10 — Energy consumption of buildings – direct impacts of a warming climate and rebound effects

- energy for heating/cooling
- effect on total energy use and GDP

– Heating energy demand of Swiss households decreases by 0.5% for a 1% decrease in heating degree-days (HDD) based on the empirical relationship between household heating and outdoor temperature.

– The decrease in heating energy consumption due to warming is not offset by a concomitant increase in cooling energy consumption.

– Despite considerable reductions in HDD due to climate change (between 5 and 21% by 2050), the corresponding decrease in total energy consumption and CO_2 emissions is projected to be modest in all considered greenhouse gas scenarios.

– For all greenhouse gas scenarios the projected total welfare gains for 2050 are positive but small (0.04% to 0.23% of GDP).

‹ Swiss households use practically no space cooling today but this may change in a warmer climate (air conditioners in Singapore; photo: Allain Py).

10.1. INTRODUCTION

In 2011, 30.8% of final energy consumption in Switzerland was used for space heating and 2.8% for space cooling and ventilation (BFE, 2012). As average temperatures in Switzerland are likely to increase due to climate change, it is expected that energy demand for space heating will decrease while space cooling, which is currently almost non-existent in private households in Switzerland, is likely to increase. Given a constant building technology, one might expect that heating and cooling energy consumption should be proportional to changes in outside temperatures. However, this proportionality may be impeded by households' behavior. For example, if outside temperatures increase, the decrease in heating energy consumption could be less than proportional because households can now get the same room temperature at a lower price, which encourages them to enjoy more of it and shed their sweater in winter rather than to hold inside temperatures constant. Despite this increase in room temperatures, total expenditures for space heating will decrease, leaving more money for the purchase of other commodities. Depending on whether the additionally consumed goods are more or less energy intensive than space heating, the total energy demand of the household increases or decreases. In particular with respect to increasing energy efficiency, such direct and indirect rebound effects are well documented (Greening et al., 2000; Azevedo et al., 2013), yet their quantitative impact is mainly an empirical question that strongly varies with respect to geographic and economic circumstances.

In this chapter, both the direct and indirect impacts of climate change on the Swiss space heating and cooling energy demand are investigated. First, past weather data are correlated with heating energy consumption by Swiss households to elicit how temperature fluctuations translate into changes of heating energy consumption. The results are then used to project future heating energy consumption by the households in the sample in response to changes in outside temperatures as provided by the DAILY-GRIDDED dataset for the RCP3PD, A1B, and A2 greenhouse gas scenarios (Chapters 2 and 3). This first part only considers potential direct rebound effects in the heating demand of households.

The indirect rebound effects, the changes in cooling energy demand and non-household energy uses are investigated with a computable general equilibrium (CGE) model. This model takes into account the utilization by energy consumers of the revenue saved thanks to lower heating needs and the additional energy consumption that may entail. It allows simulating the entire Swiss economy with the complex interdependencies between different production sectors, households, and trade with foreign countries. The empirical relationship derived before is used to calibrate households' response to changes in outside temperature. The CGE simulations project the changes in total energy consumption and CO_2 emissions up to 2050 for the corresponding CH2011 scenario range.

10.2. METHODS

Two basic thermal indices called heating degree-days (HDD) and cooling degree-days (CDD) are used to relate energy consumption to outside air temperature. HDD are defined following the Swiss standard (SIA, 1982; Christenson et al., 2006): the difference between the target indoor temperature of 20°C and the external temperature, summed over all days with external temperatures lower than 12°C, the temperature below which heating is assumed to become necessary. CDD are calculated according to the U.S. standard (Christenson et al., 2006): the sum of the differences between the external temperature and the threshold indoor temperature of 18.3°C for all days during which mean external temperatures exceed 18.3°C, i.e., the temperature above which cooling is assumed to become necessary. Both HDD and CDD are designed to be approximately proportional to the energy demand for heating or cooling of a given building, respectively. Thus, relative changes in HDD (CDD) are expected to translate into equivalent relative changes in energy consumption.

The empirical analysis of past household data is performed on the spatial resolution of the ZIP codes; the HDD are interpolated by an inverse distance weighted regression (Pesquer et al., 2010) to each ZIP code area and each year between 2000 and 2010 from daily temperature data over the same period provided by MeteoSwiss (Frei, 2014). To project heating energy consumption, HDD are interpolated to ZIP code level based on the DAILY-GRIDDED climate scenarios. For the CGE analysis, which aggregates to the national level, HDD and CDD are calculated as population weighted (based on population density in 2000) national averages for the 2035 and 2060 time periods of the CH2011 scenarios. Values for 2050 are generated by linear interpolation between 2035 and 2060.

The empirical and the CGE analysis use slightly different HDD projections that are not directly comparable. First, the household sample of the empirical analysis is not representative for population weighted conditions as considered in the CGE analysis. Second, the time period is slightly different (2060 vs. 2050).

The **empirical analysis on the household level** of the direct effect of temperature change on heating energy consumption uses household-based data on heating energy and hot water consumption from 2000 to 2010 (NeoVac ATA AG). After discarding outliers, the data comprises 41'829 Swiss households with a total of 175'298 heating consumption observations over the years 2000–2010, collected almost exclusively from apartment buildings.

The effect of HDD on residential heating consumption is estimated by a multivariate regression model. The statistical analysis allows for the fact that households living in different climatic zones may have both a different average heating consumption per year and a different development of building technology over the years 2000–2010 by including indicator variables (fixed-effects) for zip-codes and a set of indicators for regions and climatic zones for each year.

The results from the statistical analysis are used to project future heating energy consumption for Swiss households. Future HDD on the ZIP code level are provided for all greenhouse gas scenarios (A1B, A2, and RCP3PD), and for all time periods (2035, 2060, and 2085). The lack of information on changes in households' characteristics necessitates the assumption that changes in HDD have the same effect on heating consumption in the distant future as during the observed period 2000–2010.

In the **CGE analysis** the GEMINI-E3 CGE model (Bernard and Vielle, 2008) simulates the adjustments of the entire Swiss economy to changing outside temperatures caused by climate change. GEMINI-E3 has been used extensively to derive total costs and benefits of various energy and climate policies for European countries including Switzerland. A recent improvement to the model allows for the integration and examination of the impacts of climate change on the Swiss economy (Faust et al., 2012). The time horizon of the GEMINI-E3 model is 2010–2050. The model's household consumption function is calibrated to replicate the elasticity of energy consumption with respect to HDD derived from the empirical analysis. As cooling energy consumption in Switzerland has been negligible so far, its relationship to temperature fluctuations cannot be deduced from past data, but must be based on plausible modeling assumptions.

Climate impacts are measured against a baseline model simulation assuming no climate policies and no climate change impacts. Based on official Swiss statistics, the economic growth rate is assumed to be 1.7% until 2020, and then to decline to about 0.8% until 2050 (data provided by M. Surchat, SECO; Surchat, 2011), while population is assumed to reach 8.4 million in 2050 ('middle' scenario, Swiss Statistical Office, 2010). In line with the recent decision of the Swiss federal council, nuclear power is assumed to be phased out by 2034, and replaced by natural gas and renewables. In contrast to the static empirical analysis, energy efficiency of household heating is assumed to increase by 1% per year.

Future changes in HDD (CDD) according to the projections described above are incorporated into the model via a decrease (increase) of energy consumption for heating (cooling). Changes in HDD and CDD are introduced separately to distinguish their economic effects. First, the decrease in heating energy consumption of the housing sector is simulated. Then the impact of HDD changes on the services sectors is implemented by simulating a corresponding reduction of heating energy consumption in offices. In the third and fourth simulations, the increase of space cooling demand is analyzed for households and the other economic sectors, respectively. In the final simulation, changes in heating and cooling demands by all sectors are modeled simultaneously.

10.3. RESULTS

The observations used for the **empirical analysis on the household level** show high variability in HDD over the data period 2000–2010 between different years and different geographical locations. Values range from 1735 to 7234 across ZIP code regions and yearly averages over all regions from 2902 to 3669 (Chapter 4, Figure 4.3). This high variability in HDD in our observed dataset assures that projections of HDD do not extrapolate beyond the empirical sample of the HDD-energy consumption relationship, which is important for the robustness of the projected future heating energy consumption.

The empirical analysis reveals that the elasticity of heating energy consumption with respect to the observed HDD variation is only about 50%, i.e., heating energy consumption decreases by approximately 0.5% if HDD decrease by 1%. This elasticity estimate is highly significant (0.1% level) and extremely robust (48.7% to 51.3%) for different model specifications. With the medium estimate of the climate scenarios (Chapter 3) for the mid-century period (2060), it yields a projected decrease

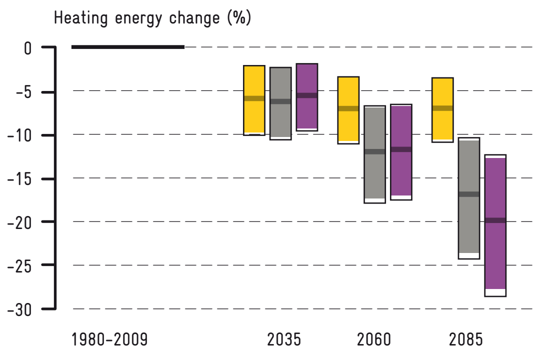

Figure 10.1: Projected reduction in heating energy consumption for the household sample in the empirical analysis for the RCP3PD (yellow), A1B (grey), and A2 (purple) greenhouse gas scenarios.

in heating energy demand averaged over all households in our sample ranging from 7% (RCP3PD) to 12% (A1B; Figure 10.1). For the end of the century (2085), projections range from 7% (RCP3PD) to 20% (A2). Combining the uncertainty estimates from the statistical model (95% confidence intervals) and from the climate change predictions (low, medium, or high; Chapter 3), projected decreases in energy demand range from 3% to 18% for the mid-century period and from 4% to 29% for the end of the century (2085).

The discussion of the **CGE analysis** focuses on the medium estimates for the 2050 period of the A2 scenario, according to the time horizon of the model, and the scenario exhibiting the most pronounced changes and impacts. In this scenario, HDD decrease by 14.5% (Figure 10.2). When only households are allowed to adjust, they lower the heating energy consumption by 7.25% with respect to the baseline, which corresponds to the 50% rebound effect of the empirical analysis. This implies reductions in the total consumption of oil and gas products by 1.8% and 0.3%, respectively (Table 10.1). In contrast, household consumption of other products grows by 0.07%, among which electricity consumption increases by 0.7%, a non-negligible indirect rebound effect. At the aggregate level, the simulation yields welfare gains of 858 million CHF, mainly from a smaller energy bill for heating consumption. As an environment friendly side effect, CO_2 emissions are reduced by 1.6%.

When adjustment is also allowed in all economic sectors other than housing, the 14.5% decrease in HDD leads to smaller fossil fuels savings: 1.3% for oil products, 0.8% for natural gas and 1.1% for CO_2 emissions. The associated welfare gain amounts to 465 million CHF, reflecting reduced production costs in the services sectors.

In contrast to heating, space cooling needs will increase with climate warming, as indicated by a CDD increase by 248.5% in 2050 (Figure 10.2). However, the impact on space cooling and associated energy use is much more uncertain, as currently the percentage of buildings equipped with air conditioners is very low in Switzerland, where air conditioning is tightly regulated. As a consequence it is difficult to project the impacts of a warmer climate on the penetration of air conditioning in buildings. The scenarios stipulate that in the services sectors 46% of spaces will be fully air-conditioned and 36% partially in 2050, in comparison to currently 19% and 20%, respectively. It is further assumed that in 2050, every tenth dwelling will be equipped with air conditioning, compared to a current share of close to zero. The projected increase in electricity consumption for cooling shows a detrimental, but relatively small effect on the Swiss economy. When only the housing sector adapts to more CDD, household electricity consumption is projected to increase by 2.5%, which raises overall electricity consumption by 0.9%. 42% of this increase is covered by renewables and 58% by thermal power plants using natural gas, which results in a 0.7% increase in

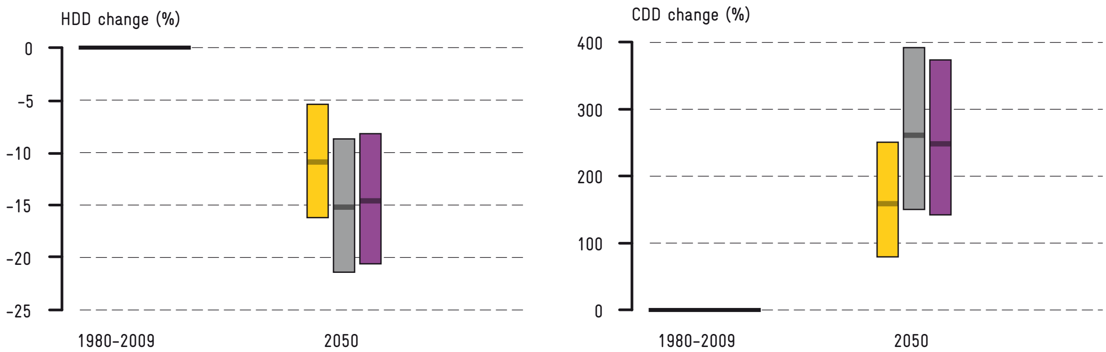

Figure 10.2: Projected changes of HDD (left) and CDD (right) from the CGE analysis for the lower, medium, and upper estimates of the RCP3PD (yellow), A1B (grey), and A2 (purple) greenhouse gas scenarios. The figure displays the percentage changes in 2050 compared to the reference period (1980–2009).

Table 10.1: Impact of heating energy savings due to climate change on total Swiss energy demand in 2050 for the A2 greenhouse gas scenario (medium estimate) as projected in the CGE analysis. Changes are given relative to the baseline scenario.

	Heating households	Heating other sectors	Cooling households	Cooling other sectors	Heating and cooling all sectors
Energy consumption change (%)					
Oil products	−1.8	−1.3	−0.2	0.0	−3.1
Natural gas	−0.3	−0.8	0.7	0.7	0.4
Electricity	0.7	−0.2	0.9	0.8	2.1
Total	−0.5	−0.8	0.4	0.4	−0.4
CO_2 emissions change (%)	−1.6	−1.1	0.0	0.2	−2.5
Welfare impact					
Million CHF (in 2010 prices)	858	465	−234	−130	955
% of consumption	0.13	0.07	−0.04	−0.02	0.15

Table 10.2: Impacts of climate change on the total Swiss energy demand in 2050 for the CH2011 range in greenhouse gas scenarios and climate uncertainty. Changes are given relative to the baseline scenario.

	RCP3PD			A1B			A2		
	lower	medium	upper	lower	medium	upper	lower	medium	upper
Energy consumption change (%)									
Oil products	−1.2	−2.4	−3.5	−1.9	−3.3	−4.7	−1.8	−3.1	−4.5
Natural gas	0.4	0.2	0.0	0.5	0.4	0.4	0.5	0.4	0.4
Electricity	1.1	1.5	1.9	1.5	2.2	2.9	1.5	2.1	2.8
Total	0.0	−0.4	−0.7	−0.1	−0.5	−0.8	−0.1	−0.4	−0.7
CO_2 emissions change (%)	−0.9	−1.9	−2.9	−1.5	−2.6	−3.8	−1.4	−2.5	−3.7
Welfare impact									
million CHF 2010	275	720	1157	487	999	1487	449	955	1429
% of consumption	0.04	0.11	0.18	0.08	0.16	0.23	0.07	0.15	0.22

overall natural gas consumption (Table 10.1). This is offset in terms of CO_2 emissions by lower consumption of oil products (–0.2%) by households who spend a greater share of their budgets on cooling. These changes entail a welfare loss of 234 million CHF. When only the services sectors adapt to more CDD, a 0.8% increase of electricity consumption and a welfare loss of 130 million CHF is found.

The corresponding simulation of all HDD and CDD changes with the coupled responses of both households and the services sectors suggests a beneficial overall impact, with welfare gains netting 955 million CHF by 2050 compared to the baseline.

Similar effects of varying magnitudes are projected for the other scenarios RCP3PD and A1B and across the climate uncertainty range (Figure 10.2 and Table 10.2). Even in the RCP3PD scenario, which supposes that greenhouse gas emissions are reduced globally by about 50% by 2050, Swiss energy demand still decreases by 0.4% relative to the baseline in 2050 due to a warmer climate, while A1B is similar to A2. Across all three greenhouse gas scenarios, a beneficial impact of climate change on the Swiss energy demand is identified, with welfare gains ranging from 275 to 1429 million CHF in 2050.

10.4. IMPLICATIONS

As the empirical analysis on household level shows, there is a pronounced direct rebound effect with respect to heating energy consumption: Households heat relatively more when the same room temperature can be obtained at lower cost. This direct rebound effect of 50% lies at the higher end of the estimates by Sorrell (2007), which range from 10% to 60% in 9 studies.

Applied to the 14.5% decrease of HDD in the medium A2 scenario by 2050, the 50% rebound effect yields a decrease in heating energy consumption of only 7.25%. This still leaves a decline of heating expenditures corresponding to 50% of the HDD effect. According to the general equilibrium analysis, this leads to a strong indirect rebound effect: the 7.25% decrease in heating energy consumption only translates into a 0.5% decrease in total energy consumption and a 1.6% decrease in CO_2 emissions. Despite a warming climate and a considerable reduction in HDD, the resulting decrease in heating energy consumption in particular and total energy consumption in general are rather modest. Thus, direct and indirect rebound effects may render partial energy savings inefficient in reducing overall energy use. It is important to keep this in mind when discussing energy efficiency standards and policies concerning heating and building technology.

Another important insight of the analysis is that the decrease in energy consumption due to a lower demand for heating is not offset by the increase in energy consumption due to an increased demand for cooling. As a result, welfare gains are projected for all greenhouse gas scenarios investigated. They are, however, projected to be modest, ranging between 0.04% and 0.23% of total household consumption. These results are in line with the findings of OcCC (2007) and other studies finding that climate change leads to decreasing energy demand in the colder and increasing energy demand in the warmer world regions (Isaac and van Vuuren, 2009).

The results rest on various strong assumptions and therefore should be considered with appropriate caution. First, the empirical projections of the direct effect of climate change on heating energy consumption by households are just that. They are not forecasts of energy consumption per se as they do not take into account changes in building energy efficiency, population size or space requirements per person, which are all expected to increase over the considered time frame. Second, for the CGE analysis a number of assumptions about the future development of the Swiss economy are made. A major source of uncertainty in our analysis is the projection of future heating and cooling needs. In particular, the projections for cooling energy demand rest on ad hoc assumptions about the future penetration of air conditioning systems in Switzerland, which is currently close to zero for private households due to restrictive regulation. Recent work suggests that the effects could be amplified in cities through the proximity of buildings (Allegrini, 2012). Nevertheless, the estimates are considered to be robust with respect to the pronounced total rebound effect. Although the reduction in

HDD days due to climate change is considerable, the effect on total energy consumption will be rather moderate.

The results indicate that promoting energy efficiency of buildings and heating systems remain important elements of an efficient climate change policy for Switzerland, even in a warmer climate.