Climate change impacts on energy systems in Austria and the Czech Republic

This paper will deal with supply and demand effects caused by climate change. The main focus will be on effects of rising temperatures on the demand for energy.

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Content

1 Executive Summary

This paper deals with the impacts of climate change on the energy sector. Global warming represents a challenge for the global civilization, as the speed of the change could be a threat for nature and for the human kind as well. On the one hand the energy sector is one of the main emitters of CO_2 emissions which cause the greenhouse effect. On the other hand climate change will have multiple consequences on the energy demand and supply.

In this paper we put focus on two main impacts of global warming on the energy sector. Firstly we considered direct and indirect effects on the supply structure of electrical energy. We believe that the fundamental impact will be pressure to move away from generating energy from carbon intensive fossil fuels towards low carbon technologies, like renewable and possibly nuclear sources. These changes take place quite slowly, so we also try to examine possible direct impacts of global warming on existing power plants and the distribution structure.

Secondly we concentrated on climate impacts on the demand side, where climate change is said to significantly change the heating and cooling energy demand. We examined the changes in heating and cooling degree days due to global climate change for cities in Austria and the Czech Republic. Our results show that the number of heating degree days decreased slightly during the 20^{th} century for Graz and Seckau, while the number of days above 30 degrees Celsius, which were used as an indicator for cooling energy demand, increased significantly in the last 15 years for Graz.

According to our calculations, which based on the output of the regional climate model (REMO) of the Max-Planck-Institute for meteorology and IPCC scenario A1B, the heating energy demand will decrease significantly in the 21^{st} century. The relative decline in annual heating degree days will be between 8,8 and 15 percent for the period 2041-2050 compared with the reference period 1961-1990, and respectively between 20 and 38,3 percent for the period 2091-2100. Much of the differences between the chosen stations can be explained by the chosen methodology.

The future cooling energy demand depends highly on the location. We showed that for the period 2041-2050 the temperature in Vysočina will be as high as it was in Prague in the reference period 1961-1990 and in Seckau it will be even lower than it was in Graz. Therefore cooling will not be needed urgently for these mountain regions. On the other hand the number of days above 30 degrees will increase remarkably for Graz. While the average number of these so called ‘tropical days’ was only three days for the reference period, it is expected to increase between 7 and 10 days for the period 2041-2050 and respectively 30 and 50 days for the period 2091-2100. These predictions can be considered to be quite low, if compared with past experiences. The former equals the average value of the 1990s, while the latter is equal to the record summer in 2003 (41 ‘tropical days’).

2 Introduction and General information

Human activity has influenced the environment for ages, but it is difficult to value if this is positive or negative. During last two centuries the character of this impact has changed – it have became more intensive because of industrial and technological development. One of the effects of industrialized civilization is also a higher amount of emissions (carbon dioxide, methane, NO_x etc.) in the atmosphere. Scientists suppose that concentration of these gases causes climate warming which affect weather and biosphere on the Earth. Human level of knowledge does not allow recognizing all consequences of this process.

The weather is defined as an instant state of atmosphere at a given place. It could change every hour or even more often. During longer periods (usually several decades) it creates specific regimes – climate which is specific for a region. It is defined by the Czech hydrometeorological Institute as "long-term characteristic weather regime conditioned by energy balance, by atmospheric and ocean circulation, by features of earth's surface and human activity. Not only the atmosphere, but also processes in oceans, on continents, in icebergs and biosphere contribute to climate creation. To describe it we use parameters as average air temperature, average rainfalls, duration and intensity of sunshine, speed of wind, humidity of the air and other climate quantities for periods of at least thirty years (nowadays the most common used reference period is 1961 – 1990). The fluctuation of some variables is also an important element for descriptions of the climate (besides average values)."1

According to Czech climatologist Vaclav Cilek, the climate is only the "long-term statistical average of relatively homogenous periods lasting usually only several decades" though its relative stability.2 Thus we could define global climate on the base of analysis of long-term time series of recorded temperatures and precipitation values and on the base of model extrapolation of observed trends for the future.

Several spontaneous climate ups and downs happened during known and documented history. The climate was warmer from the thirteenth to the sixteenth century; while the period from the seventeenth to the nineteenth century is called "the little Ice Age" because of the global climate cooling. These changes were caused by non-anthropogenic factors. A further warming was observed in the years 1915 – 1940, while the following period was relatively cooler and from the seventies the global average temperature has continuously grown. The global temperature is estimated to have increased from the nineteenth century for 0.6°Celsius on average. In consequence the sea level is constantly higher for 10 – 25 centimeters than it used to be before one hundred years.3 This warming is supposed to be an effect of human activity (emissions of so called green house gases – especially CO2 and methane).

The most alarming fact for scientists is the speed of climate change observed in last thirty years. Jeremy Legget states: "Our present environment and biological species existing in nature are result of evolution process which includes reaction on climate changes. The fundamental problem is not the change, but the speed of it. (…) It is possible that we will experience in several decades the same temperature changes which lasted before thousands of years."4

[1] See www.chmi.cz/cc/inf/index.html (20.9.2005)
[2] See Cílek 2003.
[3] See Moldán, Bedřich a Sobíšek, Bořivoj 1996, p.6
[4] See Leggett 1992, p. 141 -142

Swedish chemist Svante Arrhenius was the first who expressed a hypothesis about climate warming effect of increased CO_2 emissions to the atmosphere.5 From that time (the end of the nineteenth century) scientists observed the amount of CO_2 in the atmosphere and they state that its concentration rises. Long-term temperature series also points out the climate warming during last one hundred years.

Although there is no disagreement among climatologists about the climate warming, the causes of this phenomenon are not explained enough. The question is if it is one of the spontaneous ups and downs of our planet or if we could speak about anthropogenic impacts. The evidences for acknowledgment of hypothesis about causality between increasing CO_2 emissions in atmosphere and rising of global temperatures are not convincing, although the correlation of the data is apparent on the first sight.

The climatologists use for predictions of future climate changes computer atmosphere models, which are limited. The atmosphere is a very complicated system composed and influenced by many elements; therefore even the best computers are not able to simulate it exactly. (Not speaking about imperfect knowledge of some elements in atmosphere and its activity). We can state that all the models are simplified and dependent on the inserted data.

There are several scenarios of future development of climate change: they suppose an increase of the global average temperature between 1.5 and 4.5 degree Celsius.6 What are the consequences of this warming? The general answer does not exist, because the climate is not the same on the whole Earth (it depends on zone location, altitude etc.). The below mentioned examples are not a complete list, but all of them could have relation to energy sector.

1, agriculture sector: it is supposed that because of global warming there will besides the warmer weather more precipitation in some areas. Others could be threatening by draught. The CO_2 has a fertile effect; therefore many plants would grow faster which would be important fact for biomass cultivation.

2, extreme weather: the only obvious trend during last ten years is increased frequency of rainfalls and more frequent occurrence of extreme rains (it represents risk of floods, but also more water for hydro power plants). Concerning to hurricanes the observations does not provide clear result if the trend of their appearance is growing or declining, but their intensity is probably increasing.

3, future weather: the global climate change affects mainly lower temperatures periods and day parts. It means that night and winter temperatures have became and will become higher. This fact could have also positive impact on agriculture.7

The international organization started to discuss about this problem in the end of the eighties. The result of all activities on this field is the Kyoto protocol signed in 1997, which came into force in 2004. It obliges participating countries to reduce CO_2 emissions in order to slow down warming of the atmosphere.

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[5] See Shaw & Stroup 1990, p. 162
[6] See IPCC 2001, p. 323
[7] See Lomborg 2006, p. 327 - 341

3 Description of the main research question

a) Supply side

The most important expected change in long term horizon is the restructuring of the whole energy sector, which mean a breakthrough from fossil fuels to other, “cleaner” sources of energy. This fundamental change might happen in the next several decades and it is highly dependent on many factors (scientific research, development of prices of fossil fuels on global markets, international climate policy etc.).

We will examine the energy supply structure of Austria and the Czech Republic and possible threats by global warming in the near future. It seems that most of the power stations, which are used at the moment in both countries, are highly dependent on the runoff characteristics of rivers. This is particularly true for the hydro power plants in Austria, but also for thermal and nuclear power plants in the Czech Republic, as droughts and heat waves have adverse impacts on the cooling of these power plants. The question is how the global warming will change the water regime in temperate zone and its different altitude.

The climate change will have impact on renewable sources of energy as well. As it was already mentioned, the CO_2 concentration in atmosphere could have fertile effect on biomass (but biomass is not absolutely “clean” source of energy, because during its burning the emissions of CO_2 are releasing). It is assumed that in consequence of climate change the cloudiness and duration of sunshine could change as well as velocity of the wind.

The third question of our focus is possible impact of global warming on distribution system (grids and pipelines) which might be needed to repair more frequent or modify at all. We also should not ignore the possibility of environmental contamination.

b) Demand side

Our main research question will be how the rise in temperature will affect the overall consumption of energy in Austria and the Czech Republic. There seem to be two major effects, namely a decreasing energy demand for heating in winter and a higher energy demand for cooling in summer.

The problem is that climate is not the only factor determining the future heating and cooling energy demand. There are many socio-economic and technical developments which must be considered, e.g. the size of houses, multi- vs. single family houses, building techniques etc. Therefore it is only a first step to find appropriate indexes, which show the climate change impact on heating and cooling energy demand.

Nevertheless these indexes do have a very important role, because they represent boundary conditions for building design and the energy demand in buildings depend significantly on external boundary conditions, like the temperature. Especially in Europe buildings may over time be exposed to different climates, as they are typically built for a long lifespan. Thus it is important to know the extent of climate change, as building design can help to assist adaptation to climate change[8]

In short, this paper will comprise two questions.

[8] see also Christenson et al 2006, p. 672

(1) Are their already hints that in the last few years less heating energy and more cooling energy is needed?
(2) According to climate predictions, to what extent will heating and cooling energy demand change in the 21st century?

4 Methodology

a) Supply side

On this side we use a simple qualitative description of possible future development of energy sector and climate change impacts on present producers and distributors of energy, mainly based on literature.
The fundamental sources for this part are *Energy for sustainable development*, information from IPCC web pages and European Union portals.

b) Demand side

In order to show how climate change affects the heating and cooling energy demand indicators must be defined. In general, degree-day methods are a simple, yet fairly reliable possibility to quantify the heating and cooling energy demand in buildings. While the use of heating degree days (HDD) is widespread within Europe, there is still no standard for calculating cooling degree days (CDD). Beside that, there are much more uncertainties with CDD, as solar heat gains and different natural adaptation possibilities (like opening the window) must be considered in summer. In contrast to heating, cooling is almost limited to commercial buildings in Central Europe. [9]

As it will be shown below, there are further difficulties in calculating CDD, if only monthly temperature data are available. Consequently we did not calculate cooling degree days for the chosen stations, but provided the number of days above 30 degree Celsius as a simple alternative index to give an idea how cooling energy demand could change.

Sources of data

For the calculation of heating degree days we used temperature data provided by the Czech Hydrometeorological Institute and the Startclim database, which is provided by the Austrian Central Institute for Meteorology and Geodynamics (ZAMG). For the Czech Republic we got monthly average temperature data for the period 1961-1990 (because this is the period the climate model from the Max-Planck Institute also used as reference period)[10]. For Austria we used the Startclim database, which provided monthly average temperature data for the period 1961 to 2000.[11]

We decided to take monthly average data for calculating heating degree days, as Christenson et al demonstrate that it is acceptable to take monthly average data for

[9] see Christenson et al 2006, p. 673
[10] see http://www.chmu.cz/meteo/ok/okdat510.html
[11] see ZAMG 2002

calculating heating degree days. For example, for Switzerland the average relative error is only 0,5 percent, when monthly data is used instead of more precise daily data. On the contrary, this average relative error is much bigger for cooling degree days.[12]

Consequently we considered the number of days, where the maximum temperature is higher than 30 degree Celsius, instead of average monthly data for the summer months. This data was provided by Ulrich Foelsche, climatologist at the University of Graz.[13]

To analyse the impacts of climate change on the chosen indicators, we used the outputs of the regional climate model (REMO) of the Max-Planck-Institute for meteorology, which is embedded in the global climate model ECHAM5/MPI-OM. This regional climate model has a resolution of 50 kilometres for Europe, which is much higher than the resolution of global models. Thus the results are much more detailed and include more regional conditions, like terrain and natural cover, although they are similar to the outputs of the global model.[14]

Of course there are still uncertainties with such climate models, as there are many factors which are not included, like biogeochemical cycles. Without any doubt one of the largest uncertainties though are the natural and anthropogenic emissions for the 21st century. For our purposes we used only one of many possible emission scenarios, as our aim is rather to show how energy demand for cooling and heating could change, and not to compare different scenarios.[15]

The scenario we used is called A1B. The basic assumptions for this IPCC scenario are rapid economic growth for the 21st century, the rapid introduction of new and more efficient technologies, a convergence of the worlds' regions and a balance between fossil fuels and other energy sources.[16]

The location of the meteorological stations

Four our analyses we used temperature data from four meteorological stations. Our intention was for each country to choose two stations, which contrast with each other, that means to take one station which is known for above average mean temperatures and one station with below average mean temperatures. We chose Graz (annual mean temperature 1961-1990: 9 °C) and Seckau (6,4 °C) for Austria, and Prague (8,6 °C) and Vysočina (7,1 °C) for the Czech Republic. The lower temperatures in Seckau and the region Vysočina are largely due to their higher-than-average altitude. While Graz is 353 meter above sea level, Seckau is 843 meter above sea level[17].

The concept of heating degree days

[12] see Christenson et al 2006, p. 677
[13] see Foelsche 2005, p. 31
[14] see Jacob 2006, p. 26
[15] see Jacob 2006, p. 24
[16] see http://climatechange.unep.net/jcm/doc/emit/sres.html (20.6.2006)
[17] see http://www.austrianmap.at (23.6.2006)

The heating degree days' method is based on the fact that the energy demand for heating decreases with higher temperatures, and from a certain upper threshold temperature, no heating energy is needed. Therefore for each day below a defined threshold (e.g. 12 °C) the difference between the internal temperature of a building (e.g. 20 °C) and the external temperature is calculated and added up for a certain period.[18]

In order to transform monthly average mean temperatures into heating degree days an index for the number of days m_k in each month must be added to the calculation method on a daily basis:

$$\mathrm{HDD}_{\mathrm{m0}}(\theta_{\mathrm{i}}, \theta_{\mathrm{th}}) = m_k \sum_{k=1}^{n} (\theta_{\mathrm{i}} - \theta_{\mathrm{e},k})$$

$$m_k = \text{days in month}, \quad m_k \in \{28, \ldots, 31\} \text{ if } \theta_{\mathrm{e},k} \leqslant \theta_{\mathrm{th}}$$
$$m_k = 0 \text{ days} \quad \text{if } \theta_{\mathrm{e},k} > \theta_{\mathrm{th}}$$

In this equation θi denotes the base or internal temperature of a building, $\theta e,k$ the monthly external temperature and θth the threshold temperature for heating.[19]

At the moment there is a lack of a single standard for calculating heating degree days. While in the weather business no differentiation is done between the threshold temperature and the base temperature, most European weather agencies use threshold temperature. Beside that there is no common standard for these temperature levels. That means that the results are influenced very much by the definition of these levels, especially at the beginning and at the end of the heating period. For example, if the actual temperature is 13 °C, 7 HDDs are generated by using method 20/15 (internal temperature 20°C, threshold temperature 15°C), 0 HDDs by using method 20/12 and 5 HDDs by using method 18/18.

Of course, which of these methods are accurate indicators for the heating energy demand largely depends on the actual room temperature, which should equal the internal temperature, and on the quality of the insulation, which determines the threshold temperature. We decided to use method 20/12, as this method seems to be used for most of the calculations in Austria.[20]

Indicators for cooling energy demand

For the reasons already mentioned before, rather than calculating cooling degree days, we show the changes in the number of days, where the maximum temperature exceeds 30 degree Celsius, as in Central Europe these so called 'tropical days' are a good indicator for extremely high temperatures.[21]

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[18] see Chevalier 2003, p. 4
[19] see Christenson et al 2006, p. 677
[20] see http://www.energyagency.at/(de)/enz/res-dat.htm
[21] see Foelsche 2005, p. 30

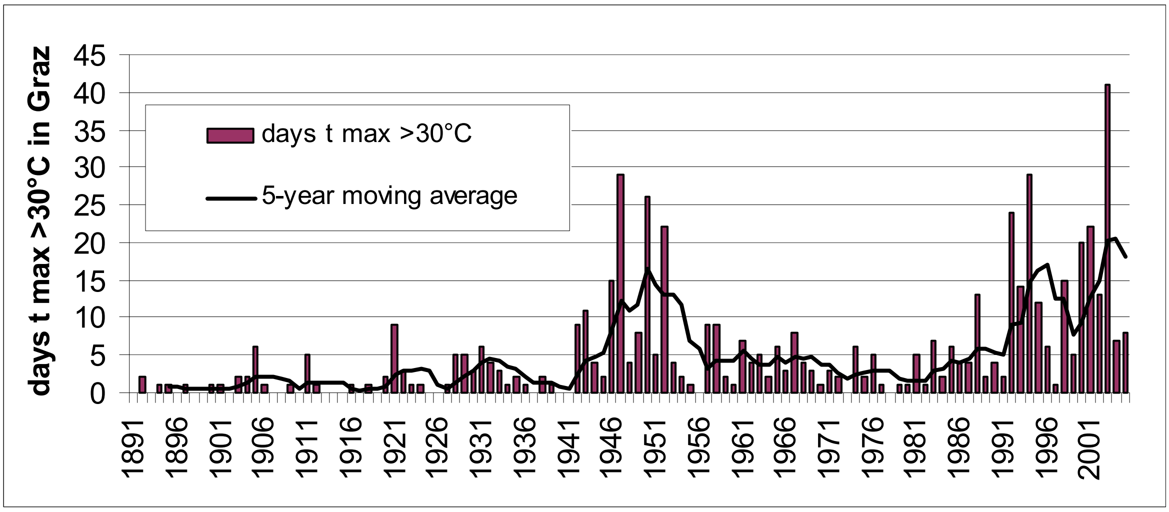

Figure 1: Annual number of tropical days in Graz 1891-2005 (source: Foelsche 2005)

Figure 1 is used as basis to compare the prediction of future 'tropical days'. It can be seen that the length of the time series is extremely important to interpret the data. Fact is, that the number of 'tropical days' was much higher in the year 2003 as in the 112 years before and for the 20th century the 90s were the decade with the most tropical days on average (12,8). On the other hand it's evident that if one take only the last thirty or fifty years to predict the future number of 'tropical days', one would ignore the peak during the 40s and early 50s. Indeed if one considers only the data from 1950 to 1980, without considering the development in the recent years, one could easily conclude that there will not be any 'tropical days' in the future.[22]

Temperature scenarios used

The results for the climate model are illustrated in the appendix. As the results are rather shown as intervals of temperature increase, and not as figures, we used the mean value of the illustrated intervals for both, Austria and the Czech Republic. When the model illustrated two different intervals for a country, again the limiting value between the two intervals was taken, e.g. when the intervals 4-5 and 5-6 °C were given for Austria we calculated with 5 °C. Table 1 illustrates the detected values.

Table 1: projected temperature change compared with the reference period 1961-1990 (Scenario A1B)

	2041-2050		2091-2100	
	AUT	CZE	AUT	CZE
winter	1,75	1,75	5,0	4,5
spring	1,5	1,25	2,5	2,25
summer	1,25	1,25	4,5	4,25
autumn	1,75	1,75	4,5	3,75

[22] see Foelsche 2005, p. 31

The same scenario also described the change in the annual number of days above 30 degrees Celsius. For these predictions the differences for each country were much bigger, as it can be seen in the appendix. Thus we tried to describe the predictions in intervals and in a more detailed way, as Table 2 shows:

	2041-2050	2091-2100
Austria		
Alpine Regions	0	0 – 25
Danube Region + Eastern Austria	2 – 5	30 – 50
Eastern Austria	2 – 5	20 – 30
South-Eastern-Austria	7 – 10	30 – 50
Czech Republic		
Western part	2 – 5	7 – 30
Eastern part	0 – 2	7 – 30

Table 2: Increase in ‚tropical days' for Austria and the Czech Republic (Scenario A1B)

5 Results

a) Supply side

We will not exaggerate in stating that the energy is the base of modern civilization and human well-being. Thus the energy sector is a strategic key industry of every developed and developing country; often this industry is in state ownership, though there are tendencies towards privatization in Europe at the moment. Because of its monopoly character the energy sector is usually under strict law regulation. The character of energy production depends on the natural resources of a country.

Concerning the Czech Republic, 64% of generated energy is produced from coal, 31% has a nuclear base, 3% originates from gas and only 2% from renewable sources (RES).[23] The Czech production on this field is self-sufficient. What is more the Czech Republic is one of the biggest European exporter of electricity (this fact is not too positive in relation to the environment, because the Czech energy comes mainly from black and brown coal).

From the environmental point of view, Austrian energy production is much "cleaner". Austria generates 69% of electricity from hydro power plants, 4% from biomass and only 25% from fossil fuels.[24] The problem of the Austrian energy sector is insufficiency of domestic production and high dependence on imports. Another problem is the fast growth of energy consumption.

How could global warming change the energy supply in both states? First of all we have to realize that all the obligatory international activities as the Kyoto protocol create pressure on the energy sector representing one of the main CO2 emitters. The developed world feeling responsibility for the contemporary state of atmosphere should look for alternative technologies.

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[23] Janouch & Schleicher 2005, p.11

[24] Janouch & Schleicher 2005, p.12

We will now examine closely the European Union policy on this field. The energy policy of EU is not as united as e.g. agriculture policy; although it has defined main priorities such as strengthen competition in energy production, increase safety of energy production and protection of the environment.

When CO_2 emissions are considered, "the cleanest" sources of energy are nuclear source and RES. In comparison with RES nuclear power plant could generate significant quantities of energy in the Czech Republic. It is planned to build new nuclear power plants – it depends on particular states; Czech Republic has a project which assume to start new building between 2015 – 2020.[25]

Concerning renewable sources of energy the EU has ambitious plan to double the share of them from 6% in 1996 to 12% in 2010. The Czech Republic does not have more potential for more hydro plants. The small possibility provides wind plants, but they have to be built on the tops of the hills, usually in recreation areas, which is quite controversial considering aesthetic measures. The only possible capacity represents biomass from the point of view of power system flexibility and reliability.[26]

As we show in the paragraphs below the change of the structure of energy sector will be slow and we cannot expect immediate stop of CO_2 emissions produced by this industry. The next question we will examine here is how continuous global warming could affect present power plants and distribution capacities.

One of the supposed climate change impacts is extreme weather. It means for temperate zones higher temperatures, draughts or extreme precipitation with the risk of floods. Water shortages are another risk factor for hydro, thermal and nuclear power plants. "Power plant output may be restricted because of reduced water availability or thermal pollution of rivers with a reduced flow of water."[27] According to a paper of the Polish scientist Kaczmarek, which can be considered partially relevant also for Czech Republic, climate change could cause extremely high as well as extremely low runoffs of the rivers.[28]

The Czech climatologists prepared "Territorial study of Czech republic climate changes" where they modeled three types of typical Czech regions. The results are not exact enough to predict future development of evaporation and precipitation. The simulation of hydrological sensitivity in case of global warming and change of precipitation pointed out that catchments areas with lower total precipitation are more vulnerable than the ones with higher total precipitation. The locations which have nowadays problems with water shortages could be touched by global warming very deeply. The climate change impacts on water regime would be unevenly distributed.[29] The analyses of power plants locations would discover their exposure to the lack of water risks.

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[25] Janouch & Schleicher 2005, p. 17
[26] Blyth 2005
[27] See IPCC www.grida.no/climate/ipcc/regional (28.6.2006)
[28] „Some scientists claim that land-use and climate changes will result in an increase in the frequency of both high and low river flows. Others have expressed the opinion that if the climate changes and snowfall decreases, there could be a widespread shift from spring to winter runoff." See Kaczmarek 2003, p. 3
[29] Moldán, Sobíšek 1996, p. 28

The water regime has also impacts on agriculture which means that some regions e.g. South Moravia with quality soil, but necessity of intensive irrigation, is potentially jeopardized. (The agriculture is mentioned especially because of the connection with biomass production). In Austria we should not overlook the impact of melting Alp's icebergs on river basins runoffs.

For Alpine regions it is expected that especially in summer the run off rates will be significantly lower than nowadays. Thus the hydroelectric power production is likely to decrease, though higher temperatures will lead to a higher peak demand due to cooling.[30]

What we could expect in the future shows an analysis of the record summer 2003 (as mentioned above there were 41 'tropical days' in Graz). Hydroelectric production was lower than normal due to low runoff rates. Simultaneously many Central European nuclear and thermal power plants had to reduce their production, because of cooling problems due to the heat and the low runoff rates. Consequently the price for electricity on the European Energy Exchange EEX was up to 492 Euro per Megawatt hour in July 2003.[31]

The following information about climate change impact on renewable sources is from IPCC and it is valid mainly for North America. Nevertheless some of the results could be usable also for some parts of Europe. "Small hydropower usually located in non-dammed streams may provide more power in periods of peak runoff. Solar energy is highly dependent on cloud cover, which may increase with expected intensification of the hydrological cycle; the exception might be the south-central area of North America, where increased insolation is expected."[32]

Concerning to grids, transmission lines and pipelines in mountainous areas they may be subject of land disturbances because of increased precipitations. We may expect necessity of more modifications and reparations of the distribution system.

b) Demand side

In the following we show the results for our calculations of heating and cooling energy demand.

Past trends in heating degree days

[30] see Findeklee 2005

[31] see Verbund 2003, p. 6

[32] See IPCC www.grida.no/climate/ipcc/regional (28.6.2006)

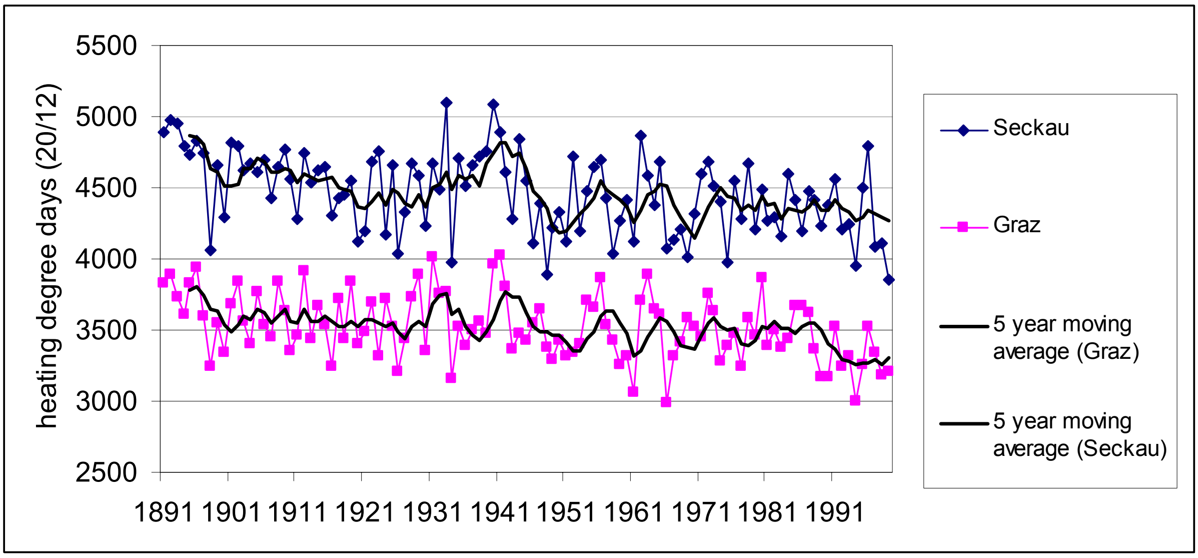

Figure 2: annual heating degree days in Graz and Seckau 1891-1999

Figure 2 illustrates the past trends for Graz and Seckau. It can be seen that the number of heating degree days decreased for both stations during the 20th century. The linear trend for the time series show an annual decrease of 2,8 HDD for Graz and 3,8 HDD for Seckau. The 1990s were clearly the decade with the least heating degree days. The second-warmest decades were the 1980s for Graz and the 1960s for Seckau. Third were the 1960s for Graz and the 1980s for Seckau.

Decrease in HDD with different temperature scenarios

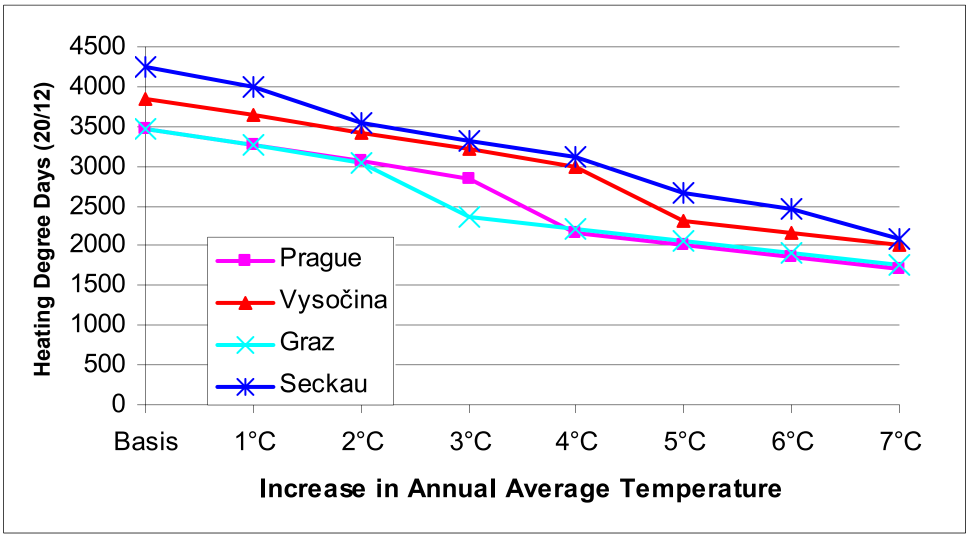

Figure 3: Decrease in HDD with different temperature scenarios compared to the basis period 1961-1990

Figure 3 shows the change in the number of HDD for the chosen stations dependent on the extent of the temperature increase. It can be seen that for both mountain villages Seckau

and Vysočina an increase in temperature by 2 degrees Celsius would result in the same heating energy demand as in Graz and respectively Prague in the basis period. A temperature increase by 7 degrees would lead to a reduction of heating degree days by approximately 50 percent.
Particular attention must be paid to the fact, that between some temperature intervals the decrease is much stronger than normal. This is the case between 2 and 3 degrees for Graz, 3 and 4 degrees for Prague, 4 and 5 degrees for Vysočina, and 1-2, 4-5 and 6-7 degrees for Seckau. Our analysis shows that this is because of the assumption that heating degree days are calculated for all days of a month, if the monthly average temperature is below 12 degrees and is not calculated for a month at all, if average temperature is above 12 degrees. Thus months, where the average temperature is only just below 12 degrees, are overestimated, because there will be some warmer days, where heating is not needed any more. Vice versa, months with an average temperature only just above 12 degrees are underestimated.
This problem can have quite a significant impact on the results, as we will show below. Consequently we suggest the introduction of a correction factor for months with an average temperature close to 12 degrees Celsius, though the development of such a correction factor would exceed the scope of this paper.

Decrease in HDD with Scenario A1B

Due to this problem we show two different tables to highlight this ‘threshold problem’. Table 3 shows the originally calculated decrease in annual heating degree day in percentages. The figures in the brackets indicate the number of months, in which the temperature jumps over the 12 degrees threshold. These months lead to an overestimation of the decrease for the affected stations.

Table 3: Relative change in annual HDD compared to 1961-1990 (in percentage)

station	**2041-2050**	**2091-2100**
Prague	- 9,8 (0)	- 29,0 (1)
Vysočina	- 8,8 (0)	- 20,0 (0)
Graz	- 10,2 (0)	- 38,3 (2)
Seckau	- 15,8 (1)	- 28,0 (1)

In contrast to that, in
Table 4 the months April, May and October, in which the ‘threshold problem’ can be observed, are eliminated and the calculations are limited to the period November-March. In this period 82 percent of the annual heating degree days is generated (reference period for Graz). Nevertheless this method results in an underestimation of the decline. This is firstly because the same absolute increase in temperature leads to a stronger relative HDD decline in warmer months and secondly because warmer temperatures generally reduce the overall heating period.

Table 4: Relative change in HDD for November-March compared to 1961-1990 (in percentage)

station	2041-2050	2091-2100
Prague	- 9,0	- 21,2
Vysočina	- 8,1	- 19,1
Graz	- 9,1	- 24,3
Seckau	- 8,2	- 21,8

Table 3 and

Table 4 show that the relative decline in heating degree days is stronger for Graz and Prague, than for Seckau and Vysočina. It seems as this is because of the fact mentioned above, that if you start from a higher temperature level, the relative HDD decline is higher. Furthermore a comparison of both methods shows that the difference between the values is only significant, when temperature in one or more months jumped over the 12 degrees threshold. We expect the actual decline to be somewhere between both methods.

Figure 4 illustrates the annual decline for Graz. The projection was drawn with the assumption of a linear decline from 1975 (1961-1990) to 2045 (2041-2050) and respectively 2095 (2091-2100). Naturally a linear increase is generelly not appropriate to describe climate change trends, though for our purposes it gives a first impression of the trend.

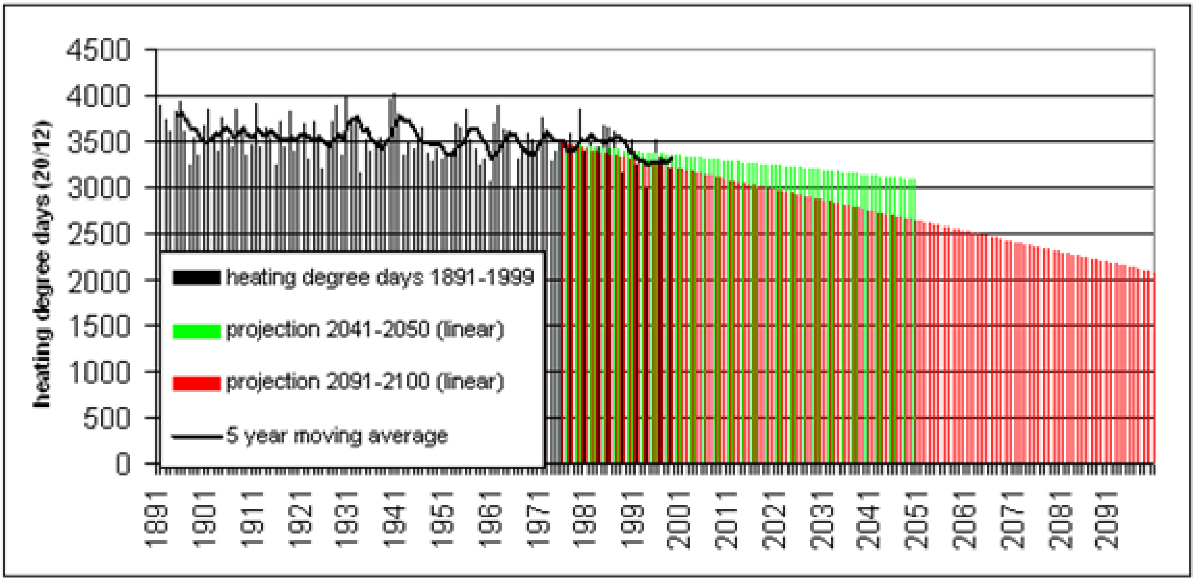

Figure 4: Projected decline in HDD for Graz (linear)

Increase in mean temperature in summer

In absence of cooling degree days we will provide two indexes to illustrate the future cooling demand. Firstly we show the monthly mean temperatures for the months May to September:

Table 5: Projected and measured mean temperatures for May - September

		May	Jun	Jul	Aug	Sep
Prague	1961-1990	13,0	16,3	17,8	17,2	13,6
	2041-2050	14,3	17,6	19,1	18,5	15,4
	2091-2100	15,3	20,6	22,1	21,5	17,4
Vysočina	1961-1990	12,0	15,2	16,7	16,2	12,6
	2041-2050	13,3	16,5	18,0	17,5	14,4
	2091-2100	14,3	19,5	21,0	20,5	16,4
Graz	1961-1990	14,0	17,1	18,8	18,1	14,8
	2041-2050	15,5	18,4	20,1	19,4	16,6
	2091-2100	16,5	21,6	23,3	22,6	19,3
Seckau	1961-1990	10,7	13,9	15,8	15,0	12,1
	2041-2050	12,2	15,2	17,0	16,3	13,8
	2091-2100	13,2	18,4	20,3	19,5	16,6

From the figures in
Table 5 the following conclusions concerning the global warming influence on cooling energy demand can be derived:

- The figures for the period 2041-2050 show that the temperature in Vysočina will be as high as it was in Prague in the reference period 1961-1990. In Seckau it will be even lower than it was in Graz in the reference period. Thus, according to this scenario cooling energy demand in these regions will not differ from the cooling energy demand in Graz and Prague experienced in the reference period.
- In the period 2041-2050 the month of June is predicted to be almost as hot as the Month of July was in the reference period.
- In the period 2091-2100 it is predicted that the month of September will be even hotter as the month of August in the reference period, the month of May only 0,6-1 degree colder as the month of June was in the reference period.

I*ncrease in 'tropical days'*

In order to give a more detailed insight about the predicted cooling energy demand, a second indicator, namely the increase in the number of days above 30 degrees Celsius is shown for Graz. As the used climate scenario estimates an increase between 7 and 10 days for the period 2041-2050 and respectively 30 and 50 days for the period 2091-2100, we used the mean values to illustrate this trend in Figure 5.

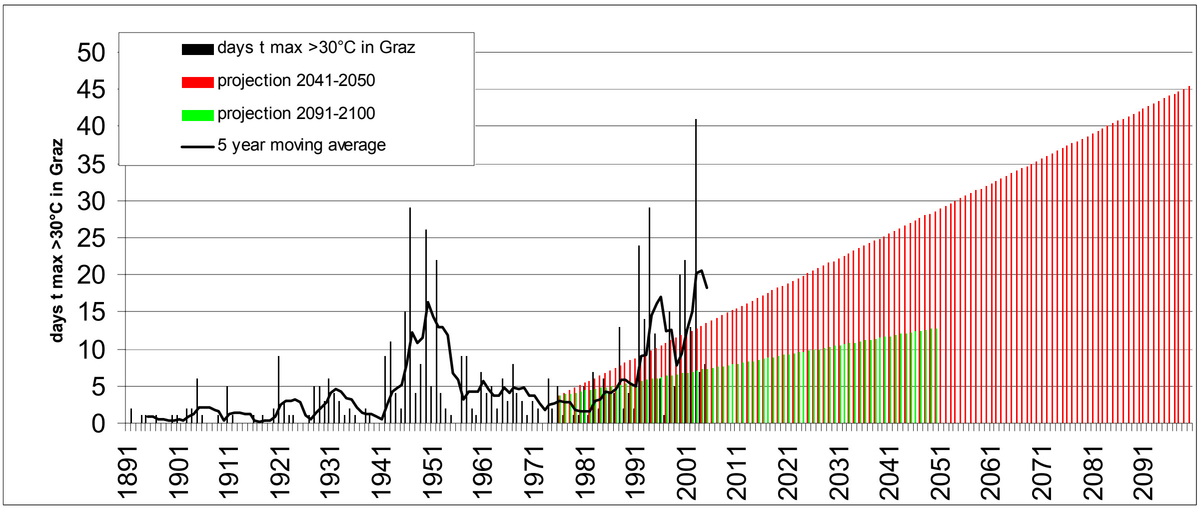

Figure 5: Projected number of 'tropical days' in Graz (linear)

It can be seen that the current 5 year moving average is clearly higher than the linear trend estimated from the climate model. It is also the case that the average number of tropical days in the 1990s is higher than the estimation for the period 2041-2050, even without considering the record value measured in 2003. The projection for the period 2091 – 2100 is approximately as high as the 2003 value. According to the climatologist Ulrich Foelsche these results are likely to underestimate the actual number, as most of the climate models due to their resolutions tend to underestimate extreme values, like the number of 'tropical days'[33].

[33]source: personal information from Mr. Foelsche, 20.June 2006

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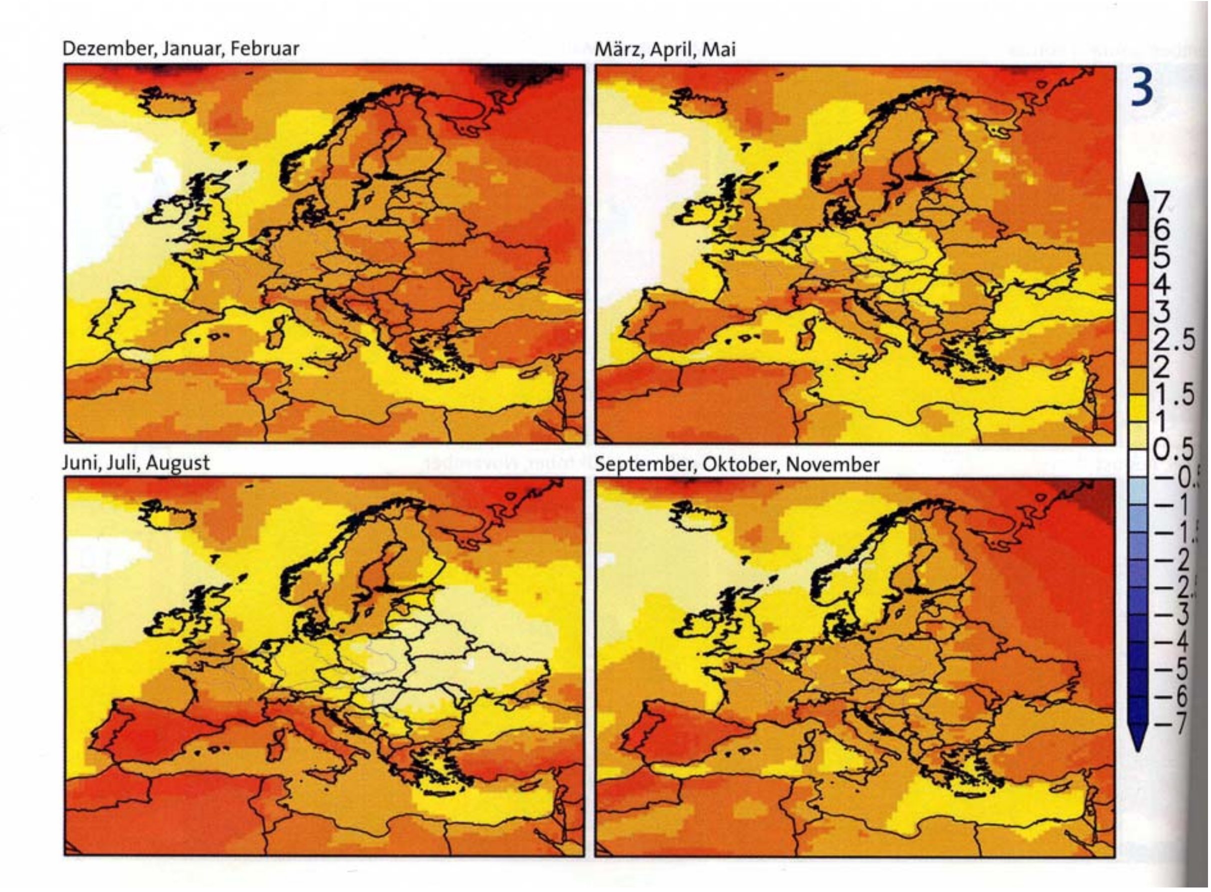
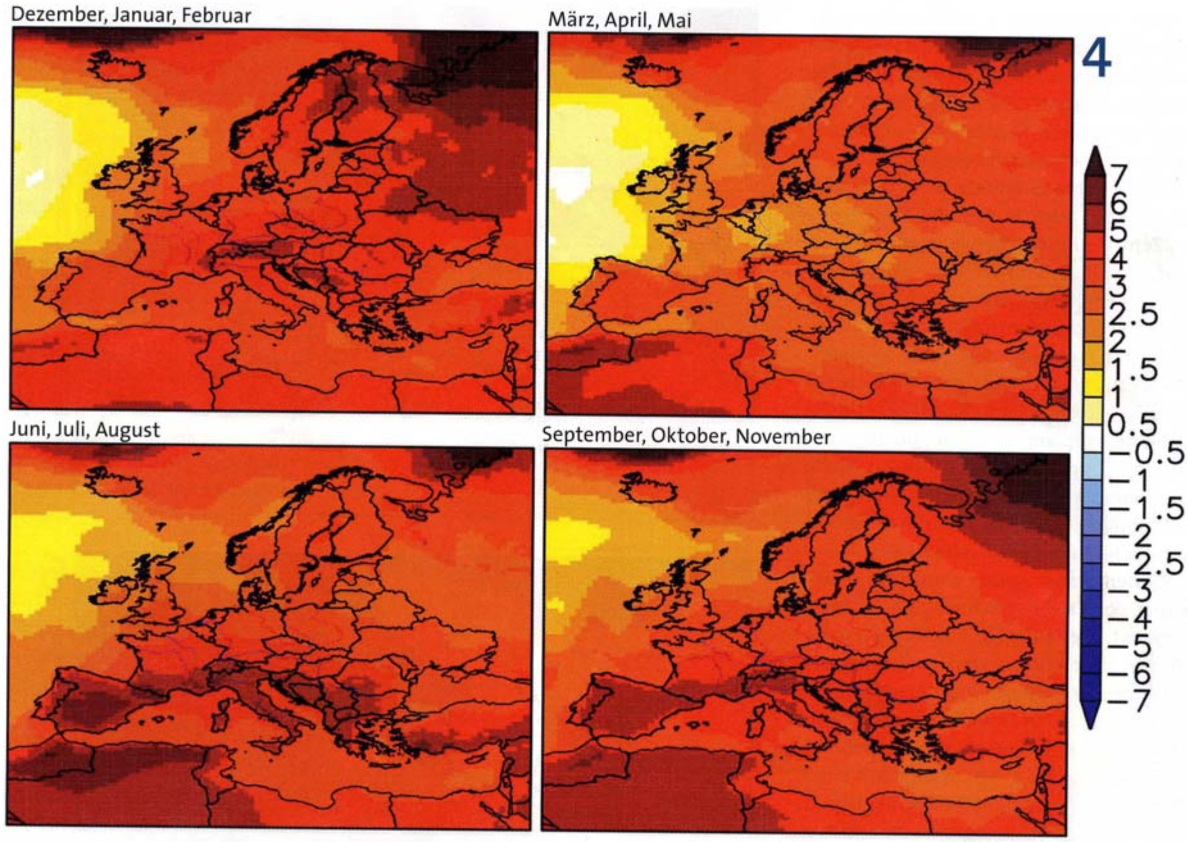
7 Appendix

Appendix 1: projected temperature change 2041-2050 compared with the reference period 1961-1990 (source: Max-Planck-Institute for meteorology 2006)



Appendix 2: projected temperature change 2091-2100 compared with the reference period 1961-1990 (source: Max-Planck-Institute for meteorology 2006)



Appendix 3: projected change in 'tropical days' (tmax > 30 degree C) for 2041-2050 (figure 8) and 2091-2100 (figure 9) compared with the reference period 1961-1990 (source: Max-Planck-Institute for meteorology 2006)