to a higher steady state. With constant returns to overall capital, as often assumed in new growth theory (e.g. in the seminal paper of Romer 1990), the dynamic effect is very large, as it is permanent. The welfare impact of this permanent dynamic effect is also measurable. The size of the dynamic gain from energy policy depends on the wedge between social and private returns to capital, which is present due to the positive knowledge spillovers (which are externalities), and on the assumed discount rate.

An additional issue is the possible emergence of a double dividend of energy and carbon taxes, with a benefit for the environment as a first dividend and an improvement of the whole "policy system"as a second dividend. The second benefit has been primarily seen in the improvement of the tax system, which is normally distorted by the negative incentives from income taxation. Thus, when labor taxes are replaced by environmental taxes, it appears that an efficient tax substitutes for a distorted tax. However, the argument neglects the shifting of the tax burden, as e.g. firms charge higher prices with environmental taxes. By studying the tax incidence it can be shown that the tax burden is shifted to the immobile factors, where again labor is very prominent. Thus, the tax interpretation of the double dividend is not entirely convincing. But in terms of growth, there may well be a second dividend. As argued above, energy policy measures may induce innovation and support the replacement of knowledge extensive sectors by knowledge-intensive sectors and activities, which fosters economic growth and is normally beneficial in terms of welfare.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Project

The project to develop a new simulation model from scratch was built on the premise that, because of increasing energy scarcity and the need to protect the atmosphere, declining energy use is an important topic for policy. When energy-saving policies are advocated, the macroeconomic effects of these measures, in particular the growth effects, have to be carefully considered. We assume that targets like the 2000 Watt society or the Copenhagen Accord are of importance for Switzerland, and that the economic conditions of the transition to these states consequently need to be understood.

Our approach is based on the insight that the application of the so-called "endogenous growth" theories promises significant new results in this important area. By applying these theories, energy policy instruments can be chosen according to their impact on growth and welfare. Consequently, the project studies the growth effects, especially the effects of induced innovation and investments on the sectoral and aggregate level, as well as the structural change of the Swiss economy.

After a thorough evaluation of the relevant growth dynamics provided by economic theory, the major effort of this project was to construct an appropriate dynamic numerical simulation model for the Swiss economy. The specific features of the newly developed **C**omputable **I**nduced **T**echnical Change and **E**nergy ("CITE") model are described in the following subsections. Our results complement recent predictions on the future of energy use based on technology development. It does so by adding the macroeconomic impact of future energy policies. The recent economic studies which come closest to this report are Ecoplan (2008) and Ecoplan (2009).

New model elements

The main challenge when building the CITE model was to capture the basic features of growth in an economy with largely divided labor. This includes several major steps.

The first is to model endogenous capital accumulation on the aggregate and the sectoral level. Here, the model builds on the seminal work of Solow (1956) and on the theory of endogenous savings.

The second is to capture the gains from specialization. The idea of growth through increasing specialization goes back to Adam Smith, who already reported in 1776 that specialization immensely increases the efficiency of the workers and therefore contributes to output growth. In his parable of the pin factory, the increase of specialization leads larger firms to have a higher output per worker and lower average cost per pin than a small pin factory.

The third step is to account for the influence of research and development (R&D) on sectoral growth. In the models of Romer (1987, 1990) and Grossman & Helpman (1991), growth is driven by R&D activities and is therefore determined endogenously. It is assumed that an expanding variety of intermediate goods (i.e. horizontal innovations) enhances the productivity of the economy by gains from specialization. This growth mechanism differs from intertemporal dynamics in other models as we do not need to assume an exogenous growth rate for endowments such as labor. All growth dynamics arise from profit incentives in the economy.

The model consists of 10 different regular sectors, an energy sector, and an oil sector, each with similar intrasectoral setups. For details see Schwark (2010a,b), Ramer (2010a,b).
The importance of the gains from specialization can be seen from the data. The empirical extent of specialization in the European Union has been estimated by Mangàni (2007), who analyzes the correlation of economic (in terms of GDP) and technological (i.e., R&D aggregate expenditure or the number of patents granted) sizes. She finds a positive correlation between the two. She distinguishes two technological dimensions: the intensity of technological activities (intensive margin) and their variety (extensive margin). The technological variety is defined as the number of technological fields in which a country is active. Both dimensions are positively correlated with the country size, i.e., larger countries have a wider spectrum of technological fields and show a larger number of patents in each technological field. In Mangàni's estimation, technological variety accounts for about 40 % of the difference in patent application between larger and smaller economies and is therefore crucial for explaining the different technological standards.
A more thorough comparison of our CITE model with a first-generation model shows that the CITE model indeed generates different reactions to policy. In a first-generation model, capital accumulation can only contribute to a substitution for energy but not to an increase of productivity. Accordingly, investment incentives through energy policy are weaker than in the CITE model. In the CITE model, most industries show a strong sensitivity to the change in input costs, which is according to expectations.

Data and parameters

The model is based on the Swiss input-output table (hereafter named IOT) for the year 2005 (Nathani, van Nieuwkoop and Wickart, (2008)), which is the most recent version available. It gives detailed information on the flow of goods between sectors and to final demand, and also on the use of inputs and on trade. The original table contains data for 42 production sectors and differentiates between fifteen types of consumption (twelve for private households, three for public consumption) and three types of investments. As for the use of factor inputs, it presents information on the use of labor and capital. It is therefore an almost complete source of data for the type of model we are using. For the purpose of our model, the original IOT was aggregated to 12 sectors (10 regular sectors, an energy sector and an oil sector, see Table 1 on the next page for an overview). Also, we do not differentiate between the different types of consumption. However, we distinguish two types of investments, physical capital investments and investments in R&D.
The choice of parameter values, most notably of the elasticities of substitution, may have a substantial influence on the model results. It is therefore important to choose these values carefully and reasonably. Whenever possible, we set the values in accordance with existing studies and empirical estimations. Sectoral differences in substitutability of inputs on the different levels of the production process are taken into account by setting sectorally differentiated values for the corresponding elasticities whenever available and reasonable. An overview of the elasticities used is given in Table 2.
A key feature of the model is that it includes the gains of specialization that stem from the accumulation of capital already in the benchmark scenario. The model is calibrated so that it reflects both projected output

growth and growth rates of the capital input. To be more precise, we assume for the business as usual scenario that capital grows at an annual rate of 1%. This matches the observed growth rate of capital goods in Switzerland since 1990. In our calibration, this leads to an annual growth rate (again for the business as usual scenario) of about 1.33%, which is in line with the rate assumed in the high GDP scenario of the Energy Perspectives. Further details on the data, the parametrization and the calibration of the model are available in Ramer (2010a).

Table 1: Overview of the sectors used in the model

Sector	NOGA-Classifications
Agriculture (AGR)	01-05
Refined Oil Products (OIL)	23
Chemical Industry (CHM)	24
Machinery and Equipment (MCH)	29-35
Energy (EGY)	40
Construction (CON)	45
Transport (TRN)	60-63
Banking and Financial Services (BNK)	65
Insurances (INS)	66
Health (HEA)	85
Other Services (OSE)	50-55, 64, 70-75, 80, 90-95
Other Industries (OIN)	10-22, 25-28, 36-37, 41

Simulation scenarios

Our base policy scenario takes up the ideas from scenario IV of the energy perspectives. Scenario IV assumes that energy use has to be reduced by 35% by the year 2035 (compared to the year 2000) if the long-term goal of a 2000-Watt society is to be met by the end of the century.

Because we use data for the year 2005, we base our reduction targets on the energy use of this year. Compared to 2005 levels, energy use then has to be reduced by 37.5%. The fact that only one region is included in the model implies purely domestic abatement and disregards emission offsets abroad, which are often seen as being less costly. The policy instrument implemented to achieve the reduction target is a carbon tax. This carbon tax increases the prices of the two fossil fuels included in the model, refined oil and gas. Refined oil (referring to the output of the refined oil sector) and gas are the two inputs for the production of fossil energy. Fossil energy is then again an input for production in the energy sector. The fact that the use of the two fuels is not equally polluting is taken into account by assuming different carbon intensities. The tax is directly tied to the carbon intensity. As we assume a uniform tax rate for both fuels but a higher carbon intensity for oil, this implies that oil is effectively taxed at a higher rate than gas.

In the base scenario, the tax revenues are redistributed back to the representative household and enter the budget constraint as additional income.

Table 2: Elasticities

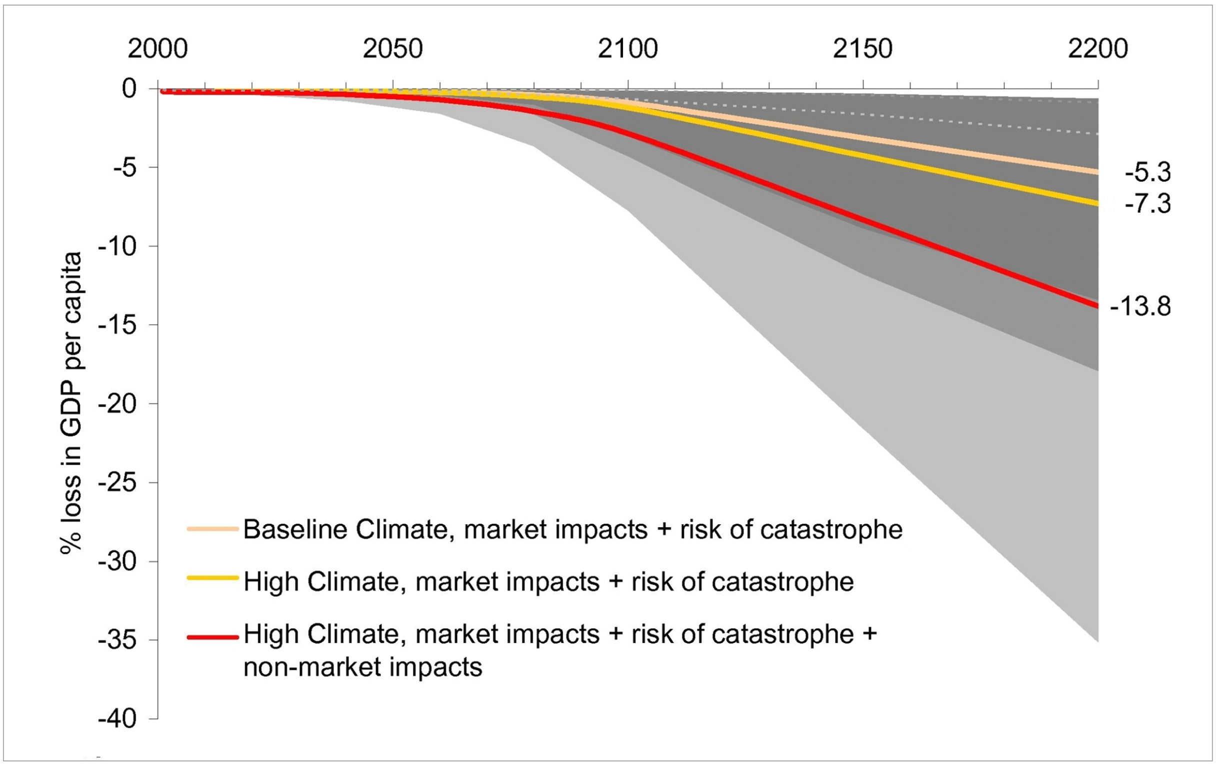
Parameter	Description	Value
$\sigma_{Y,i}$	Elasticity of substitution between the intermediate composite and inputs from other sectors	0.392 (AGR), 0.848 (OIL, CHM), 0.518 (MCH), 0.100 (EGY), 1.264 (CON), 0.352 (TRN), 0.568 (OIN), 0.492 (rest)
$\sigma_{X,i}$	Elasticity of substitution between the three inputs in the production of intermediate varieties	0.7 (AGR, OIL, CHM, EGY), 0.8 (MCH), 0.52 (CON), 0.82 (OIN), 0.4 (rest)
σ_E	Elasticity of substitution between fossil and non-fossil energy	0.3
σ_I	Elasticity of substitution between physical investments and non-physical capital	0.3
σ_N	Elasticity of substitution between investments in R&D and research labor	0.3
σ_C	Elasticity of substitution between energy and non-energy goods in consumption	0.5
σ_W	Intertemporal elasticity of substitution in the welfare function	0.6
$\sigma_{A,i}$	Armington elasticities	3.2 (AGR), 3.8 (EGY, OIN), 4.6 (MAS), 2.9 (rest)
σ_T	Elasticity of transformation	1.0

In an alternative set-up, the tax revenues are used to subsidize sectoral R&D activities. This mechanism may be a more purposeful way to use the revenues, because it directly supports the growth mechanism in the sectors and should thus facilitate the shift to a less energy-intensive economy. Furthermore, we simulate two additional scenarios imposing, e.g., different assumptions for the energy policies abroad. In all these later scenarios, the tax revenues are redistributed back to the household.

In the base scenario, the tax rate starts at 7% in 2010 and is augmented gradually until 2035. This tax profile leads to the requested reduction of 37.5% under the basic assumptions. In order to reach the requested reduction in the other scenarios, different tax rates are necessary. The tax profile thus differs from scenario to scenario, while the reduction target is always the same.

An additional scenario considers the reduction targets that have been discussed at the United Nations Climate Change Conference in Copenhagen. Although there is no definitive agreement on binding targets, the range in which the targets will have to be in order to ensure at least a mitigating effect on climate change is relatively clear. For industrialized countries, reductions in CO2 emissions between 25% and 40% until 2020 and between 80% and 95% until 2050 (compared to 1990 levels) are necessary to limit global warming to two degrees Celsius. We simulate a path that leads to a 30% reduction until 2020 and an 80% reduction until 2050. The policy instrument is again a sures. Additionally, in accordance with scenario I of the "energy perspectives", it includes the assumption that per capita energy use is constant in the long run even in the absence of political intervention. As already mentioned above, the endogenously determined benchmark yearly growth rate of the economy is about 1.33%. Thus, in the BAU scenario, all sectors and consumption are growing at this rate.

Figure 1: Projected effects of undamped climate change (Source: Stern Review)



CO2 tax, implemented in the same way as before. Again, we set the tax so that the two targets are exactly met. Here, the initial tax rate is 0.05. This rate is again augmented (at a higher rate after 2020) until 2050. The revenues from the tax are redistributed back to the representative household.

The graphs displayed below show the growth paths of sectoral output and consumption (both initially normalized to 1), compared to the business as usual scenario (referred to as BAU scenario from here on). Note that the BAU scenario abstracts from climate change and includes no environmental policy mea-

An important point to consider when interpreting the aggregate effects is that our BAU scenario is not a realistic case, because it abstracts from climate change and its possible negative effects. A benchmark path that comes closer to reality would thus be one that considers climate change, but does not include any political intervention. The Stern Report (Stern (2007)) includes projections of losses in GDP per capita, given undamped climate change (see Figure 1).

Due to the long time horizon of these projections, there is obviously a considerable uncertainty on the effects on per capita GDP, and the range of possible long-term impacts is large. However, it seems clear that especially in later decades, the losses increase sharply in the absence of political intervention. Depending on the assumptions on the impacts of climate change and on what other effects are considered, losses could augment up to 35% in 2200 compared to the benchmark. Policy measures aiming at mitigating climate change should thus be able to significantly reduce these losses in later decades. Thus, although it may lead to larger losses in the shorter term, implementing policy measures that mitigate climate change should be beneficial as possibly even larger losses in the long run can be avoided or at least reduced. Thus, to compare the aggregate effects derived in the scenarios analyzed below, we have two very different reference cases. The first is undamped climate change as given in Figure 1. The second is "business as usual" without climate change (our BAU scenario). BAU is easier to calculate but is only relevant if there were no climate change at all.

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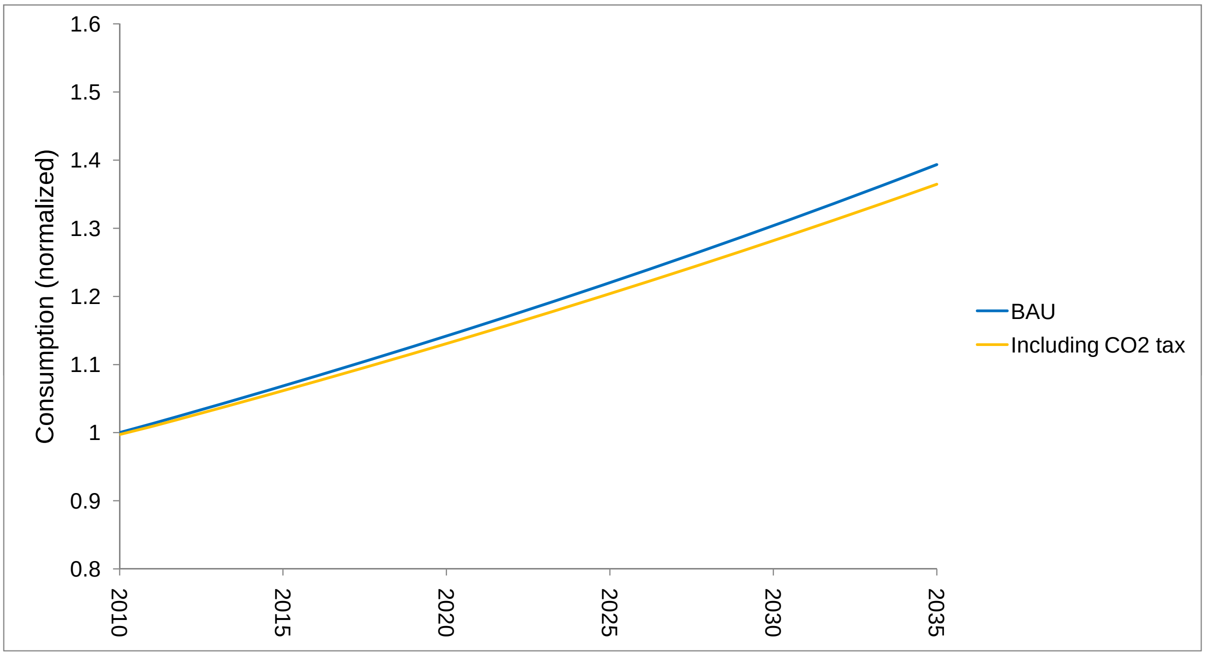
Base scenario: Tax revenue redistributed to the household

This scenario (hereafter referred to as the base scenario) is closely related to scenario IV of the energy perspectives and the idea of the 2000 Watt society. According to scenario IV, total energy use has to be reduced by 35% compared to the year 2000 (or 37.5% compared to 2005) until 2035 if the goal of a 2000 Watt society is to be reached by the end of the century. The policy instrument implemented to reach this target is a CO_2 tax. In accordance with scenario IV, we do not make any assumptions on policies for the time after 2035, which means that the model horizon ends at that point in time. Figures 2 and 3 show the results.

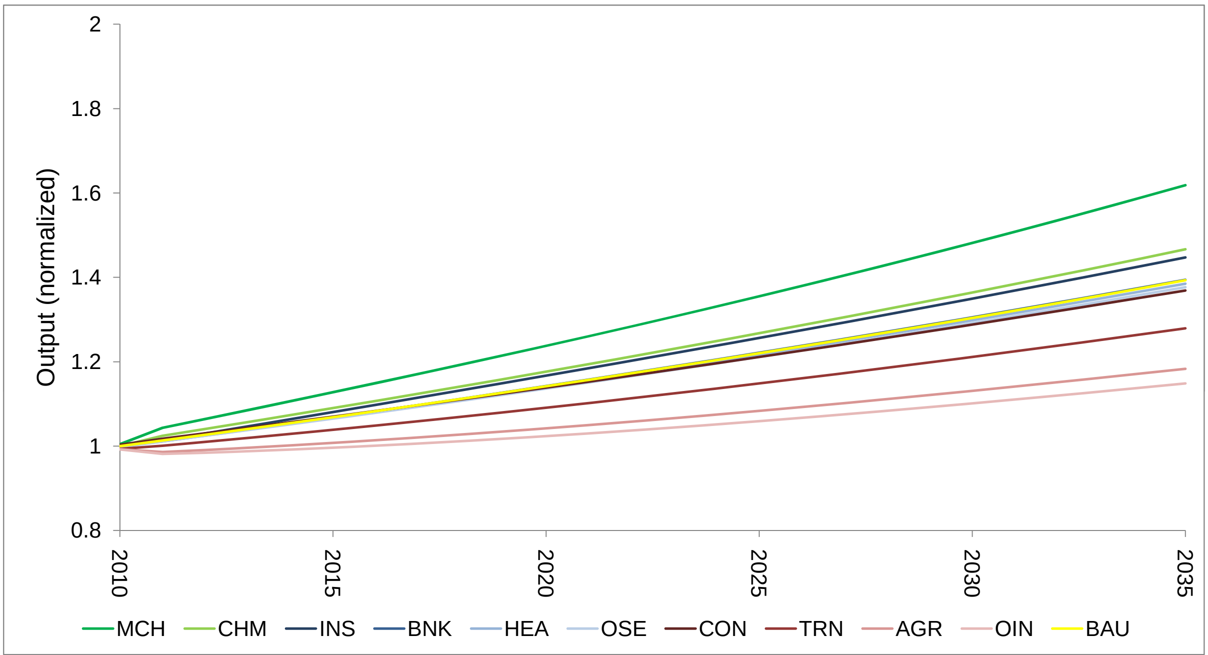
Figure 2: Consumption compared with BAU path (Base scenario)



Given the ambition of the target and the stringency of the policy, one would expect strong impacts on consumption and welfare. However, this is not the case. The effects both on consumption and welfare are quite moderate. Welfare, which is measured by total discounted consumption over the entire model horizon, is 1.2% lower than in the BAU scenario. The used discount rate is 1.1%, which is a very low value. A higher value would decrease the predicted welfare change. Moreover, note that there are no secondary benefits of energy policy included in the model, such as positive effects on health costs due to cleaner air. Again, the welfare change would be smaller if these positive side effects were considered. Consumption is still growing over time, but at a lower rate than in the BAU scenario. The average annual growth rate of consumption is now 1.26%. This leads to a level of consumption in 2035 that is about as high as the level in the middle of the year 2033 in the BAU scenario. Or, put differently, consumption in 2035 is about 2% lower than in the BAU scenario. This confirms previous findings that even relatively stringent policies are economically feasible from a consumer point of view. Both consumption over time and overall welfare

are only affected moderately, implying that even restrictive policy measures come at a bearable cost. One reason is that lower energy use causes induced innovation and capital accumulation, which support the growth process. Another reason is that energy plays a relatively minor role in consumption. Its share on total consumption of final goods is around 2%. The direct effect of the tax through an increase in the relative price of energy goods is thus small. The CO_2 tax also affects the prices of non-energy goods, because they use energy as an input to production. Non-energy goods are assumed to be good substitutes. The household thus has a relatively flexible consumption structure that facilitates substitution of energy intensive for non-energy intensive goods.

Figure 3: Sectoral outputs (Base scenario)



At the sectoral level, the introduction of the tax leads to pronounced structural effects (see Figure 3). All regular sectors still exhibit positive growth rates, but, compared to the BAU scenario, some sectors benefit from the introduction of the CO_2 tax (in the sense that they now grow at a higher rate), while others are negatively affected and grow slower. Reactions in sectoral growth rates range from an increase to an annual growth rate about 1.9% per year in the machinery industry to a decrease to a rate of 0.6% in other industries. The sectoral effects can be roughly divided into three groups. The two biggest gainers (indicated by the green lines in Figure 3) are the machinery industry and the chemical industry (the latter now growing at an annual rate of about 1.54%). These two sectors benefit most from the introduction of the policy. The second group, denoted by blue lines, includes the service sectors. They are only moderately affected, and their growth paths do not deviate significantly from the BAU path. The exception is insurances, whose growth rate increases to 1.48%. The third group includes the remaining industries (denoted by red lines). These sectors experience lower (but still positive) growth after the implementation of the CO_2 tax.

There are various reasons for these structural changes. A first explanation is certainly the energy intensity of the sectors, i.e. the relative importance of energy as an input in the production of a sector. The more energy a sector uses in its production process, the more it should be affected by the tax. Indeed, the sectors that suffer losses are those with the highest energy intensities. The three sectors that have the highest energy intensity are those that suffer the largest setback in growth. Construction also grows at a smaller rate than in the BAU scenario, but the decrease is smaller. The negative effect on the construction sector may, however, be overestimated in this model, because an important aspect of technology development and of Swiss energy policy is excluded. Increased standards for energy efficiency for new buildings and corresponding regulations for the renovation of existing infrastructure are an important aspect of future reductions in energy demand. These regulations should clearly be favorable for the construction sector if they were included in the model, as the demand for construction services should increase significantly. This mechanism being excluded, the decrease in output of the construction sector can be readily explained by its relatively high energy intensity.

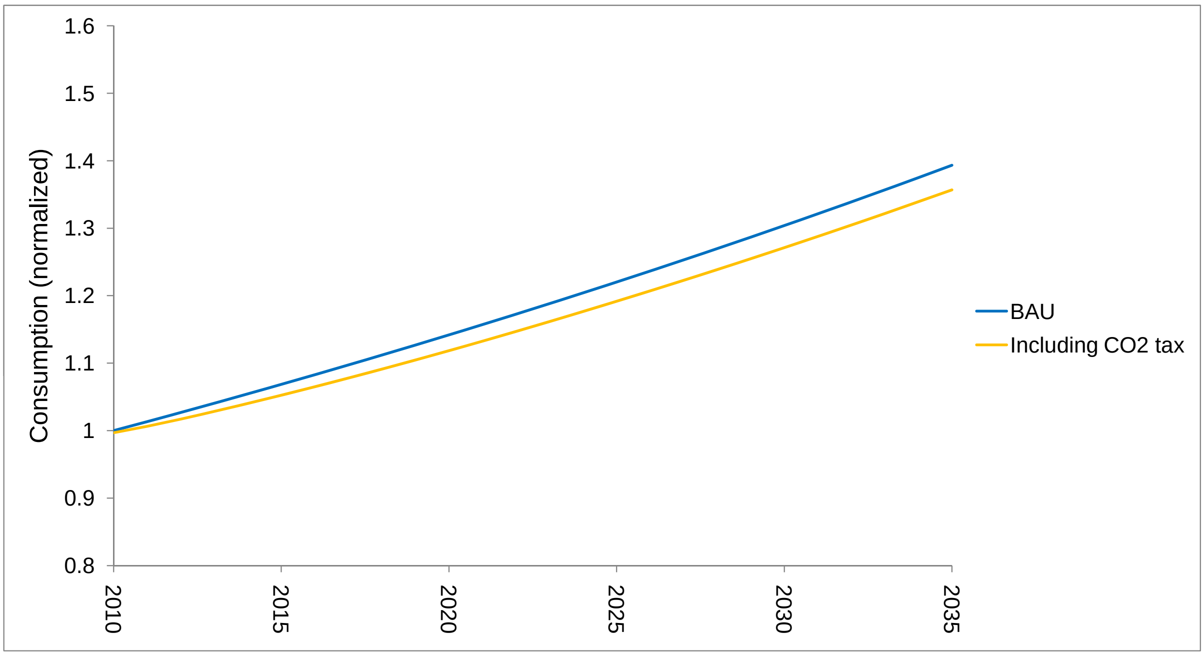
The service sectors on the other hand generally have very low energy intensities. Their shares are in a range between 2.6% for other services to 0.6% for banking and financial services. These low values show that services are clearly less exposed to the tax, and therefore their reactions to the tax are very small. The fact that their growth rates still slightly decrease can be explained by their comparably low substitution possibilities. For the service sectors, we assume a lower elasticity of substitution between the inputs in the production of the intermediate varieties. The potential to avoid the tax is smaller than for other sectors, most notably than in the two industries that benefit from the introduction of the carbon tax. This leads to a small decrease in output of most service sectors, despite the low energy shares. On average, the machinery industry and the chemical industry also use relatively little energy in their production (the machinery industry has a high labor share, the chemical industry is very capital intensive), and they both have better substitution possibilities for energy than the service sectors (reflected by higher values of σ_X). These two characteristics give them a comparative advantage over the other sectors and enable them to benefit from the policy.

The capital stocks (not shown here) exhibit a similar pattern to output, which means that there is a clear indication that capital is shifted to the non-energy intensive sectors. The non-energy intensive sectors are more attractive for investors in the presence of the carbon tax, because they are less affected by the tax. This leads to higher investments and an increase in their capital stocks. A second reason for the structural changes are the linkages of the different sectors to the energy sector and the oil sector. These linkages are reflected in the use of outputs of other sectors in the production process. As the oil sector and the energy sector reduce their output in a substantial amount due to the tax, they also require fewer inputs from the other sectors. The oil sector is strongly linked to other industries and to transport. The energy sector also relies on a lot of inputs from other industries (apart from gas and oil). Outputs from the machinery industry, the chemical industry and from the service sectors (most notably from insurances) only play a minor role in the production of the energy sector and the oil sector. These linkages may however not be as important as the energy intensity. The oil sector is a very small sector, and the amounts of output used from transport and other industries are therefore also small. The energy sector is relatively factor intensive and relies on relatively few inputs from other sectors. Therefore, the arguments made here may not drive the results, but they add to the effects from the energy intensity. Third, and most importantly in the dynamic context, certain sectors directly benefit from the increased investments. Physical investments require inputs from industries such as construction and the machinery industry. As capital stocks and thus also investments increase significantly in certain sectors, sectors that provide goods that are necessary to implement these investments therefore make additional gains. Moreover, research benefits through increased capital accumulation due to learning effects.

Tax revenue used as a subsidy for R&D

In this scenario, we apply an alternative approach for the redistribution of the tax revenues collected from the CO_2 tax. The revenues are no longer redistributed to the households, but are now used to subsidize the build-up of the sectoral non-physical capital stocks. the production process of non-fossil energy. The yearly subsidy rate is calculated directly from the tax revenues and is uniform across all sectors. As we have a rising tax rate until the year 2035, the rate of subsidy is also rising during that period. The tax rate has

Figure 4: Consumption compared with BAU path (R&D subsidies)

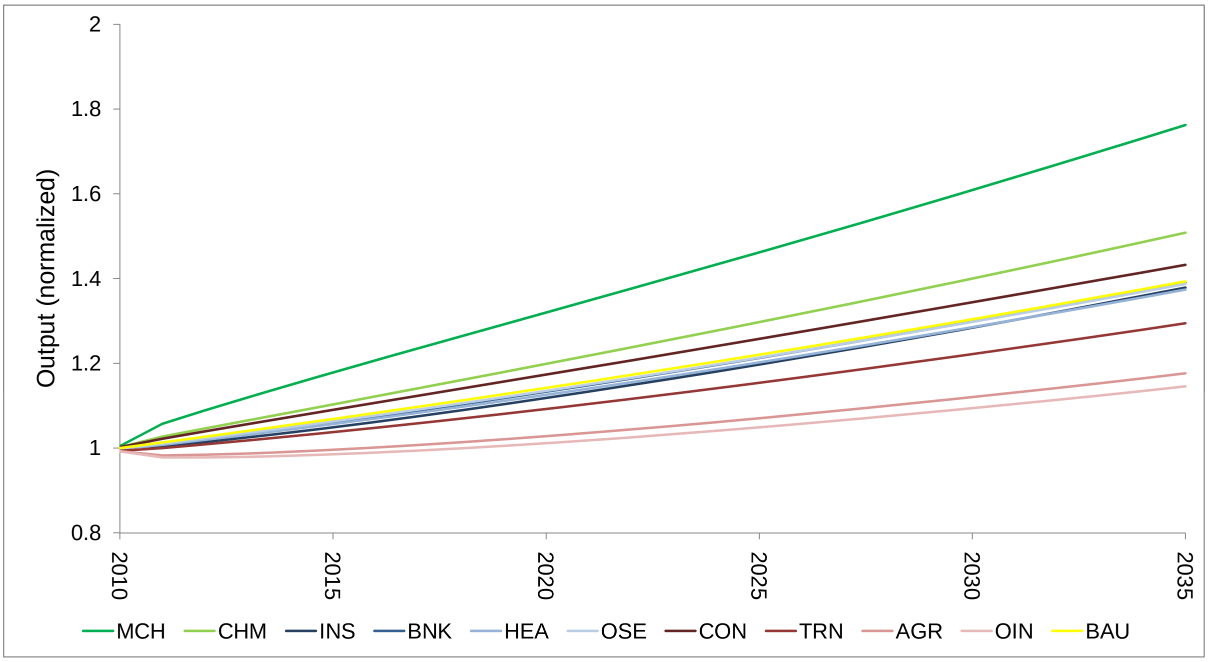


Due to our formulation of the investment process, this can also be interpreted as a subsidy to sectoral R&D. As already explained, the build-up of capital is the engine that drives growth in this model. This alternative way of redistribution directly supports the growth mechanism in the sectors. From an environmental policy point of view, it would not make sense to subsidize the oil sector as well. It is therefore excluded from the redistribution. Energy, on the other hand, is subsidized as well, as the subsidy affects only to grow at a slightly higher rate than in the base scenario to ensure that the reduction target is met. The results are shown in Figures 4 and 5.

Variations in aggregate consumption are more pronounced in this scenario. Consumption declines more during the phase until the reduction target is reached. It is 2.6% lower in 2035 compared to the BAU scenario, while the corresponding decrease in the base scenario is only about 2%. The annual growth rate of consumption in this scenario is around 1.24%. Correspondingly, welfare loss is also higher (2%). The sharper decrease in consumption has to be attributed to the increased investment activity. The subsidy leads to an increase in the capital stocks of almost all sectors, as both physical and non-physical investments increase significantly. Thus, compared to the case discussed above, households devote less of their income to consumption and increase their investment activity in earlier periods, because investment incentives rise due to the subsidy. An important point to consider here is that the time horizon of this policy and thus of the time frame considered in the simulations is rather short. If we assumed a longer time horizon, the higher investment activity and thus the increased accumulation of capital would eventually have a beneficial effect and the welfare change would become smaller than in the case with the original redistribution mechanism. Given the assumptions here, the time horizon is too short to reap the benefits from the subsidy and the increased capital accumulation.

There are a couple of changes in sectoral effects compared to the base scenario. First of all, some sectors now grow at a considerably higher rate than in the base scenario. This implies that the subsidy actually works as a supportive mechanism in these sectors. On the other hand, the subsidy also leads to a wider range of effects. The biggest gainers are the machinery industry (whose annual growth rate increases to 2.27%), the chemical industry and construction (with annual growth rates of 1.65% and 1.44%, respectively). Additionally, banking and financial services now also grow at a higher rate compared to the BAU scenario without a tax. Insurances on the other hand, which are among the winners in the first scenario, now exhibit slower growth until 2035. The two most energy-intensive sectors (agriculture and other industries) now grow at even lower rates than in the base scenario, indicating that the subsidy leads to an even more pronounced reallocation of capital.

Figure 5: Sectoral outputs (R&D subsidies)



The structural effects are not much different in this case. It is apparent that some sectors benefit more from the subsidy than others. The explanation for this is the importance of initial investments (both physical and non-physical). Capital-intensive sectors that rely heavily on investments, or sectors that have high activity in R&D experience larger upwards shifts than those where none of the two is an important factor in the production process. Two examples to illustrate this point are construction and insurances. Construction has very high initial physical investments. As the subsidy indirectly also supports the build-up of physical capital, construction now benefits from the introduction of the tax and eventually becomes a gainer of the policy in this scenario. The opposite holds for insurances, where neither physical investments nor R&D are an important factor. Consequently, they are not able to benefit from the subsidy and are worse off in this case.

The two biggest gainers in this scenario, the machinery industry and the chemical industry, both have favorable preconditions to benefit from the subsidy. The chemical industry has large initial investments in non-physical capital, the machinery industry has relatively high physical investments, and R&D also plays a significant role. The same holds for other services, which have relatively large initial physical and non-physical investments. Thus, the subsidy, despite increasing investment activity in all sectors, is mostly beneficial for the sectors that have high initial investments. Other than that, the structural effects are similar to the previous scenario. In the presence of the subsidy, the energy-intensive sectors also experience slower growth and attract less capital than in the benchmark. The non-energy intensive sectors on the other hand benefit from the introduction of the tax. The subsidy slightly intensifies the investment incentives and therefore increases the range of observed sectoral growth rates.

Additionally, the fact that increased accumulation of capital benefits sectors that actually provide the goods and services necessary to conduct the investments has a more pronounced effect here. Construction and the machinery industry, two sectors that play a role in this respect, increase their output considerably. This can be partly attributed to the increased demand for investment goods in most sectors.

The policy implemented here could have even more pronounced effects if the subsidies were more purposefully designed. One may argue that it does not make sense to subsidize the build-up of non-physical capital in sectors where it does not have a significant influence. Therefore, one could think of subsidizing only the sectors that have relevant R&D activity, or to subsidize these sectors at a higher rate than those that do not rely much on R&D. Sectors with high initial physical investments could also be included, as they benefit considerably from the subsidy as well. From the patterns observed in Figure 5, it seems reasonable to assume that such a policy should increase the range of the effects on the outputs and the capital stocks and thus increase the differences between the sectors. The winning sectors would benefit even more, and the decreases at the bottom would be larger. This is indeed the case. If only the sectors that have significant initial investments (both physical or non-physical) are subsidized, the range of effects gets wider, and both the increases and the decreases are more pronounced.

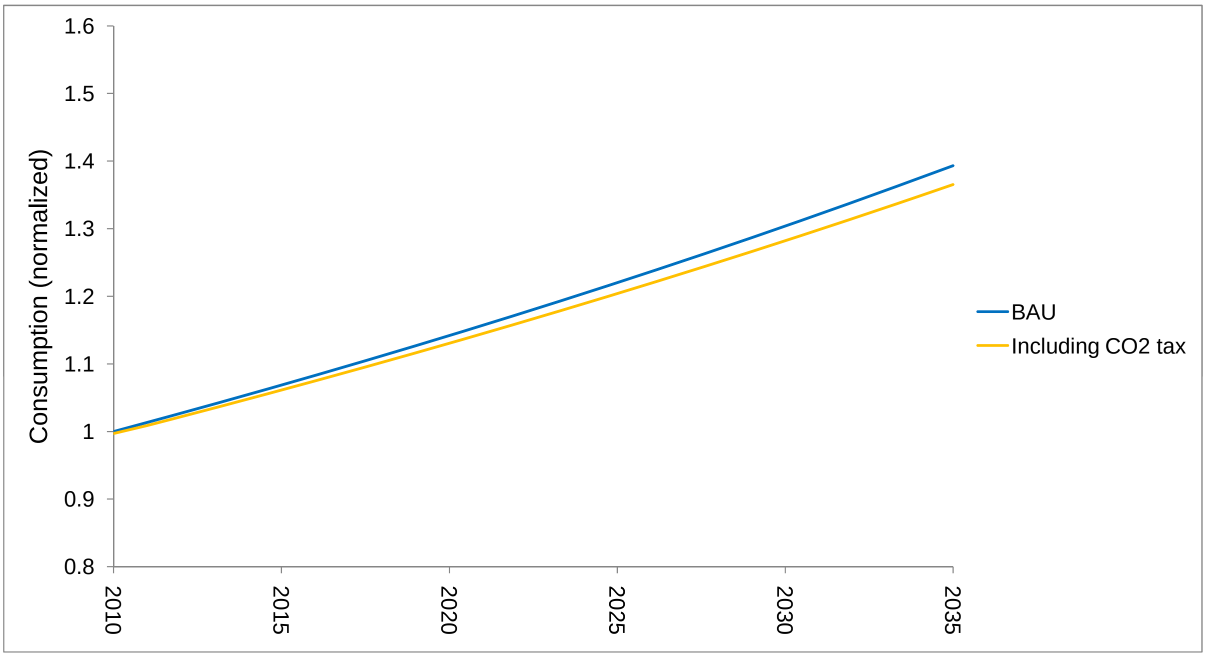
Another possible policy would be to subsidize only the non-energy intensive sectors. This again increases the range of effects, which is not surprising as we noticed above that the energy-intensive sectors are most affected by the CO_2 tax. Thus, there would be an even more pronounced shift of capital from the energy-intensive to the non-energy intensive sectors, and larger adjustments in sectoral outputs.

Different policies abroad

It is reasonable to assume that not only the policies implemented in Switzerland itself affect the Swiss economy: The measures taken by foreign countries may also have an impact. So far, we have implicitly assumed that foreign countries implement similar reduction targets and therefore a similarly stringent policy. This, however, does not necessarily have to be the case. The discussions at the United Nations Climate Change Conference in Copenhagen showed that there is a lot of disagreement on future climate and energy policy. Future policies and reduction targets may thus considerably diverge between countries. This raises the question on how the effects of domestic policies vary if different policies are implemented abroad.

As the CITE model is a one-country model, there is no possibility to model policies in foreign countries in an explicit way. However, differences in reduction targets or CO_2 taxes can be expressed by varying the trade elasticities. If environmental policy is less stringent in the rest of the world, this implies (considering our formulation of environmental policy) that foreign countries set lower taxes on CO_2- emissions than Switzerland. Thus, there is a higher premium on the prices of fossil fuels in Switzerland than abroad, which means that foreign goods are relatively cheaper compared to domestically produced goods. This increases the incentives to import goods rather than producing them in Switzerland. In terms of model parameters, this means that the Armington elasticities rise, as there is an increased preference for foreign goods.[7] At the same time, Swiss goods become less attractive for foreign consumers, as they are relatively more expensive because of the higher tax. Demand for exports decreases, which is reflected by a lower value of the elasticity of transformation. The

Figure 6: Consumption compared with BAU path (More stringent policy abroad)



[7]The Armington elasticities (Armington (1969)) define the degree of substitutability between domestically produced and foreign goods. The underlying assumption is that domestic and foreign goods are not perfect substitutes. The elasticity of transformation is a similar concept on the export side and distinguishes between domestic and foreign demand

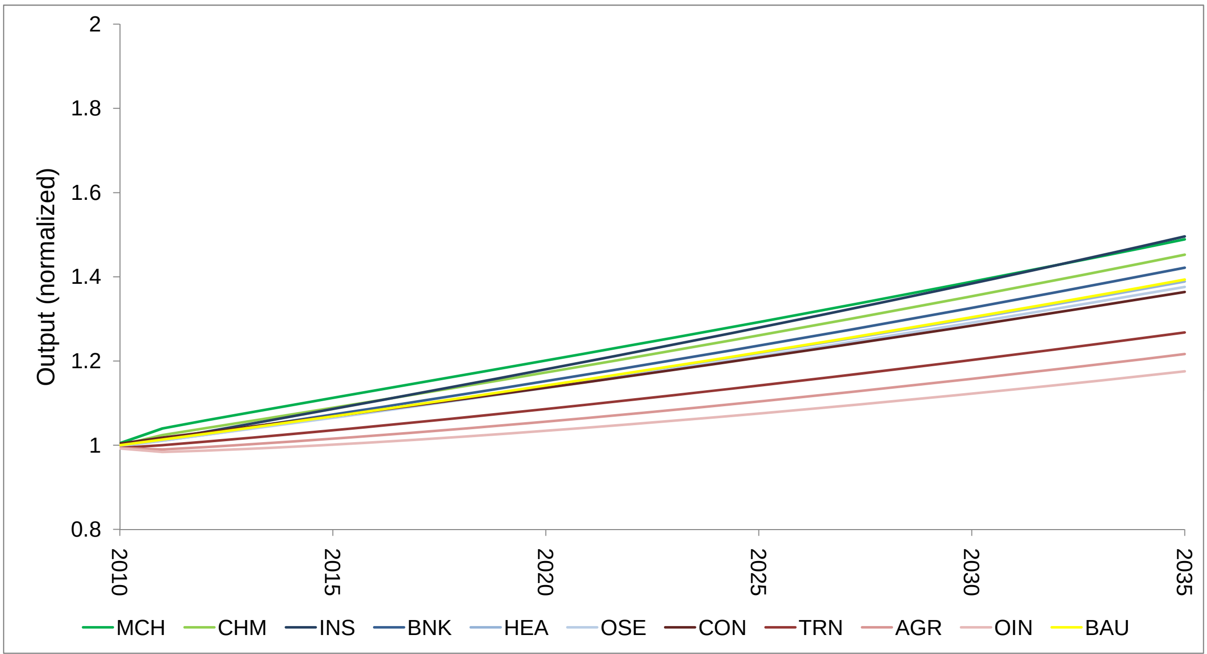
opposite holds if we assume that Switzerland implements a less stringent CO2-tax regime than foreign countries. The premium on the fossil fuels is smaller in Switzerland, and thus Swiss goods become more attractive for foreign countries, and export demand rises. Correspondingly, the elasticity of transformation also rises. Foreign goods on the other hand are now relatively more expensive and therefore less attractive for domestic consumers. This means that domestically produced goods cannot be readily replaced with foreign goods, so the Armington elasticities decrease.

More stringent policy abroad

First, we assume that Switzerland does not follow the rest of the world and implements a comparably loose energy policy regime. The underlying assumption here is that the rest of the world sets a higher tax rate, which corresponds to a more ambitious reduction target. As explained above, this higher tax rate abroad has an influence on the relative prices of domestic and foreign goods. To model this, we reduce all Armington elasticities and increase the elasticity of transformation. The results are shown in Figures 6 and 7.

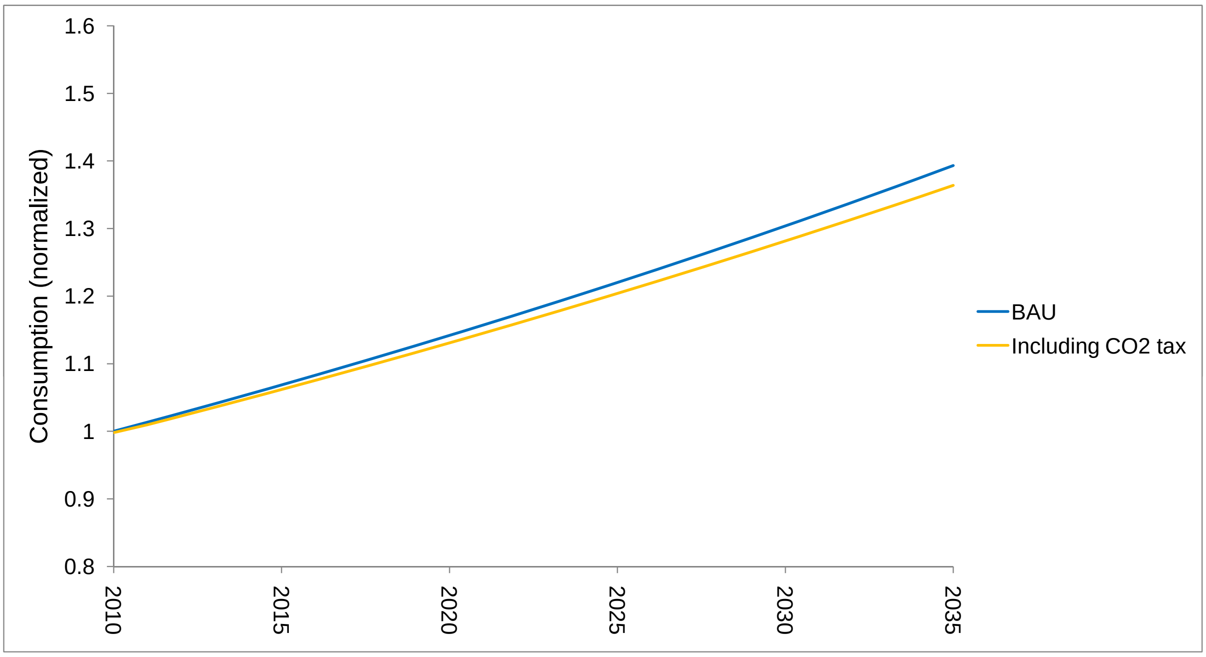
In welfare terms, implementing a less stringent tax regime leads to a similar outcome for the domestic economy as in the base scenario. The decrease is again about 1.2% and thus is at a similar magnitude. This implies that consumption over time evolves in almost the same way. Its annual growth rate is again 1.26%, leading to consumption being just about 2% lower in 2035. An important difference to the base scenario is that we need a higher tax rate (or a higher growth rate of the tax rate) to reach the reduction target. The tax profile of the base scenario would not lead to the requested decrease in energy use under these circumstances, indicating that the incentives to cut down energy use are smaller when foreign policy is more stringent.

Figure 7: Sectoral outputs (More stringent policy abroad)



Compared to the results derived with the standard values for the Armington elasticities and the elasticity of transformation, the range of effects on sectoral output gets much smaller. The reactions to the tax are less pronounced than in the case with similar policies. Due to the fact that domestic goods (that are affected by the tax in Switzerland) cannot be readily replaced by foreign goods, the policy has a smaller overall effect and leads to smaller adjustments, both on the positive and on the negative side. One possibility to react to the tax, namely substituting domestic for foreign imports, the decrease in the corresponding Armington elasticity affects the machinery indus- try negatively. However, its growth rate is still higher than in the BAU scenario. Insurances, a sector with comparably little trade activity, benefits the most in this scenario and increases its growth rate to 1.62%. Banking and financial services are also among the winners in this scenario. This sector benefits from the increased elasticity of transformation due to its high export share. Other than that, structural change is similar in direction, but less pronounced in magnitude

Figure 8: Consumption compared with BAU path (Less stringent policy abroad)



goods, becomes unattractive in this scenario, because the foreign goods are relatively more expensive. An interesting observation is that the machinery industry (a relatively trade intensive industry) is no longer the biggest winner in this scenario. Relying heavily on compared to the base scenario. The energy-intensive industries at the bottom grow at slightly higher rates than in the base scenario, while the reactions in the service sectors (except for insurances) are still very small.

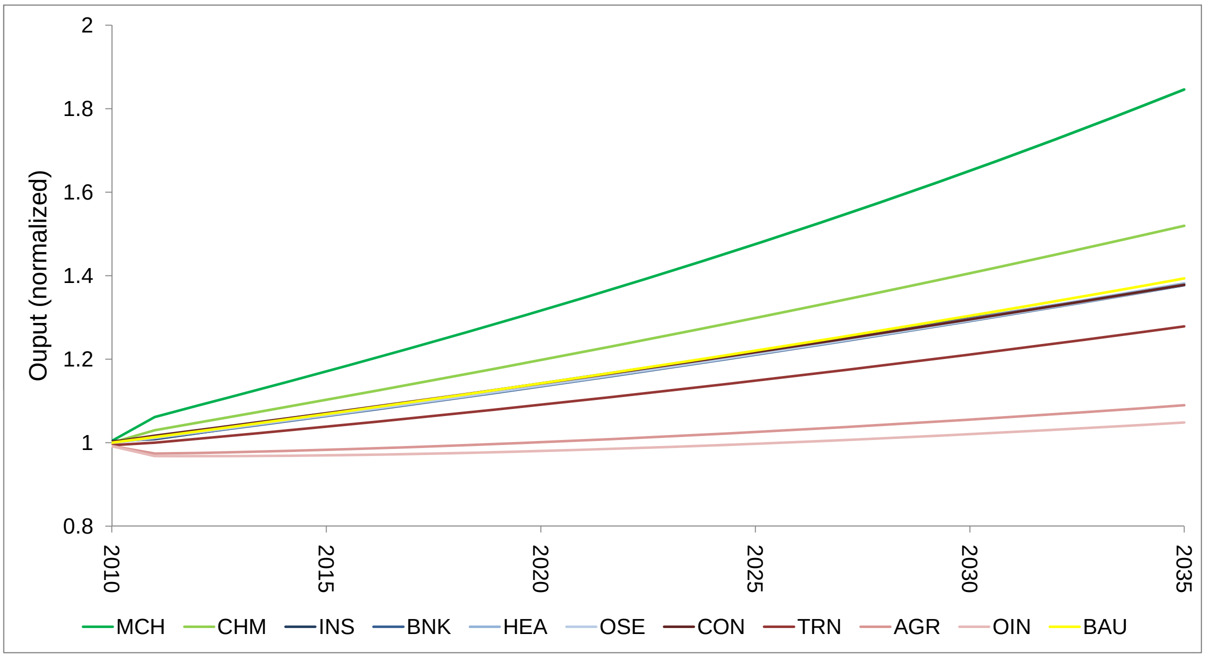
Less stringent policy abroad

The contrary assumption that the rest of the world implements a less stringent policy than Switzerland is modeled in the opposite way compared to the case above. All Armington elasticities are increased, and the elasticity of transformation is reduced. Figures 8 and 9 show the results.

Given that the rest of the world implements a less stringent policy, the reduction target in Switzerland can be met with a lower tax (compared to the BAU scenario), which is just the opposite compared to the case discussed in the previous sections. Welfare is now reduced by almost 1.3%, and consumption grows at a slightly lower rate (1.25%) If we implemented the same tax profile as in the base scenario, the decrease in welfare would rise considerably, and energy use would be reduced by more than the requested 37.5%. Thus, in this case, the reactions to the tax are much more pronounced. Foreign goods are now relatively cheaper than domestic goods, which translates to higher Armington elasticities. This is primarily beneficial for the sectors with high import shares, such as the machinery industry and the chemical industry. The machinery industry accordingly increases its growth rate significantly in this scenario. The chemical industry also experiences faster growth.

However, these are the only two sectors with higher growth rates than in the BAU scenario. Banking and financial services for example, which were a winner in the scenario with a more stringent policy abroad, now reduce their output, as the elasticity of transformation is lower. The three most energy-intensive sectors (transports, agriculture and other industries) suffer even larger losses than in the original case with similar policies. Thus, there are much more pronounced adjustments in this case, with a clearer shift towards a less energy-intensive economy. The economy as a whole is more flexible in this scenario, because the potential to substitute domestic for foreign goods is higher in all sectors.

Figure 9: Sectoral outputs (Less stringent policy abroad)

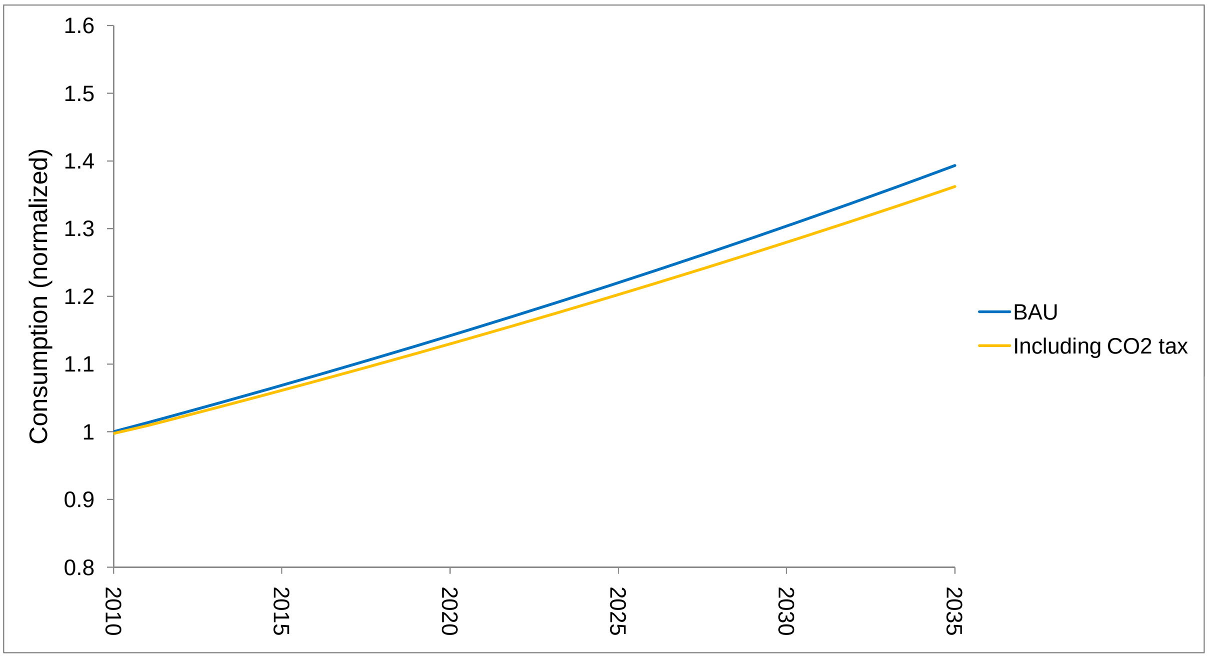


From these two scenarios, it becomes apparent that the policy of the rest of the world has a significant influence on the Swiss economy, both at the sectoral and the aggregate level. If Switzerland implements stronger regulations than the rest of the world, welfare loss increases, albeit only by a small amount. Additionally, the effects on a sectoral level are much stronger. In this setting, a first-mover strategy in the sense of implementing strict regulations - no matter what the rest of the world does - is not beneficial, as welfare reductions are slightly higher than in the case with similar policies. A first-mover policy could have positive effects if learning effects were included in the model. Setting comparably stringent reduction targets necessitates an increased use of new, less energy-intensive technologies. If the use of these technologies entails learning effects, it may be beneficial in the long run if the technologies are used in production earlier than abroad. The corresponding cost reductions due to learning-by-doing may lead to considerable comparative advantages. As this effect is excluded in this analysis, the negative effects of the first-mover strategy prevail and welfare is slightly lower than in the case with similar policies.

Larger labor force

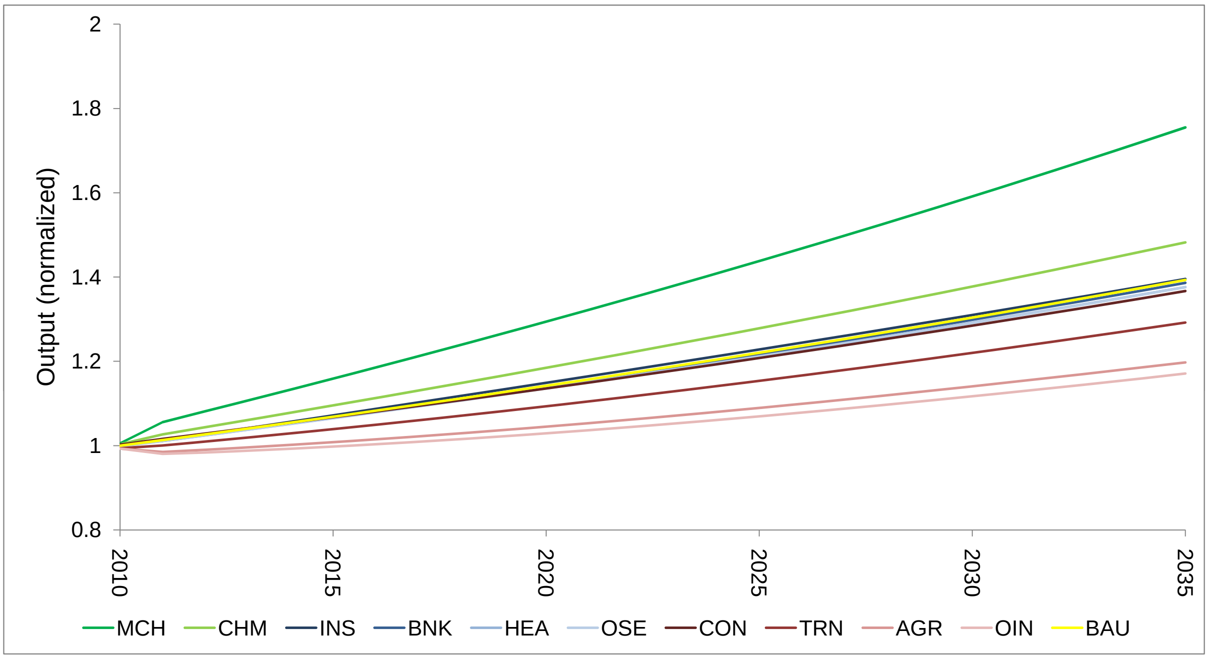
A prominent issue in the current political and public debate in Switzerland regards the possible effects of the recently signed agreement with the European Union concerning the "free movement of persons", which facilitates immigration for EU citizens to Switzerland. The main concern is that this agreement leads to a substantially higher inflow of citizens from the EU, and thus to a population growth rate that would push the level of residents in Switzerland close to or even beyond a bearable limit. An additional related concern is a negative effect on the wages. Thus, one may ask how high labor growth or a substantially higher population affects the results derived earlier. Our model is calibrated such that labor growth is set to zero, i.e. the size of the labor force is constant. The inclusion of a positive growth rate of population would complicate the calibration procedure significantly. We thus abstract from analyzing the effects of an increasing labor force. Instead, we look at the effects of a larger initial (but constant) labor force. To do this, we increase overall labor input by 10%. In order not to change the sectoral shares on overall labor, we

Figure 10: Consumption compared with BAU path (Larger labor force)



simply augment labor in each sector by 10%. In order to account for the fact that a higher initial labor force also implies a higher initial energy demand, the corresponding benchmark values are adjusted as well. We is just about the same as in the scenario with a more stringent domestic policy. Similarly, the requested reductions can be achieved with a lower tax rate than in the base scenario. This again implies that adjust-

Figure 11: Sectoral outputs (Larger labor force)



assume that a 10% increase in the labor force simply leads to a 10% increase in initial energy demand. 50% of this increase is covered by higher imports, the other 50% by higher domestic production. Due to the assumption that only 50% of the higher energy demand are covered by increased domestic production, imports are considerably higher in this case. As we assume a larger initial energy use in this scenario, this means that the reduction in energy use has to be larger than in all the scenarios previously discussed. Given the assumptions made here, energy use has to be reduced by 41% to reach the requested level. The results are shown in Figures 10 and 11.

Compared to the results derived in the base scenario, the increase in the initial labor input and in initial energy demand leads to no significant change in welfare. The reduction in welfare is again around 1.2%. Consumption grows at an annual rate of 1.25%, which ments would be larger with the original tax profile. This holds for both the aggregate level (i.e. for consumption and welfare) as well as for sectoral growth rates.

Interestingly, the results are mainly driven by the assumption on how much of the additional energy demand is covered by imports. In this case, where we assume that 50% is covered by imports, the share of imports in total demand is higher than before. As we assume a relatively high Armington elasticity for the energy sector and thus a good substitutability between domestic and foreign energy goods, the larger share of imports in total demand, and thus the increased importance of foreign energy, leads to larger adjustments in the energy sector. If we were to assume that all of the additional energy demand were covered by increased domestic production, the adjustments would be much smaller and the differences to the BAU scenario would only be minimal. However, it seems reasonable to assume that a considerable share of the increased initial energy demand is covered by imports. On a sectoral level, there are only small differences compared to the base scenario. The machinery industry and the chemical industry grow at higher rates, while insurances now grow even a bit slower than in the BAU scenario. As indicated above, increasing only the labor force (and thus neglecting the fact that this implies a higher demand for energy) would lead to almost identical results as in the base scenario. This is mainly due to the fact that the labor market is relatively inflexible in our model and not formulated in a detailed way. The only channel through which the results may be affected are thus through its influence on the energy share, or, put differently, on the relative importance of energy in production. Additionally, as we assume that all labor is fully employed, there are no potential negative side effects such as higher unemployment. The effects in fact minimal if we assume that all the additional energy demand can be covered by increased domestic production. What is driving the results here is how much of the additional energy demand of an increased initial labor force would be covered by additional imports. A higher import share and thus an increased importance of foreign energy leads to larger adjustments in the energy sector and to a larger decrease in welfare.

Sustainability Economics

Simulation Models

CITE Model

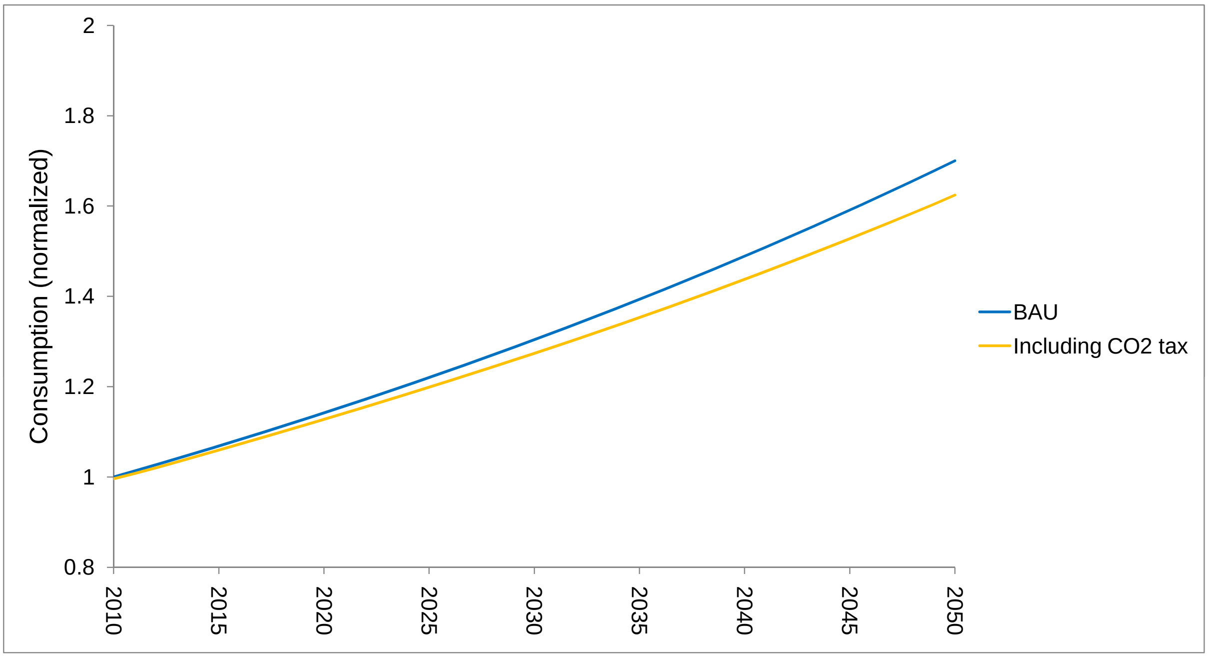
2000 Watt Society

Copenhagen Targets

Conclusions

We now look at the results for the Copenhagen targets. These targets are based on the agreement (given in the Copenhagen Accord) that the increase in global temperature should be limited to 2 degrees Celsius.This requires reductions in carbon emissions of 20% to 35% until 2020, and 80% to 95% until 2050 levels. In this scenario, the CO2 tax is set so that carbon emissions are reduced by 30% in 2020, and by 80% in 2050 (compared to 1990 levels). As our model is calibrated to 2005 data, this is again the relevant base year. This implies that the reductions have to be slightly higher (about 32% until 2020 and 81% until 2050). The first target is thus reached 10 years after the beginning of the model horizon, the second one after 40 years. The results are shown in Figures 12 and 13. Compared to the scenarios discussed above, the time horizon is longer and the policy implemented is more stringent. Additionally, the reduction target is no longer tied to energy use, but to carbon emissions.

Figure 12: Consumption compared with BAU path (Copenhagen)

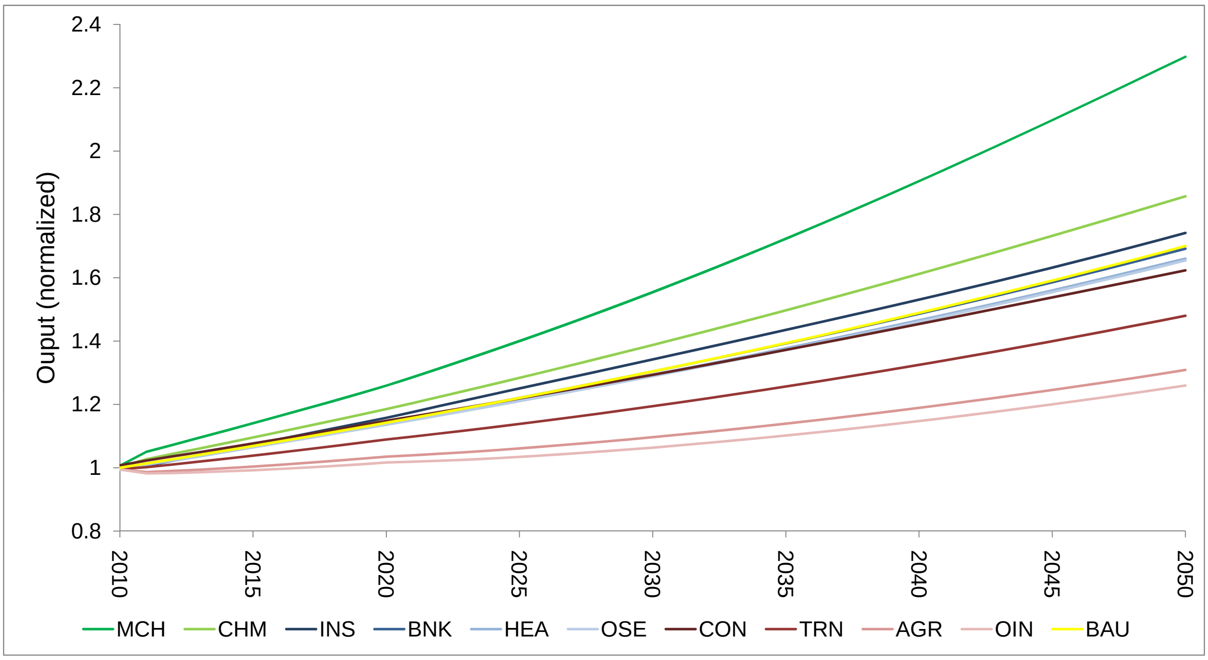


From Figure 12, it can be seen that the effect on consumption over time is a bit stronger than in the base scenario. After the implementation of the policy, the growth rate of consumption drops to 1.23%. This leads to a consumption level in 2050 that is about 4.5% lower than in the BAU scenario. Or, expressed differently, the level of consumption in 2050 after the introduction of the tax is obtained 2.5 years earlier in the BAU scenario. This corresponds to a welfare loss of 2.6% compared to the BAU scenario, but it has to be repeated that BAU disregards climate change. Again, given the stringency of the policy, this seems to be a bearable (though not negligible) cost.

We recall that - besides the neglect of climate change effects - several aspects that could dampen the welfare difference to the BAU case are not included in the model. First, abatement is purely domestic, which means that all reductions have to be achieved in Switzerland and not abroad. Second, there are no additional benefits from climate policy or reduced carbon emissions included in the calculations. Finally, strategic aspects of international trade and international knowledge diffusion are disregarded. Given these limitations, the calculated welfare change appears as a moderate effect of a strict climate policy.

The effects at the sectoral level are very similar to the scenarios previously discussed. The direction of structural change is virtually identical. The non-energy intensive sectors with a relatively high substitution potential for energy benefit from the introduction of the tax. The service sectors, having very low energy shares, but also smaller elasticities of substitution at the level of production of intermediate goods, exhibit only small reactions. The three most energy-intensive sectors again experience a slow-down in growth, but still grow at positive rates. The range of effects is larger than before, which can be explained by the longer time horizon and the increased stringency of the policy. The effects on capital accumulation again work in the same direction as output. The non-energy intensive sectors become more attractive for investors after the introduction of the tax; thus, capital is reallocated to these sectors. This leads to considerably higher growth rates in the machinery industry (2.17%) and the chemical industry (1.62%) and a general shift towards a less energy-intensive economy.

Figure 13: Sectoral outputs (Copenhagen)



Sustainability Economics

Simulation Models

CITE Model

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Copenhagen Targets

Conclusions

The project has integrated endogenous growth theory into a multi-sector numerical model to evaluate the long-run effects of energy and climate policies in Switzerland. The continuous and sector-specific expansion in capital varieties builds the basic mechanism for long-run development. The modeling of endogenous growth, and especially of sector-specific growth, has provided a successful foundation for predicting the development of the Swiss economy over the long and very long run.

We have studied the effects of various measures aiming at realizing the goals of the 2000 Watt society and the carbon reduction commitments of the Copenhagen Accord. We find that these policies cause moderate but not negligible welfare costs, provided that we take development without climate change as a reference case. However, the reference case with considerable economic costs of undamped climate change is more likely. Compared to such a development, the costs of energy and carbon policies appear to be lower, even when the adopted measures are strict. However, to avoid the costs of climate change, international coordination of climate policies is needed. Specifically, we have to assume that the world as a whole will act according to the Copenhagen Accord; only this will lead to the desired effect on global emissions.

Sectoral differences in the simulated growth rates are significant; they reflect energy intensities, sectoral linkages, and distinct specialization in capital goods. Under the considered conditions, all the sectors (except oil) will be able to grow in the future, though not with uniform, but rather sector-specific rates.

The targets of the 2000 Watt society for 2035 entail somewhat lower welfare losses than the Copenhagen policy for 2050, because the required CO_2 reductions are larger in the second case. The distribution of tax revenues has an impact on consumption and welfare, which depends on the considered time horizon: in the shorter run, research subsidies cannot develop their full advantages for the economy, while in the long run, these subsidies are superior to the redistribution of revenues to households. According to the results, policies implemented in the other countries, as well as the size of the labor force, have an impact on the evaluation of domestic policies.

The model assumptions are conservative in several respects. Technology development is modeled in a top-down manner, which excludes the consideration of specific technology potentials that might also be highly influential on energy efficiency. Learning effects are not a focus; accordingly, the build-up of new core competencies to be used as a comparative advantage in international trade does not emerge. Moreover, the entire CO_2 abatement has to be undertaken domestically; the option of carbon offsets abroad is disregarded. Finally, all elasticities and parameter values are assumed to be at conservative levels. To complete the evaluation of climate change, one would have to add secondary benefits of energy and carbon policies, such as positive effects on health and local pollution. In addition, the extension of this endogenous growth model to a full-fledged multi-region model would be desirable. This is left to future research.

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