

Springer Climate

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Editors

Economic Evaluation of Climate Change Impacts

Development of a Cross-Sectoral
Framework and Results for Austria



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Economic Evaluation of Climate Change Impacts

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This volume deals with the multifaceted and interdependent impacts of climate change on society from the perspective of a broad set of disciplines. The main objective of the book is to assess public and private cost of climate change as far as quantifiable, while taking into account the high degree of uncertainty. It offers new insights for the economic assessment of a broad range of climate change impact chains at a national scale. The framework presented in the book allows consistent evaluation including mutual interdependencies and macroeconomic feedback. This book develops a toolbox that can be used across the many areas of climate impact and applies it to one particular country: Austria.

"This study is a landmark, setting a new standard for the assessment of the impacts of climate change. It stands out for the comprehensiveness of its coverage of potential impacts across different sectors of the economy and its methodological innovations, including tracing climate impacts to economic endpoints."

Michael Hanemann, Professor of Economics, Arizona State University and Professor of the Graduate School, University of California, Berkeley

"This volume develops a consistent, bottom-up approach for a robust evaluation across the whole range of impact fields, acknowledging their macroeconomic feedbacks and budgetary implications."

Thomas Sterner, Professor of Economics, University of Gothenburg

"The lasting value of this book will come from the methodology with its frameworks, consistent toolbox and comprehensive integration, as well as the lessons learnt and shared, exemplified through application in Austria."

Roger Street, Director of UK Climate Impacts Programme, University of Oxford

Environment

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Preface

Our current actions determine the future options. Beyond climate change, the scale of action and potential impact on the world's poor appropriate response may entail a radical change. There is a clear need for adequate information.

Climate change impacts
high degree of uncertainty.
broad set of disciplines and

In this volume, we show how climate change impacts can be integrated into the generation of information relevant to the assessment of climate change. A tool for the assessment of climate impact is developed

Climate scenario analysis associated with climate change values are surrounded by a number of issues to consider the potential range of outcomes (and lower damage values). Identifying and clarifying that several different socio-economic development scenarios can determine how resilient societies are (and whether they will be in a position to respond). For example, the impact of infrastructure in flood prone areas can increase the urban heat island effect, and people's homes are equipped with air conditioning (expected future ageing), which can increase transport, production processes and energy use, crucial in determining a society's resilience.

Chapter 13

Buildings: Heating and Cooling

Lukas Kranzl, Marcus Hummel, Wolfgang Loibl, Andreas Müller,
Irene Schicker, Agne Toleikyte, Gabriel Bachner, and Birgit Bednar-Friedl

Abstract While energy savings in buildings is among the key prerequisites for a low-carbon future, our ability to maintain temperatures in buildings within a specific comfort range, and thus our demand for heating and cooling energy, are also highly sensitive to climate change. We quantify two main impact chains: (1) a higher temperature in winter leads to a reduction of heating energy demand and (2) a higher temperature in summer leads to an increase in demand for cooling. The demand for cooling energy depends largely on the future uptake of air conditioning in the building sector and is subject to considerable uncertainty. On quantifying these two impacts for the example of Austria for the period around 2050 a net saving of about 230 million euros per year is found, triggering slightly positive effects on welfare and GDP. The result is depending on the development of energy prices and in particular by the ratio of electricity to fuel price in the heating sector. The results show that, in absolute terms, the energy reduction in heating is much higher than the increased energy demand for cooling for the time horizon and the geographical location investigated. This stems from the fact that energy demand for

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air conditioning in Austria in 2008 was only 0.4–0.5 % of the final energy demand for heating. The impacts and costs resulting from a strong increase in electricity peak loads in summer are investigated in Chap. 14 (Electricity).

13.1 Introduction

One of the crucial purposes of buildings is to protect people against weather conditions and ensure a comfortable indoor climate. Construction systems and technologies are designed to meet specific climatic conditions and indoor requirements. *Ceteris paribus*, a change in climatic conditions not only affects indoor climate, it also has an impact on the suitability of prevailing building configurations. While some building occupants adapt autonomously, e.g. by changing heating mode or behaviour or by investing in additional cooling devices, several individuals may not have the means to do so.¹ This can result in loss of comfort, productivity, or even worse, loss of health. The latter possibility is discussed in Chap. 11 (Human Health). Climate change may affect the functionality of buildings in several ways due to a higher frequency of extreme events and natural disasters. In Austria, singular and local storms follow no specific pattern or frequency. Usually they are short events concentrated in the eastern lowlands and in valleys and typically damage only a few objects. Only hurricanes (wind speed >118 km/h) are large to continental-scale events which may result in large damage to settlements or forests. During the last 10 years, seven of such continental scale events with wind speeds between 100 and 200 km/h have been observed. However, the impact on roofs due to the higher magnitude and frequency of storms is not quantified in this work since the respective climate scenarios do not provide reliable predictions. How climate change affects buildings in particular the direct impact of floods and storm damage, is addressed in Chap. 18 (Catastrophe).

This chapter concentrates on climate induced effects on heating and cooling. Owing to the volume of buildings exposed and the expected regularity of events, the general annual costs associated with the resulting changes in heating are significant. This is why climate change impact has the potential for releasing large changes in this impact field and making it highly relevant for our analysis.

Section 13.2 describes climatic and non-climatic factors which have an impact on heating and cooling of buildings in the next decades. Section 13.3 starts with a discussion on past and current climate exposure and describes the impact chains in the sector. Section 13.4 provides the approach and results of our evaluation. Finally, in Sect. 13.5 we derive conclusions.

¹ On the relation between indoor comfort and control strategies see e.g. Roberts (2008).

13.2 Dimens

The energy demand nature of building ence between ind may lead to a cha

13.2.1 Clima

We have divided

- (1) Impact on en days) and sol vance, but are
- (2) Impact on en (cooling degra change in clo role (for heati small and unce been ignored. waves are like devices and th

13.2.2 Non-C

Buildings are am within the buildin in other economi sector accounts fo recast 2010), it is climate policy. Im cooling systems e energy sources are established all ove demands of climat include the need to (as a result of risi improving the ther

Other major d include: population size, GDP growth

13.2 Dimensions of Sensitivity to Climate Change

The energy demand of buildings for space heating and cooling is determined by the nature of building components, solar and internal appliance gains, and the difference between indoor and outdoor temperature. A change in outdoor temperature may lead to a change in energy demand for heating and cooling.

13.2.1 Climatic Factors

We have divided the main factors into two impact chains:

- (1) Impact on energy demand for heating: temperature change (heating degree days) and solar radiation. Other factors such as wind speed have some relevance, but are omitted here.
- (2) Impact on energy demand for cooling and ventilation: temperature change (cooling degree days). While changes in solar radiation (due to a possible change in cloud cover), and changes in wind and in humidity would play a role (for heating and for cooling), the impact of climate change impact is rather small and uncertain (Bednar et al. 2013). In this present analysis they have thus been ignored. In contrast, the expected length, severity and frequency of heat waves are likely to have a distinct impact on the market penetration of cooling devices and thus have to be considered.

13.2.2 Non-Climatic Factors

Buildings are among the most durable goods in our society. As a result, changes within the building sector tend to occur at a slower pace than changes taking place in other economic sectors (e.g. tourism, industry etc.). Given that the building sector accounts for about 40 % of European greenhouse gas emissions (EPBD recast 2010), it is of no surprise that this has become a focus in the energy and climate policy. Improving the energy efficiency of building envelopes, heating and cooling systems etc. offers high potential for reducing GHG emissions if fossil energy sources are used. Efficiency targets for new and old buildings have been established all over the world at both the national and regional level. Apart from the demands of climate policy, other reasons for increasing building energy efficiency include the need to reduce fuel poverty and the desire to increase energy security (as a result of rising energy prices). All of these factors drive the change towards improving the thermal quality of the building stock.

Other major drivers behind changes in the structure of the building stock include: population growth, changes in family structures and related household size, GDP growth, comfort requirements in terms of dwelling size per capita and

indoor temperature levels, the impact of spatial planning on building structure, and the mix of different type of buildings. Particularly economic development plays a crucial role in the overall development of residential and non-residential areas and thus in the market penetration of air conditioning (AC) devices (Isaac and van Vuuren 2009).

The Austrian population in 2010 was 8.38 million. The baseline scenario (based on Statistik Austria projections, see Chap. 6—SSP) let expect for 2030 around 9.0 million, while in 2050 the number is expected to reach 9.5 million people. The relative increase in the number of households is higher, rising from a current figure of 3.6 million households (in 2010) to 4.05 million in 2030 and to 4.31 million in 2050. Currently, no specific figures are available on the expected future number of buildings. However, figures do exist with respect to the gross floor area of residential and non-residential structures (excluding industrial facilities). The figures for our reference scenario are: 570 km² gross floor area in 2010, expected to grow to 690 km² by 2030, and to 730 km² by 2050,² which is an increase of 120 km² and 160 km² respectively.

A more wealthy society also increases the demand for additional floor space leading to higher personal comfort, by raising individual flat size. All this increases the demand for energy—first for heating, and perhaps in future, more and more for cooling.

Currently, in Austria space heating is much more relevant than cooling: At the moment energy consumption for space cooling amounts to only 0.4–0.5 % of the energy consumption for space heating (see Müller and Kranzl 2013). Thus, in the case of Austria, cooling is a relatively new subject as in former years it was not a distinct requirement for securing indoor thermal comfort. However, increasing temperatures and growing heat island effects in urban environments as a result of densification and less nocturnal cooling (see Chap. 17—Cities) are expected to increase future demand for the active cooling of flats. Moreover, under typical climatic conditions in Austria thermal building insulation may lead to higher cooling loads unless specific measures for the reduction of cooling energy needs are taken (e.g. shading devices).

In Austria, a considerable effort is currently being made to further improve thermal building quality in new and renovated buildings and to increase the extent of renovation activities. National targets for zero-energy-buildings (for the period up to 2020) were established in 2012 (OIB 2012). However, the current rate of renovation is in the range of about 1 %, and thus still remains far below expectations and official targets (Müller and Kranzl 2013; Bundesministerium für Wirtschaft 2010).

² Based on extrapolation of “Energieszenarien bis 2050; Wärmebedarf der Kleinverbraucher” on the reference scenario.

13.2.3 Identifying Comfort

Factor interplay in the building sector may arise due to other hand, and cooling energy (where the latter has been discussed et al. (2011) on costs.

In terms of depends on the in the building than those in w efficient building e.g. Zangheri et al. of higher winter hand, the lower between the ba demand level is should only be u as an argument

Regarding th loads, the follow due the high de problematic): (1 more frequent conditioning, (3 tion of urban ar ance internal lo demand for elec gains in solar ra adverse changes Chap. 14 (Electr

13.3 Exposure

13.3.1 Past Impacts

Both for heating degree days and

13.2.3 Identification of Potential Large-Damage Combinations

Factor interplay in the assessment of potential climate change damage in the building sector has both positive and negative effects. On the one hand, a benefit may arise due to an expected reduction in the demand for heating energy. On the other hand, an adverse impact may be expected due to increasing demand for cooling energy or due to rising costs associated with storm damage to roofing (where the latter is not addressed specifically in this chapter). These effects have been discussed e.g. in Aguiar et al. (2002), Cartalis et al. (2001), Olonscheck et al. (2011) or Kranzl et al. (2010), however only partly with respect to related costs.

In terms of absolute energy levels, the extent to which benefits materialize depends on the strength of the following: (1) uptake of energy efficiency measures in the building sector, (2) whether temperature increases in summer are stronger than those in winter. Regarding the first point, one must remember that in more efficient buildings the heating period is shorter than in less efficient buildings (see e.g. Zangheri et al. 2014). Thus, more efficient buildings are better able to make use of higher winter temperatures (Kranzl et al. 2010; Bednar et al. 2013). On the other hand, the lower the efficiency of buildings, the higher the difference in benefits between the baseline and mid-range climate scenario, since the absolute energy demand level is higher in the case of a low efficient building stock. Of course, this should only be understood as a *ceteris paribus* condition and must not be understood as an argument for lower efficiency standards in the building sector.

Regarding the adverse impact of climate change in the form of increased cooling loads, the following factors lead to increased costs (when acting in combination, due to the high degree of non-linearity, the impact of such factors is particularly problematic): (1) Higher temperature increases in summer than in winter, (2) longer, more frequent and more severe heat waves, leading to a higher uptake of air conditioning, (3) greater urban heat island effects due to expansion and densification of urban areas (see Chap. 17—Cities), (4) limitations on reductions in appliance internal loads (e.g. no improvement in appliance efficiencies) and higher demand for electric appliances in buildings and (5) lack of measures for combatting gains in solar radiation e.g. by shading. Other factors relating to damage caused by adverse changes in cooling peak loads in the electricity system are discussed in the Chap. 14 (Electricity).

13.3 Exposure to Climatic Stimuli and Impacts to Date

13.3.1 Past and Current Climatic Exposure and Physical Impacts

Both for heating and cooling the past years have already shown increasing cooling degree days and decreasing heating degree days. Regarding the impact on heating,

corresponding data is given in Sect. 13.3.3. The impact of climate change on cooling energy demand in recent years in particular is under discussion. Only rather few estimates are available for Austria concerning cooling energy demand in buildings (Haas et al. 2007; Prettenhaler and Gobiet 2008; Zoll 2010; Müller and Kranzl 2013) which show slightly different results in the range of about 250–500 GWh/yr for the time frame around 2005–2010. Official energy statistics do not provide separate data for cooling energy demand (Statistik Austria 2011). Thus, there is no clear evidence on how energy demand for cooling in Austria has developed in recent years. More information in this respect is available for other countries, in particular for more southern countries with higher cooling load requirements (Tolokyte et al. 2012). E.g. Giannakopoulos and Psiloglou (2006) show the historical data concerning variations in energy consumption, temperature and the gross national product (GNP) for the case of Greece. They argue that all these parameters show a clear upward trend in the period 1993–2001. The maximum daily energy consumption was 38 GWh in 1993 while in summer 2001 it had reached 58 GWh. While it is not clear which factors exactly triggered this development, the study shows that there is a declining trend for HDD (heating degree days) and an increasing trend for CDD (cooling degree days) in the investigated period. Beccali et al. (2007) indicate that summer electricity consumption in the building sector in Italy has grown steadily due to the growing demand for cooling. Moral-Carcedo and Vicéns-Otero (2005) get similar results for the case of Spain from a correlation analysis of electricity peak loads, temperature and cooling energy demand.

Summing up, based on the literature one can say that it is not always possible to clearly separate the effects of increased demand for cooling energy (i) due to climate change and the impact of corresponding autonomous adaptation, and (ii) due to changes in behaviour reflecting a higher demand for personal comfort and thus changes in lifestyle. Notwithstanding this, there is still sufficient evidence that cooling energy demand has increased at least in some southern countries. One indication of the increase in demand for cooling energy in Austria—or at least for an increase in the amount of attention being paid to cooling energy demand—can be witnessed in the development of the respective official standards. The relevant 2011 standard (OIB 2011) requires that the overheating of residential buildings during summer has to be avoided (see ÖNORM B 8110-3).

13.3.2 Impact Chains in the Socioeconomic System

Table 13.1 lists the identified impact chains for the impact field Buildings: heating and cooling which are triggered by temperature increases.

In order to determine the quantitative impact of changing temperature levels in climate scenarios on heating and cooling energy demand, we applied the model Invert/EE-Lab according to the work done in the ACRP project PRESENCE (Kranzl et al. 2013b). Invert/EE-Lab is a dynamic bottom-up simulation tool used

Table 13.1 Impact chains

Climate change parameter
Increase in temperature in winter ^a
Increase in temperature in summer

^aAccording to Petoukhov et al. (2008) temperature in winter. However, research

to develop scenarios for building behaviours, climate trends of renewable energy at regional level. The water systems at a needs and energy supply building components agents (i.e. owner/tenant segment. Rebound effect effective indoor temperature e.g. in Müller et al. (2013a).

The building stock demand was calculated based on COIN climate a reference scenario to estimate the uptake

13.3.3 Economic

For the evaluation of the heating and cooling expenses under climate change purpose we consider the stock of heating

Table 13.1 Impact chains “buildings: heating and cooling”

Climate change parameter	Impact chain	Quantified in the model
Increase in temperature in winter ^a	→ Reduced heating energy demand → [change in final demand for energy]	Yes
Increase in temperature in summer	→ Higher cooling energy demand and stronger growth of air conditioning in buildings → [change in final demand for energy and for AC units] → Higher temperature levels in buildings (in case that there is no air conditioning and no passive adaptation measures at the building level) → lower comfort of occupants	Yes No

^aAccording to Petoukhov and Semenov (2010) climate change could also lead to lower temperature in winter. However, this is not the case in the climate scenario taken into account in our research

to develop scenarios (price scenarios, insulation scenarios, different consumer behaviours, climate change impact, etc.) and their respective impact on future trends of renewable as well as conventional energy sources at a national and regional level. The basic idea is to model building stock, heating, cooling and hot water systems at a highly disaggregated level in order to calculate related energy needs and energy supplies, to determine reinvestment cycles and new investment in building components and technologies, and to simulate the decisions of various agents (i.e. owner types) with respect to investment decisions in a specific building segment. Rebound effects of renovation activities are covered in terms of higher effective indoor temperature after building renovation. More details are available e.g. in Müller et al. (2010), Kranzl et al. (2010), Müller (2012), Kranzl et al. (2013a).

The building stock has been subdivided according to climatic regions. Energy demand was calculated on a static, monthly basis to derive hourly load profiles based on COIN climate scenarios (Kranzl et al. 2013b). Based on the Chap. 6 (SSP), a reference scenario has been developed and applied in the model Invert/EE-Lab to estimate the uptake of renovation measures and investments on an annual basis.

13.3.3 Economic Impacts Up to Now

For the evaluation of economic impacts of climate change up to now, we compared the heating and cooling expenses in a climate base period (1980–2010) with the expenses under current climate (HDD bias corrected value of 2010). For this purpose we considered the building stock in the structure of the year 2010 including the stock of heating systems of this year.

In 2010, the energy consumption for space heating and hot water in Austria was 380 PJ, adjusted to mean climate³ (Müller and Kranzl 2013; Statistik Austria 2011). The corresponding expenses for heating energy amounted to about 7.2 billion Euros (retail prices including taxes). Cooling energy demand is estimated to be around 400 GWh_{el} (Müller and Kranzl 2013) with related corresponding energy expenses of 70 million euros. Assuming a constant climate for the reference period 1980–2010 and with energy prices according to the assumptions in this study (Chap. 6—SSP), heating energy expenses would have been about 11 million euros higher and cooling energy expenses 5 million euros lower. These data relate to an overall GDP of about 300 billion Euros in the year 2011. In the past few years, the market penetration of cooling devices has risen strongly. However, it remains unclear to what extent this is due to climate change and to what extent it is due to a general trend towards higher levels of comfort.

13.4 Future Exposure to and Impacts of Climate Change

13.4.1 Mid-Range Climatic Scenario for Heating and Cooling

In order to consider regional differences in climate and climate change, a set of different climatic regions was defined, based on Schicker and Formayer (2012). Semi-synthetic climate data (SSCD) sets based on observations and regional climate model (RCM) simulations of the A1B scenario were created. For the analyses in this chapter, MPI-REMO A1B climate data were used as proxy for the COIN A1B data in order to allow the use of substantial previous modelling results (Kranzl et al. 2014).⁴ Compared to other RCM projections (RCM-ALADIN driven by the ARPEGE GCM), these results show a rather large increase in winter temperatures and small increase in summer temperatures. These data serve as input for a building energy model. Due to topography and other differences in climatic conditions in Austria it was decided that a set of various climatic clusters needed to be defined. On the one hand, these clusters are based on the INCA climatology (Haiden et al. 2011) of temperature and radiation conditions in January and July. On the other hand, a more robust clustering was applied using a 30 year data set (1971–2000) from the Austrian Central Institute for Meteorology and Geodynamics (ZAMG).

For the two months January and June, temperature and radiation classes were defined:

³ Climate adjustment has been carried out for the year 2010 according to the mid-range climate scenario of Chap. 5 (Climate).

⁴ We are aware that the RCP scenarios derived for the IPCC AR5 would be more up-to date. However, at the time when the analyses in this chapter started, these results were not yet available.

- June: temperature < 10°C and radiation < 230 W/m²
- January: temperature > 0°C and radiation > 50 W/m²

Not all possible clusters are available.⁵ The SSCD program (Heindl et al. 2012) provides conditions for a reproduction of diffuse radiation input. Additionally, monthly mean values for a SSCD year.

For future climatic conditions, RCM simulations and observations of present and near future conditions for 19 climatic clusters were used. The mean monthly values were added to the observed values for the future SSCD.

We used hourly data for heating and cooling demand calculated by a static monthly model as described in Bednar et al. (2012).

13.4.2 High and Low Temperature and Cooling

According to the specific scenarios were taken into account for heating and cooling. Table 13.1 shows the indicators. The values for the decrease of heating demand for the climate scenario is not a quantitative assessment for the mid-range scenario. The development for the different scenarios is shown in Fig. 13.1.

Besides these effects, the increase in extreme periods can lead to a significant increase in heating demand beyond the pure cooling demand.

⁵ A map of these clusters is shown in Fig. 13.1).

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were not yet available.

- June: temperature $< 18^{\circ}\text{C}$, $18^{\circ}\text{C} < \text{temperature} < 22^{\circ}\text{C}$, and temperature $> 22^{\circ}\text{C}$, and radiation $< 230 \text{ W/m}^2$ and radiation $> 230 \text{ W/m}^2$.
- January: temperature $< 15^{\circ}\text{C}$ and temperature $> 15^{\circ}\text{C}$, radiation $< 50 \text{ W/m}^2$ and radiation $> 50 \text{ W/m}^2$.

Not all possible cluster combinations are present in Austria. In total, 19 climatic clusters are available.⁵ These were taken into account for the further analysis. The SSCD program (Heindl et al. 1990) was used to calculate the semi-synthetic hourly conditions for a representative year. It requires data on temperature, global radiation, diffuse radiation, wind speed, and relative humidity on an hourly basis as input. Additionally, mean monthly values of each parameter are needed to generate a SSCD year.

For future climatic conditions based on the three bias-corrected and localised RCM simulations and on three time slices (1981–2010 E-OBS/past, 2011–2040 present and near future, 2036–2065 future), grid cells corresponding to each of the 19 climatic cluster were used. Differences between the simulated and observed mean monthly values of the parameters were calculated for every time slice and added to the observed monthly values which could then be used as data in the future SSCD.

We used hourly data for temperature and solar radiation in order to determine heating and cooling demand load profile. The annual energy demand was calculated by a static monthly approach implemented in the model Invert/EE-Lab, as described in Bednar et al. (2013), Müller et al. (2010) and Kranzl et al. (2013b).

13.4.2 High and Low Range Climatic scenarios for Heating and Cooling

According to the specification in Chap. 5 (Climate), high- and low-range climatic scenarios were taken into account to assess the cost range of inaction for heating and cooling. Table 13.2 shows the heating and cooling degree days as exemplary indicators. The values indicate a substantial increase of cooling degree days and decrease of heating degree days in the hottest climate scenario, whereas the coldest climate scenario is relatively near to the mid-range climate scenario. For the quantitative assessment of the range of cost of inaction, the data described above for the mid-range scenario were up- and downscaled with HDD and CDD development for the different climate regions described above.

Besides these effects of increasing CDD, heat waves and extreme heat periods could also lead to a substantial increase in air conditioning unit sales. Thus, such extreme periods can have an impact on the buildings' energy demand which goes beyond the pure cooling energy need during this period.

⁵ A map of these clusters is presented in the supplementary materials (Supplementary Material Fig. 13.1).

Table 13.2 High- and low-range climate scenarios for the example of cooling degree days (CDD) and heating degree days (HDD), Chap. 5 (Climate)

		CDD		HDD	
		Absolute increase (Kd)	Relative increase (%)	Absolute increase (Kd)	Relative increase (%)
	Ø 1981–2010	89	0	4,338	0
Hottest	2030	233	262	–1,235	–28
	2050	583	655	–1,879	–43
Coldest	2030	38	43	–391	–9
	2050	89	100	–554	–13

13.4.3 Specific Method(s) of Valuation and Their Implementation

The following steps were carried out to assess the costs of the two impact chains space heating and space cooling:

- Development of a reference scenario as well as scenarios with diminishing and enhancing heating and cooling energy demand. First, these scenarios are calculated ignoring the impact of climate change, and then taking climate change into account. This includes the uptake of renovation measures and changes in the mix of heating and cooling technologies. This step was carried out using the model Invert/EE-Lab (see above). Input data regarding energy prices,⁶ growth and the regional distribution of population and building stock was based on Chap. 6 (SSP). Factors such as building codes and support instruments were determined according to the reference scenario assumptions, i.e. slow progress in building codes etc. was assumed, reflecting the requirements of the European Energy Performance of Buildings Directive (recast) but not beyond. The scenarios are based on Kranzl et al. (2013b).
- For the cost evaluation, the costing method “change in final demand” was selected (Chap. 7—Economic Framework). This method is primarily based on private, residential buildings. For private, non-residential buildings the change of heating and cooling systems and related energy demand may be understood as a change in the system of production. In the case of public buildings, the change in heating and cooling systems and related energy demand would reflect a change in public final demand. Due to constraints in data availability and uncertainty, we decided to use the costing method “change in final demand” for all building types. A change in costs occurs for heating and cooling energy demand as well as for investment in heating and cooling systems. However, we decided not to take into account the change in the investment in heating systems,

⁶ In fact, energy prices may also be affected by climate change. This is discussed in Chap. 14 (Electricity).

assuming that indoor design outdoor temperature in a warmer climate the scenarios were evaluated cooling (C_{en}), calculated (Q_{en}) for all energy for cooling and cooling systems categories (bca)

- The costs of inaction the climate change (change).
- To gain input for effects have been macro-economic
 - Costs for biomass
 - Costs for heat
 - Costs for natural
 - Costs for air c

13.4.4 Range of Parameters

The possible pathways exposure and sensitivity linked to the growth regions with different thermal quality of buildings and their energy change behaviour, technology

In the cost assessment described above we ranges are documented. Some of these factors quantitative assessment

cooling degree days (CDD)

(Kd)	Relative increase (%)
	0
	-28
	-43
	-9
	-13

two impact chains

with diminishing and scenarios are calculated climate change into changes in the mix out using the model es, ⁶ growth and the s based on Chap. 6 ts were determined progress in building e European Energy l. The scenarios are

final demand" was primarily based on buildings the change ay be understood as buildings, the change and would reflect a ta availability and e in final demand" and cooling energy tems. However, we in heating systems,

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assuming that installers would continue to design heating systems for the same design outdoor temperature, although this temperature occurs less often in a warmer climate than in a climate where no climate change occurs. Thus, the scenarios were evaluated in terms of costs of energy carriers for heating and cooling (C_{en}), calculated on the basis of energy prices (p_{en}) and energy demand (Q_{en}) for all energy carriers (en) as well as regarding required investment costs for cooling and ventilation units ($C_{inv,ac}$), derived from the specific costs of cooling systems (c_{ac}) and the installed capacity (P_{ac}) in the different building categories (bca).

$$C_{en} = \sum_{en} p_{en} \cdot Q_{en}$$

$$C_{inv,ac} = \sum_{bca} c_{ac, bca} \cdot P_{ac, bca}$$

- The costs of inaction are calculated by taking the difference between the costs in the climate change scenario and those in the baseline scenario (i.e. no climate change).
- To gain input for the macro-model and to assess feedback from other sectors the effects have been divided into the following sectors, corresponding to the related macro-economic sectors:
 - Costs for biomass fuels
 - Costs for heating oil and coal
 - Costs for natural gas, electricity and district heating
 - Costs for air conditioning and ventilation devices

13.4.4 Range of Sectoral Socio-Economic Pathway Parameters Co-Determining Climate Impact

The possible pathways involved have an impact on the building sector's future exposure and sensitivity with respect to climate change. Sectoral exposure is mainly linked to the growth of the building stock and the location of buildings in various regions with different climate change signals. Sensitivity is mainly a function of the thermal quality of buildings, the energy efficiency of heating and cooling systems and their energy characteristics in summer, and also of required comfort levels and behaviour, technology, energy carrier mix, and energy price levels.

In the cost assessment, some—but not all—of the socio-economic factors described above were taken into account. Relevant factors for these socio-economic ranges are documented in more detail in the supplementary material to this chapter. Some of these factors, which are listed there were taken into account in the quantitative assessment, like summer indoor temperature, improving thermal

quality by building renovation or energy carrier mix for heating. Other factors, like growth and regional distribution of building stock, development of electric appliances and related internal loads, number of buildings with AC and on-site PV were not considered in the assessment of cost ranges in socio-economic scenarios.

The methodological approach used in considering the various scenarios is documented in the description of the monetary evaluation.

13.4.5 Monetary Evaluation of Impacts

13.4.5.1 Direct Sector Impacts (Costs and Benefits) in the Absence of Feedback Effects from Other Sectors

The baseline development of energy demand for space heating and hot water preparation (reference scenario) results in a decline by about 40 % till the 2050s. The reduction in practice will of course depend on how strictly policies are applied. For example, there is considerable room for leeway with respect to the thermal insulation of buildings. In general, this scenario seems roughly in line with the renewable energy targets for 2020 described in the European renewable energy directive. Some doubt remains since the national renewable energy action plans (BMWFJ 2010) do not distinguish between space heating and process heat. The same holds for the climate mitigation and energy efficiency targets (Table 13.3).

This is related to energy expenses for biomass in the range of about 0.6 billion Euros, for coal and oil of 2 billion Euros and for natural gas, electricity and district heating of about 3.7 billion Euros in the base year and 2050, respectively.

The climate change signal reduces the final energy demand for space heating by about 5.8 TWh/yr in 2050. In order to calculate the economic benefits of this reduction in energy demand two steps were carried out: first the energy demand reduction was derived by energy carrier, and second, for each energy carrier the prices prevailing in 2050 (based on reference SSP assumptions) were applied.

Table 13.3 Baseline scenario final energy demand by energy carrier for space heating and hot water preparation (reference scenario with constant climate, GWh)

GWh	2010	2020	2030	2040	2050
Coal	930	391	78	75	136
Oil	22,121	16,256	8,218	3,726	2,351
Natural gas	27,869	26,921	24,008	20,060	16,922
District heating	17,417	19,233	20,909	20,315	18,608
Electricity	8,118	5,603	3,852	3,512	3,382
Biomass	19,479	20,890	21,346	20,678	20,004
Ambient Energy	1,313	2,493	3,819	5,003	5,714
Solar thermal Energy	1,276	2,080	3,486	4,499	5,182

Without any discounting, the total cost of the energy demand reduction is about 25 million euros/year in the 2050s.

Comparing baseline and reference scenarios, the energy demand for space heating and hot water preparation of 470 GWh/yr in 2010 is reduced to 136 GWh/yr in 2050 (into account retail prices for energy carriers and costs of inaction). The total cost of the energy demand reduction in the field relates to the energy demand reduction. The approach here was to assume the absence of feedback effects and the more realistic scenario and certain regions (Müller et al. 2014).

While the low and mid-range scenarios show a significant increase of the energy demand reduction and costs in terms of energy demand reduction and effort requirements, the high scenario, the consistent economic development, is not taken into account in this analysis and account in this analysis and 13.2; Tables 13.1 and 13.2; Tables 13.1 and 13.2.

13.4.5.2 Macroeconomic Impacts

Concerning heating and hot water preparation, the energy demand reduction (intermediate demand) is shown in Sect. 13.3.2 for a reference scenario. Material Table 13.3 shows the macroeconomic impacts of the energy demand reduction representative for the period 2036–2065) and the energy demand reduction scenarios relative to the reference period (2030 and 2050).

⁷The full list of socio-economic impacts is given in Material Tables 13.1 and 13.2.

⁸The "rebound effect" is the effect of the rebound-effect are calculated after building renovation.

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75	136
726	2,351
060	16,922
315	18,608
512	3,382
678	20,004
003	5,714
499	5,182

Without any discounting of the costs of inaction, this results in about 383 million euros/year in the 2050s.

Comparing baseline (no climate change) and mid-range climate change final energy demand for space cooling reveals an additional electricity demand for cooling of 470 GWh_{el}/yr, and additional 120 million euros/year in 2050 (taking into account retail electricity prices from above and assuming no discounting of costs of inaction). Moreover, additional investments in air conditioning of about 25 million euros/year are also expected in 2050. One of the key uncertainties in this field relates to the market penetration of air conditioning in the building stock. Our approach here was to link the penetration of air conditioning to indoor temperature assuming the absence of an active cooling system: the higher the indoor temperature and the more frequent high temperature levels occur in certain building types and certain regions, the more likely becomes the installation of an active AC system (Müller et al. 2014).

While the low-range climate scenario does not deviate strongly from the mid-range scenarios, it becomes clear that the high-range scenario leads to a strong increase of the effects—both benefits in terms of reduced heating energy demand and costs in terms of increased cooling energy demand. A few aspects of diminishing and enhancing effects of socio-economic development (summer comfort requirements, energy efficiency measures)⁷ were also taken into account. For cooling, the consideration of high-range climate scenarios and enhancing socio-economic development leads to more than doubling of costs. However, it should be taken into account that there are still a lot of factors which have not been taken into account in this analysis (see discussion of uncertainties in Sect. 13.4.7; Figs. 13.1 and 13.2; Tables 13.4 and 13.5).

13.4.5.2 Macroeconomic Effects

Concerning heating and cooling those impact chains which are triggering changes of energy demand⁸ of private households, the government as well as industry (intermediate demand) are implemented in the macroeconomic model (see Sect. 13.3.2 for a detailed description of the impact chains and Supplementary Material Table 13.4 for a summary of how the effects are implemented into the macroeconomic model). All macroeconomic effects are calculated for 2030 (representative for the period 2016–2045) and for 2050 (representative for the period 2036–2065) and effects are expressed for the climate change impact (CC mid-range) scenarios relative to the baseline without climate change in the same respective period (2030 and 2050).

⁷ The full list of socio-economic factors is shown in the supplementary materials (Supplementary Material Tables 13.1 and 13.2.)

⁸ The “rebound effect” is neglected in the macroeconomic assessment. Some aspects of the rebound-effect are covered implicitly in Invert/EE-Lab (increased effective indoor temperature after building renovation).

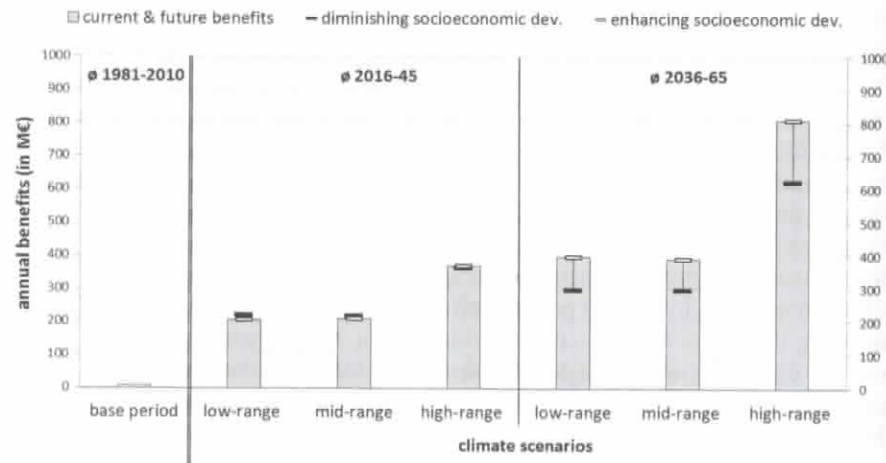


Fig. 13.1 Average annual economic impacts for heating energy in climate change and socio-economic scenarios

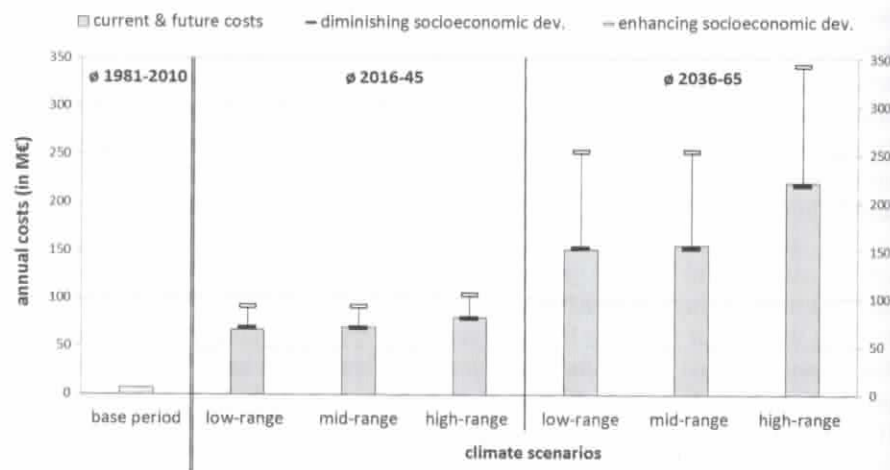


Fig. 13.2 Average annual economic impacts for cooling in climate change and socio-economic scenarios

When combining heating and cooling effects which are triggered by climate change, the absolute reduction in heating is stronger than the increase for cooling (measured in expenditures). Hence, expenditures for energy (i.e. demand) is lower in the climate change scenario compared to the baseline. Table 13.6 gives an overview of selected winners and losers after implementation of the quantified impact chains regarding final and intermediate demand changes. All numbers show absolute changes between the climate change and the baseline scenario, given in million euros. The sectoral effect on gross output value is decomposed into two

Table 13.4 Average a

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Table 13.5 Average a

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(M€ p.a.)

Ø 2016–2045

Ø 2036–2065

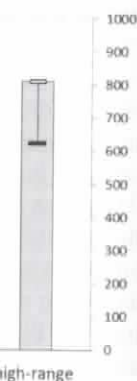
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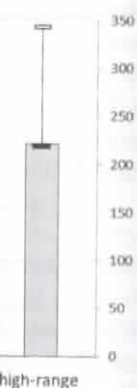
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Table 13.4 Average annual economic impacts for heating in Austria

Projected future benefits (M€ p.a.)			Climate change		
			Low-range	Mid-range	High-range
Ø 2016–2045	Socioeconomic development	Diminishing	217	216	360
		Reference	205	208	368
Ø 2036–2065		Diminishing	293	294	619
		Reference	395	390	809

Table 13.5 Average annual economic impacts for cooling in Austria

Projected future costs (M€ p.a.)			Climate change		
			Low-range	Mid-range	High-range
Ø 2016–2045	Socioeconomic development	Diminishing	69	69	79
		Reference	67	70	80
		Enhancing	92	92	104
Ø 2036–2065		Diminishing	153	153	218
		Reference	152	156	222
		Enhancing	253	253	343

additive components, namely intermediate demand and value added (equivalently value added is obtained by subtracting all intermediate inputs from gross output value). The change of value added is giving information on how much the sectoral contribution to GDP is changing.

Starting with the sectoral losers (in terms of value added), we see that those sectors which are supplying energy carriers⁹ have a lower value added in the climate change scenario, as demand is lower. The Energy sector is hit hardest (−39 million euros on average per year in 2030 and −79 million euros in 2050), followed by Forestry (−14 million euros and −33 million euros) and Coke and Petroleum products (−1 million euros and −1 million euros, respectively). As demand is lower, less output is necessary and therefore also intermediate demand as well as output value is lower in the climate change scenario for those sectors.

Regarding sectoral winners (in terms of value added), we see that the Trade sector is on top, as there more demand for air conditioners is leading to higher output (as well as price). Next to that, there are also positive effects on other sectors, as private households can expand their consumption for other goods and services than heating and cooling. Therefore consumption for Real Estate, Accommodation (including a part of tourism) as well as Rest of Services is higher in the climate

⁹ Sector "Energy" is providing electricity, gas and district heat; sector "Coke and Petroleum Products" is providing coke and fuel oil; sectors "Forestry" and "Trade" are providing biomass; sector "Trade" is providing air conditioners.

Table 13.6 Sectoral and total effects of quantified climate change impacts for heating and cooling, average annual effects relative to baseline (for periods 2016–2045 and 2036–2065)

Changes in M€ p.a. relative to baseline	Ø 2016–2045			Ø 2036–2065		
	Gross output value	Inter- mediate demand	Gross value added	Gross output value	Inter- mediate	Gross value added
Gaining sectors	+139	+57	+81	+285	+119	+166
Trade	+33	+13	+20	+55	+22	+33
Real estate	+26	+8	+18	+55	+17	+38
Accommodation	+14	+5	+9	+30	+11	+19
Rest of services	+10	+2	+8	+21	+5	+16
All other gaining sectors	+56	+29	+27	+123	+64	+59
Losing sectors	−260	−203	−58	−532	−414	−118
Energy	−209	−170	−39	−435	−356	−79
Forestry	−30	−16	−14	−71	−38	−33
Coke and petro- leum products	−7	−7	−1	−9	−9	−1
All other losing sectors	−14	−9	−4	−16	−11	−5
Total effect (all sectors)	−122	−146	+24	−246	−295	+48
GDP at producer price			+0.01 %			+0.01 %

Note: Baseline scenario = reference socioeconomic development without climate change; climate change scenario = reference socioeconomic development and mid-range climate change; quantified climate impact chain: final and intermediate demand changes

change scenario, leading to more value added in those sectors. Compared to the baseline scenario, the overall effect concerning sectoral winners is a higher value added in the amount of +81 million euros in 2030 and of +166 million euros in 2050 (on average per year). Note that the positive effects are accompanied by higher prices, which amplifies the demand driven quantity effect.

Summing up across all sectors, value added in 2030 is by 24 million euros higher in the climate change scenario due to the implemented climate impact chains regarding heating and cooling effects. The effect is stronger in 2050, where gross value added is higher by 48 million euros (compared to the baseline scenario in 2030 and 2050 respectively).

By summing up sectoral effects on value added and correcting for indirect taxes minus subsidies, we obtain the effect on GDP. The impact chains regarding final and intermediate demand changes lead to effects on GDP of +27 million euros (+0.01 %) on average per year in 2030 and of +54 million euros in 2050 (+0.01 %)

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13.4.7 Sector

The estimations uncertainties:

Impacts for heating and
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- Poor data availability regarding the current diffusion of AC. In addition, the development trends concerning the diffusion of air conditioning units in residential and non-residential buildings are far from clear. Factors such as comfort requirements, economic development, length, frequency and severity of heat waves are all subject to considerable uncertainty. The approach taken here links indoor temperature levels in buildings directly to the diffusion of air conditioning. However, the empirical evidence for this link remains rather poor.
- Autonomous adaptation in the form of shading devices and reduction of cooling loads. We assumed that autonomous adaptation mainly refers to maladaptation in the form of a higher share and operation of air conditioning. However, the uptake of shading devices and other efficiency measures for reducing cooling loads is also a possible form of an autonomous, uncoordinated adaptation response.
- The heat island effect was not quantified in our study. This indicates that we are probably underestimating the future cooling energy demand and load. Further related aspects are investigated in Chap. 17 (Cities).
- The overall net monetary result is strongly influenced by the level of energy prices. Since the reduced costs for heating energy demand (which is mainly non-electrical energy) are offset to some extent by the increased costs for cooling energy demand, the ratio of electricity price to fuel prices has a significant impact on magnitudes when assessing the net effect.
- When interpreting the results we should be aware that the COIN mid-range climate scenario is among those scenarios in the A1B family with relatively low summer temperature levels. So, the results of the mid-range climate scenario are probably underestimating the effects of cooling energy need, related costs and comfort losses.

13.4.8 Relevance for Other Sectors

Energy demand for cooling is mainly covered by electricity. The results in Chap. 14 (Electricity) indicate that the impact on peak electricity loads in summer could become highly significant. The feedback loop from potential higher electricity peak prices in summer on costs for cooling energy demand was not considered since real time pricing is not very common up to now.

As far as cooling energy demand is not covered by passive or active technologies, higher indoor temperature results and may impact human health. This is covered in Chap. 11 (Human Health) of this book.

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13.5 Summary and Conclusions Regarding Climate Costs for Heating and Cooling

Based on the analyses performed for this study we conclude that the change in heating energy demand and cooling energy demand, together with the additional investments required in cooling devices, represent the main areas through which the impact of climate change on the investigated sector will be felt. We quantified these effects in our analysis. The overall final energy demand for space cooling in Austria in 2008 was only about 0.4–0.5 % of the energy demand for space heating. Thus, the climate-induced decrease in energy demand for heating strongly outweighs the increase in energy demand for cooling and related investment requirements. This is true even though the price of electricity is much more significant in the cooling sector than in the fuel mix applied in the heating sector. There is thus a climate-induced net benefit (i.e. lower net costs for heating and cooling) of about 120 million euros/year in 2030, and of 226 million euros/year in 2050. This does not take into account the additional costs which may result from the need to increase plant capacity to meet higher peak electricity demand for cooling in summer. This is further investigated in Chap. 14 (Electricity). Regarding the macroeconomic consequences of climate change concerning heating and cooling positive effects on welfare are emerging as the same level of utility can be achieved with less expenditures. The effects on GDP are also slightly positive and unemployment is marginally lower.

The analysis of climate and socio-economic ranges indicate that both effects (reduced heating energy expenses and increased cooling energy expenses) could strongly increase in hotter climate scenarios.

Several impacts could not be quantified in the present study. This includes for example changes in comfort levels.

High efforts in energy efficiency improvement in the building sector are one of the key prerequisites for ambitious climate mitigation targets. Due to the very long lead times in the building sector, there is an urgent need to adopt effective policies creating the regulatory and economic framework for a low-carbon building stock in 2050. This has to be accompanied by adaptation measures in order to reduce not only heating energy demand but also address cooling energy demand. In particular, considering passive measures to reduce cooling energy demand (e.g. shading, night cooling) in building codes is of high relevance.

The results in this book are derived for the case of Austria. To which extent the results can be transferred to other regions, mainly depends on the following conditions: (1) The relation and absolute level of heating and cooling energy demand should be comparable. At least, this is the case in Western and central EU countries. (2) The results are strongly driven by the energy price level. Thus, in regions with strongly different energy prices and in particular with different relation of fuel and electricity prices, the results would deviate correspondingly. (3) The results depend also on the energy policy targets and framework which can be assumed for the development in the next decades. Thus, these conditions should

be considered as comparable. Last but not least, in countries with a significantly higher current share of air conditioning devices in the building stock, the uncertainty regarding the future market penetration of these units would be much lower. Thus, the corresponding methodological approach could and should be adapted.

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