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The Effects of Climate Change on the Energy Industry in Germany

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Executive Summary

Climate change is one of the most debated issues of our time and its effects have often been investigated. These investigations, however, often disregard the potential effects climate change might have on the energy sector and attention is often only paid to the reverse relationship. This study will fill this void focusing on the effects of climate change on the energy sector in Germany by calculating the effects of warming temperatures on heating and electricity demand in residential buildings. In order to do so three scenarios were created assuming a temperature increase of 1℃, 2℃ and 3℃ and applied to the STE building simulation model. As a result, it was shown that heating energy consumption is likely to decrease while cooling energy demand will rise. Moreover, the direct and indirect effects of climate change will largely affect the fuel choices underlying heat and electricity generations which will significantly impact German energy companies, household consumers and Germany's geopolitical status, especially regarding its relations with Russia.

Keywords

Climate Change, Energy, residential buildings, temperatures

Contribution to

Projekt Politikszenarien

Contents:

I Background research

Despite the fact that most studies so far seem to focus on the effects of the energy industry on climate change rather than vice versa some studies employing the opposite approach do exist and shall be reviewed here. While the majority of these studies focus on countries other than Germany their approaches shall still provide useful examples. Moreover, some of the results already provide relatively good indications on the direction of the possible results of this study and shall therefore, be used to develop several hypotheses. One example does seem to exist which has a focus on the German energy market, yet, it does not take on a holistic approach but only focuses on the electricity sector [Pilli-Sihvola et al., 2010]. Regardless, however, its results will be largely important for parts of this study and shall therefore also be investigated.

Firstly, however, looking at the results of the investigations of the IPCC we find a brief section dedicated to the possible effects of climate change on the energy industry. According to the IPCC it is argued that most generally all throughout Europe heating energy demands will decrease while cooling energy demands will increase. Furthermore, there seem to be great regional differences regarding the possible effects. Whereas, for example, in the UK and Russia temperatures are predicted to rise to 2°C by 2050 which will have an effects of reducing fossil fuel consumption by 5-10% and electricity by 1-3% in Finland the reduction is even larger with 10% which is likely to rise to 20-30% by 2100. Lastly, in the Mediterranean temperature effects are estimated to be so large that a substantial increase in cooling energy demand throughout the summer is predicted which might in some regions even shift peak energy demand from the winter months to times of heatwaves during the summer [IPCC, 2007].

Considering, however, that Germany has a relatively moderate climate it is unlikely that even temperature increases of 2-3°C will shift peak demand to the summer.

Yet, a second study focusing on the effects on energy demand in Australia does not predict a shift in peak demand but argues that peak demand is more affected by the changes in demand than the average base demand, an effect that could also apply to the German case [Howden & Crimp, 2001].

Returning, however, to overall energy demand another study investigating the effects of climate change on the US energy industry finds results similar to those of the IPCC. This study, however adds that substantial changes will only be seen starting from 2025 and that severe changes will only become effective in the period 2050-2080. Moreover, this study also already takes a more in-depth look at how these changes will affect the different energy carriers arguing that the amount of gas consumed will substantially decrease due to the decrease in heating consumption whereas the use of electricity is supposed to increase due to higher demand for cooling. Overall, however, these changes almost offset each other and it is likely that the increase for cooling will even be larger leading to a larger overall energy demand [U.S. Climate Change Science Program, 2008].

On the other hand, a different study focusing on the changes in US energy demand as well thereby employing a building energy model argues that the results are regionally differentiated but that it is difficult to estimate how this will affect total energy consumption in the end. Furthermore this study also looks at climate factors beyond temperature such as solar radiation and humidity but finds that they seem to have no significant effect on energy demand [Scott et al., 2005].

Therefore, it shall also suffice for the purposes of our study to focus on temperature changes and no further climate parameters shall be included.

A last study using the US as its case example takes a more in-depth look at how consumer choices are affected by climate change and therefore also focuses on the fuel choices households makes. It agrees that overall electricity will become more important as an energy carrier but also differentiates between different seasons thereby arguing that a warming of the climate during the winter months actually rather achieves an increase in the amount of gas used since more people, at least those living in households that have access to gas for heating, will choose gas over fuel oil. Consequently, the use of gas will not necessarily decrease and the increase in the use of electricity will to a large extent take place during the summer months only [Mansur et al., 2005].

Taking into consideration that due to the moderate climate in Germany heating will still play a large role it can be predicted that similar results will be found according to which gas will remain an important energy carrier and demand for electricity will mainly increase during the summer months.

Another study focusing on energy demand in Switzerland takes a very similar approach to this study by using different temperature scenarios and applying them to a building model. Thereby it also calculates the effects of different energy efficiency measures for buildings, especially focusing on the insulation levels and finds that insulation acts complementary to climate change by decreasing heating demand even further [Frank, 2005].

Yet, while improved building energy efficiency measures according to EnEV regulations shall be taken into consideration for the purposes of this study by being applied as a constant to new buildings and potential new buildings which might be constructed until 2050 their direct impact and combined impact with climate change will not be measured for reasons of limiting complexity and to be able to isolate the effects of climate change on energy consumption from other possible factors.

A last study focusing on several European electricity markets but employing the German electricity market as one example shall be of major importance for this study to already give an indication of the magnitude of possible changes. However, no concrete figures are provided but it is only argued that despite rising temperatures electricity demand in Germany will decrease since even though electricity only plays a minor role in heat generation the decreases in heating demand offset and are bigger than the increases in electricity demand during the summer period [Pilli-Sihvola et al., 2010].

This is a new angle which so far has not been considered. However, it is likely that these estimates also depend largely on the predicted temperature increase. Seeing that the study by [Pilli-Sihvola et al. 2010] foresees a temperature increase of less than 2℃ for Germany it is possible that by using different scenarios which predict a larger temperature increase these results might change.

However, [Cartalis et al. 2001] also argue in their study that it is far more difficult to estimate the effects of climate change on cooling energy demand since buildings can also be cooled by applying non-energy intensive measures such as ventilation.

Overall, however, several hypotheses can be derived from the previously mentioned research.

In the following we will therefore now give a brief overview over some of the hypotheses that have been derived from this research and shall be tested within the course of this study. Moreover, before doing so it is important to mention that all hypotheses derived and the general effects of climate change on energy demand will be tested up until the year 2050 and therefore, apply to a limited time frame. Therefore, it can indeed be possible that some will prove as not applicable for the given time frame and only become effective later or that different effects can be measured for time periods that lie further in the future.

II Hypotheses

The first hypothesis that can be derived from these previous studies is:

1. Global warming will lead to a decreased demand for heating energy in Germany thereby reducing the amount of heating degree days.

Considering that, as has been mentioned, heat generation is mainly based on gas in Germany it can be deduced from that that the overall demand for gas will also decrease [Schiffer, 2008]. Yet, we will discuss later of this might be offset by some other developments.

Regarding the electricity sector, however, it seems rather more difficult to establish a hypothesis considering that the majority of studies argue that electricity demand will increase while the one study using Germany as a specific case example argues the opposite. Yet, based on the fact that the German climate is moderate to cold throughout most of the year it seems more likely that heating consumption will be more affected and that even with warmer temperatures throughout the summer cooling appliances will rather remain limited mainly to commercial buildings and will only be applied in a small number of residential buildings. Therefore:

2. Despite increased demand for cooling, global warming will lead to a reduction in demand for electricity due to a decrease in the demand for heating in Germany.

Combining these two hypotheses important implications regarding overall energy consumption can be deduced leading to a third hypothesis:

3. Global warming will lead to a decrease in overall energy consumption in residential buildings in Germany.

This is still likely to apply even if the second hypothesis proves to be wrong since it is argued that climate change is likely to have a non-linear effect on energy consumption, meaning that in colder places heating demand is more likely to be affected while in warmer places the same applies to electricity demand [Mansur et al., 2005].

As a result, it can then be argued that even if electricity demand in Germany should increase these increases are likely to be outweighed by the decrease in heating energy demand which will lead to a decrease in total energy consumption.

Lastly, the fourth hypothesis to be established shall pertain to the issue of peak times. As was mentioned above, the [IPCC report, 2007] predicts that in some Mediterranean countries like Spain seasonal peak time demand might shift from the winter months to particularly warm summer periods. However, in Germany with its relatively moderate climate such a shift is rather unlikely and therefore the last hypothesis states:

4. Global warming will not shift seasonal peak time demand from the winter to the summer period in Germany.

Having, therefore, clarified and stated the underlying hypotheses of this study we shall in the following test in how far the latter can be confirmed or have to be discarded. Yet, before this is done the next sections will give an overview over the data employed in this study as well as its design.

III Framework conditions

As was discussed earlier on population development as well as the number of households play an important role in determining energy demand. While it has also already been stated that there seems to be a trend towards an increasing amount of households due to an aging population in Germany population figures show the opposite trend.

Currently there are approximately 82 million people living in Germany. However, there are several factors that will affect future population growth such as birth rates, life expectancy as well as migration and immigration into the country. Based on these factors the National Statistical Office developed several scenarios out of which the two most important ones define a lower limit as well as an upper limit for possible future population developments. Those two scenarios are conform in their first two assumptions which state that birth rates will remain at 1,4 children per woman in Germany and that life expectancy will increase by 8 years for men and 7 years for women in the next decades. However, they differ regarding potential immigration figures with the lower limit assuming a maximum amount of 100000 immigrants per year, the upper limit scenario predicts an amount of 200000 [Egeler, 2009].

Based on these scenarios it is then estimated that in the lower limit scenario the population of Germany would only reach 69 412 000 people by 2050 which would only constitute 84.6% of today's population. In the upper limit scenario the population would still reach a size of 73 608 000 which constitutes 89.8% of its current population [Statistisches Bundesamt, 2010].

Overall, however, it is important to note that population numbers will decrease in the future. Moreover, for the purposes of this study only the figures for the upper limit scenario will be employed.

As for the amount of households we see a more varied trend whereby the number of households is predicted to increase within the following decades until about 2030 but will then start decreasing again until the year 2050. Furthermore, by the year 2050 the overall amount of households will be smaller than it was in 2010 but only marginally so. This total trend is especially reflected in the predictions for one- and two-person households which are similarly predicted to increase and then decline again, however, their number is likely to continue increasing until the year 2040. Additionally, as opposed to the overall trend, the amount of one- and two-person households in 2050 will be larger than the current amount. Larger households starting from 3-person households and more are overall expected to decline within the next decades [Statistisches Bundesamt, 2010].

Therefore we can assume that despite decreasing overall population numbers the quantity of living spaces is likely to remain constant or even increase further due to a trend towards smaller households.

And indeed when taking a closer look at the predicted quantity of future living space we can see that overall they follow a trend similar to that predicted for households with the overall amount of living space increasing until 2030 and then decreasing until 2050 whereby also in the case of living spaces total numbers in 2050 will still be higher than they were in 2010. Considering the different subcategories taking into account the number of people living within a particular household we can see that the predictions made for the size of future living-space follow exactly those predictions made for future household numbers. The only outlier in this case seem to be threeperson households which are predicted to occupy a slightly larger living space in 2020 than they currently do, yet, will also decrease again in the following period [Statistisches Bundesamt, 2008; Statistisches Bundesamt, 2009].

Taking into consideration all these factors it is therefore difficult to predict in how far these numbers are likely to affect future energy consumption considering that declining population numbers could be hypothesized to work in conjunction with climate change and decrease overall energy demand whereas the increased number of households and an increased size of living space could reverse this trend since a greater amount of living spaces will also require more energy for heating and cooling, for instance.

Unfortunately, it will not be within the frame of this study to discuss these effects, yet, in order to depict potential future developments in consumption patterns as accurately as possible these developments will be accounted for within the framework of our calculations.

Another factor which will further be considered is improvements in building energy efficiency. It is important hereby that for all the new buildings the standards outlined in the EnEV 2009 regulations will automatically be applied.

Lastly, energy price developments for fossil fuels such as oil, gas and coal shall also be accounted for. Thereby a distinction is made again between general oil products and heating oil. Starting from 2010 fossil fuel prices for all the fuels previously mentioned are predicted to increase until the year 2050 [Umweltbundesamt, 2009].

This is especially important considering the results of several studies which have previously attempted to determine the effects of price on energy demand. One of these studies by [Martinsen et al. 2007], for instance, takes a closer look at how price changes in oil prices affect energy demand. Therefore, two scenarios were created in which one reflects long-term price increases and is referred to as the “high-price scenario” whereas another one looks at the consequences of short-term price shocks. As a result it was found that even in the reference scenario energy demand will decrease by 17% until 2030 but that price increases lead to further demand decreases of 4-5%. Moreover, the more prices increase the more fossil fuels such as gas and oil will increasingly be substituted by renewable energy sources [Martinsen et al., 2007].

Furthermore, another finding that is important when looking at the effects of price changes is that consumers take a longer time to adjust to possible price changes than they would if their income changed, for instance. Yet, price increases seem to bring about a more drastic and faster response than price decreases would [Gately & Huntington, 2001].

This then leads to the conclusion that increased prices are likely to act as a complementary factor to a warming climate and will intensify the results and decrease energy demand even further than possible climate changes might. Furthermore, a price increase would also work complementary regarding existing legislation concerning the use of renewable energy sources and would promote an increased use of renewables from a certain price level which would then also have an effect on the fuel mix in Germany.

As a result, we can see that all these factors will also greatly contribute to changing energy demand in the future with rising prices and improved efficiency standards likely to decrease energy demand which could outweigh increased demand to an increased number of households and overall larger living space. Taking these factors into consideration they will help provide a more accurate picture of future demand. However, since they are also included in the reference scenario which does not foresee any climatic changes and are kept constant throughout the study their effects will be isolated from the effects of warming temperatures.

IV Data

Before starting the empirical analysis several scenarios regarding potential future climate changes were developed which shall be outlined in this section. As a basis for these scenarios a reference scenario was developed which was based on the heating degree days as well as the average temperature of the time period between 1990 and 2006. For further clarification, heating degree days are usually derived from calculations of the difference between the indoor and outdoor temperature on heating days. Heating days are thereby defined as days on which the outdoor temperature sinks below a minimum of 15°C. For the period 1990-2006 an average of 3296 heating degree days was calculated as well as an average temperature of 11°C. This already shows a decrease compared to the average figures for the time period 1970 to 1989 which could partially already be due to climatic changes, yet this would be only speculation [Saatweber, 2008].

Based on the average temperature of our reference scenario three further scenarios were developed which predict different potential climatic changes. Using the prediction of the IPCC as a basis we can see that for the time period between 2046 and 2065 a temperature increase of 1.3 to 1.8°C is predicted [IPCC, 2007a].

However, these figures refer to total global climate change which makes it necessary to employ other studies which have a more regional focus. So, for instance, a study by [Zebisch et al., 2005] which developed seven climate scenarios and predicts that until 2080 temperatures in Germany will rise by 1.6°C to 3.8°C whereby these large differences are mainly due to the different assumptions and rationales underlying them.

Considering, however, that our estimations refer to the time period until 2050 a further study was consulted which was developed by the Max Planck Institute for Meteorology in Hamburg. Using the REMO model the institute developed several climate predictions for the year 2050 which however, show strong regional differences within

Germany. While, for example, for Berlin an increase of 1.2℃ until the year 2050 is predicted for Freiburg the temperature is supposed to increase to almost 3℃ [Traufetter, 2009].

Combining these figures then an overall temperature increase of 2.6 ℃ for the whole of Germany until 2050 was predicted. However, shortly after the publication of this study criticism became loud arguing that the institute had largely overestimated potential future changes. Yet, it soon became clear that mistakes which had been made only concerned the amount of precipitation predicted and only referred to the time period after 2060 [Mrasek, 2009].

Since this study, however, only takes into account temperature figures as well as only looks at the time period until 2050 it should not be problematic to partly base the established scenarios on the figures developed by the Max Planck Institute.

Looking at these future predictions we can see that the highest possible increases until the year 2050 lie at around 3℃ whereas the lowest potential increases are estimated at around 1℃. Therefore, the first scenario assumes a temperature increase of 1℃, the second one uses the mean with a temperature increase of 2℃ and the third scenario applies the maximum increase of 3℃. Adding these figures to the average temperature of the base scenario energy demand is calculated based on average temperatures of 12℃, 13℃ and 14℃ for the three scenarios respectively.

V Empirical Analysis

Applying these parameters then, the STE building simulation model was used in order to model potential future energy consumption in residential buildings. This model was developed by the research institute Jülich and is computed in order to mirror the building typology of residential buildings in Germany thereby including all types of currently existing buildings in Germany in terms of the age of the building as well as the size of the latter and further comprises different heating and warm tap water systems. In order to thereby reflect the real current building stock as accurately as possible it also takes into consideration the most typical types of buildings and weighs them according to their share within the entire building stock [Hansen, 2010].

Moreover, the model can further adapt to changed technological conditions as well as to a changing political framework and energy policies and most importantly for this analysis can take changed climatic conditions as well as prices into account [Martinsen et al., 2007].

As a result, the STE building simulation model will calculate potential future energy consumption with a particular focus on heating energy [Hansen, 2010].

Therefore, this model is well suited for the purposes of this study to reflect upon a change in overall energy consumption as well as on the fuel mix underlying heat and electricity generation.

The results derived from the calculations with the STE building model then show that total energy consumption is supposed to decrease from 2.638 Petajoule [PJ] in 2010 to 1.882 PJ by 2050 without taking into account the effects of climate change. This decrease is mainly due to decreasing consumption within the heating sector while cooling energy demand as well as consumption of energy to run electrical appliances is predicted to increase. However, due to the majority of energy in residential buildings being consumed for heating purposes the decreases in heating largely outweigh the before mentioned increases.

Looking then more closely at the constituents of total energy consumption we find that energy consumed for heating and warm tap water is supposed to decrease from 2.268 PJ in 2010 to 1.486 PJ by 2050. This is a decrease of almost 34.5% in heating energy consumption which clearly shows that higher prices as well as the application of improved energy efficiency standards clearly outweigh an increase in the number of households as well as increases in the size of living space. Moreover, it also shows that these factors have a significantly large impact on energy consumption itself.

In addition, it is of great importance hereby to observe that especially the share of fossil fuel as a part of heating energy is predicted to decrease significantly while the share of renewable energy sources will continue to increase. Most affected by this is gas as the prime energy carrier for heat generation. While by 2010 gas still holds a share of almost 50% within heat generation by 2050 this share will have decreased to 28.8%. Thereby a significant amount of this decrease in gas consumption will be substituted for by the use of biomass and solar energy. The amount of fuel oil used for heat generation will also decline greatly from 707 PJ in 2010 to 309 PJ by 2050. Due to this decrease fuel oil will only amount to be the third most important energy carrier for heat generation by 2050 and will have been overtaken by biomass. The use of other fossil fuels such as coal will also decrease, however, the effects on the coal sector seem to be less dramatic considering that coal already plays a rather minor role in heating energy generation as compared to gas or fuel oil. The same applies to district heating and electricity whereby their share within total heat generated will decrease to a much smaller extent.

Comparing these results to the scenarios which take climate change into consideration it becomes obvious that total energy consumption as well as energy consumed for heating purposes decrease even further. In the first scenario, assuming a warming of temperatures by 1°C until 2050, we can see that total energy consumed only decreases slightly as compared to the reference scenario to 1.799 PJ. This is mainly due to a slightly higher decrease for heating energy demand as compared to the reference scenario which is however remotely balanced by an increase in cooling energy demand from 36 PJ in the reference scenario to 44 PJ in the scenario describing a 1°C temperature increase.

This shows that global warming does have an effect on energy consumption, however, for slight temperature increases like an increase of 1 °C it does not yet significantly differ from the reference scenario in which no temperature increase is assumed. Moreover, the shares of different energy carriers as a part of heat generation remain the same despite the fact that the total amount of, for instance, gas which is consumed decreases even further.

Most importantly, when regarding this scenario is to compare the overall decrease in electricity used due to a decrease in heating consumption and the increase in cooling energy demanded. When doing so it can be seen that while cooling energy demanded rises by 42 PJ from 2010 to 2050 the quantity of electricity used for heat generation decreases by 63 PJ and thereby outweighs the gains achieved through an increased amount of cooling energy demanded. This also does not change if the increase in electricity used for an increasing amount of electrical appliances is taken into consideration and leads to the conclusion that overall electricity demand will also decrease for this scenario.

Despite rising temperatures in the second and third scenario to 2 °C and 3 °C respectively this trend does not change and the overall amount of electricity consumed is still expected to decrease since the savings due to declining heating consumption still outweigh the increased demand for cooling. This then confirms the findings by Pilli-Sihvola et al. [2010] as well as confirms our hypothesis that global warming will lead to an overall reduction of demand of electricity.

However, it becomes obvious that the difference between the increase in electricity demanded for cooling and the decrease in electricity used for heating becomes increasingly smaller with rising temperatures which could lead to the conclusion that if temperatures were to increase further eventually the amount of electricity demanded for cooling will offset the decreases in electricity as part of heating energy. This in turn would then lead to an increase in total electricity consumption.

Yet, while this does not apply to the scenarios established for this study the increase in temperatures has several other important side effects such as adding to the total number of cooling degree days per year. So, for instance, it can be seen that in the first scenario which expects 1 °C warming an amount of 184 cooling degree days are expected until 2050 while for the second and third scenario this number rises to 234 and 291 respectively.

On the other hand, returning to heating energy consumption it was already mentioned that demand for heating will decrease even further due increasingly warm temperatures. Comparing, for instance, the reference scenario to the first scenario of 1 °C increase a slight difference in the consumption of heating energy is found with the former predicting a consumption of 1.486 PJ while the latter expects this amount to decrease further to 1.395 PJ by 2050. Considering that the reference scenario already predicts a decrease of 34.5% in heating energy consumption by 2050, an increase of temperature by 1℃ over time predicts a decrease in consumption by 38.3% and would therefore add to a decline in consumption by another 3.8%. Thereby the shares of the different fuels used for heat generation do not differ from the reference scenario, yet, the total amount consumed decreases like in the case of gas from 428 PJ in the reference scenario to 402 PJ in the first scenario.

Investigating the second and third scenario further a similar pattern is found with overall consumption of energy as well as heating energy in particular decreasing further, so, for instance, heating consumption decreases to an amount of 1.304 PJ in the second scenario assuming a warming of 2℃ and to 1.213 PJ for the third scenario assuming a warming of 3℃ respectively.

As a result, this would then mean a decrease in consumption by 42.3% and 46.2% meaning that a warming of 2℃ would decrease consumption by a further 7.8% as compared to the reference scenario and a warming of 3℃ would lead to a substantial further decrease by 11.7%.

Moreover, the amount of gas consumed as part of heating energy would decline to 376 PJ in the second scenario and to 349 PJ in the third scenario. Other fossil fuels would also experience a larger decrease whereas renewable energy would continue increasing but to a lesser extent in terms of total capacity.

Consequently, these results confirm the first three hypotheses established earlier which argue that global warming will lead to a decrease in total energy consumption in Germany as well as a decrease in heating energy consumption. Furthermore, the second hypothesis that argued that the amount of electricity used for cooling purposes would increase, yet, total electricity consumption would still decrease since the former would be outweighed by the decrease in electricity as a source of heat generation was also proven to be true.

Additionally, it was found that the underlying fuels for heat generation largely change in terms of their shares as a part of heat generation and overall amounts employed with renewable energy becoming increasingly important and a declining importance of fossil fuels. Considering, however, that the same effect was already observed in the reference scenario this cannot be traced back to the effects of climate changes as such but is most likely rather due to expected increasing prices for fossil fuels such as gas and oil as well as to the political framework according to which renewable energies are mainly promoted. Moreover, this is also contrary to the results brought forth within the study by [Mansur et al., 2005] which uses a consumer choice model and predicts that the use of gas for heating will increase during the winter period. Yet, this difference could be due to the fact that a different case example, namely the US, was used and more importantly due to the fact that consumer choices are not taken into consideration in the model employed for this study.

Lastly, considering the fourth hypothesis focusing on seasonal peak time demand the results presented here will be slightly more speculative since the amount of heating degree days was not calculated by the STE building simulation model. Yet, it did provide some output regarding cooling degree days which are expected to rise from a level of 135 cooling degree days in 2008 to 184 cooling degree days in 2050 if a warming of 1 °C is assumed. Furthermore, for a warming of 2 °C and 3 °C the quantity of cooling degree days would rise to 234 and 291 respectively.

Comparatively, however, it can be seen that the number of heating degree days is much larger with, for instance, a number of total heating degree days of 3335 in the year 2005/2006. Moreover, comparing long-term averages such as the time period 1970-1989 in which the average number of heating degree days reached 3581 and the period 1990-2006 with an average number of 3296 it becomes obvious that there seems to be a tendency towards a decreasing amount of heating degree days. Seeing that the average temperature difference between these two periods lies around 1 °C with the average temperature in the first period being around 10 °C and in the latter around 11 °C simple arithmetic can be used to apply this to future time periods [Saatweber, 2008].

Assuming therefore that a temperature increase of 1 °C is equal to a reduction in the amount of heating degree days by 285 an increase of temperatures by maximum 3 °C until 2050 would lead to a reduction of heating degree days to 2441 compared to the average sum of the 1990-2006 period. Despite the fact that this might not be an entirely accurate depiction of the total number of heating degree days in 2050 it is highly likely that the number of heating degree days by 2050 will still be much higher than the number of cooling degree days and that it is therefore unlikely that seasonal peak time demand will shift from winter to summer.

Overall, therefore, while these results show a clear trend towards less energy consumption the total numbers should not entirely be taken at face value and assumed to give an accurate depiction of future energy consumption. This is due to the fact that the model assumes that building efficiency measures as specified by the EnEV will be employed accurately. However, as was discussed earlier, it is unclear in how far these have so far been accurately implemented and how or whether this will change in the future [Staiß et al., 2005].

As a result, on the basis of these trends the following section will now take a more in-depth look at the implications of these changes. Thereby the direct implications of the results for the residential building energy sector will be discussed, yet, other studies with a greater focus on total energy consumption in Germany will also be taken into consideration to arrive at a more realistic overall picture.

VI Implications for the energy industry in Germany

VI.1 Implications for the German energy sector's fuel mix

As has been discussed, the STE building simulation model provides a fairly detailed depiction of how the fuel mix underlying heat generation for residential buildings in Germany will change until 2050 with fossil fuels becoming increasingly less important and renewables increasing their share as a part of heat generation. The most important finding hereby seems to be the relatively large decrease of the share of gas in heat generation which is, according to the findings of this study, to a great extent not a direct effect of climate change itself but an indirect effect caused by legislative measures aimed at mitigating climate change. However, climate change directly intensifies this effect by further reducing total energy consumption and thereby also reducing the total amount of gas consumed.

Moreover, considering that more than 75% of energy consumed in German households is devoted to space heating this would then lead to the conclusion that the importance of gas as a primary energy carrier will decline in the future [Schuler et al., 2000].

Yet, contrary to this assumption the majority of studies focusing on future energy demand and supply actually predict an increase in the importance and demand of gas. Hereby predictions vary between increases of 10%-40% in demand for gas [Lochner & Bothe, 2007]. These variations are likely to be due mainly to varying underlying rationales of the studies considered as well as the factors determining future energy consumption which were taken into consideration. However, it is unlikely that the majority of these studies take climate change into account when estimating future energy demand and resulting from that also future gas demand. Therefore, it could be that while there is an overall trend towards an increasing importance of gas it is necessary to revise some figures predicting large increases by taking the effects of climate change into account.

Moreover, an important distinction needs to be made here since the findings of this study refer solely to the demand for gas in the residential building sector while the latter seem to focus on overall demand for gas and thereby also include demand from other sectors such as industry. As a result, both predictions are likely to be accurate but simply reflect two inherently different parameters with this study only focusing on a subsection of total energy demand in Germany.

Regardless, however, it is possible that energy demand in the residential building sector can still contribute to a rising demand for gas since the model does not provide a detailed depiction of how the fuel mix underlying electricity generation in Germany will change until the year 2050. As a result, it could be assumed that the increase in the demand for gas could be related to changing patterns regarding this underlying fuel mix. Taking therefore a closer look at the current fuel mix underlying electricity production it can be seen that nuclear energy by far makes up the biggest share in electricity production [Schiffer, 2008].

Yet, as has been mentioned earlier, nuclear energy has increasingly come to be criticized within the German public due to the Chernobyl incident in 1986 and in 2000 legislation was passed which determines the closing of nuclear power plants by 2021 [Pfaffenberger, 1999; BusinessWeek, 2008].

Consequently, it could indeed be true that gas will be used in order to replace current nuclear capacities in electricity generation.

However, reviewing more recent news it can be found that due to political change in Germany the closing of nuclear plants in the near future seems uncertain again since the new coalition of the CDU and FDP has announced intentions to delay the closing of these plants which to a large extent is due to economic and environmental considerations [Wutke, 2009].

If it should indeed be decided that the life-span of these plants will be prolonged it will, at least in the short-term, become more difficult to increase the share of gas as a part of electricity generation.

Nevertheless, considering that the other two most important primary energy carriers underlying electricity are coal and brown coal it is likely that the share of gas in electricity generation will increase despite an extended life-span of nuclear power plants [Schiffer, 2008].

This is mainly due to the fact that gas is a much cleaner energy carrier than coal and an increased use of gas over coal will be necessary to achieve emission reduction targets set by the German government. Therefore, due to current environmental policies which have led to the establishment of prices on CO_2 many companies have already switched from coal to gas for electricity generation which would prove that gas will become increasingly important for electricity [Beggs, 2002].

Moreover, a study by [Delarue et al. 2008] shows that an increasing price of emission allowances leads to increasing use of gas over coal whereby a drop in prices achieves the opposite effect. Therefore, with prices likely to rise further in the future due to increasingly stringent regulations within the EU ETS it is likely that gas will become an even more important substitute for coal. However, it is also pointed out that an increasing reliance on gas for electricity generation could lead to increasing cross-border trade with the Netherlands as was previously observed in 2005 since the Dutch electricity sector mainly relies on gas-fired power plants while the German electricity sector mainly uses coal-fired ones [Delarue et al., 2008].

This finding is especially important for German electricity companies and generators and shall be discussed in more detail in the following section.

In consequence, however, what can be derived from this analysis is that while the importance of gas for heat generation in the residential building sector is predicted to decrease it is possible that the effects of the latter will be slightly reduced due to an increase of demand for gas for electricity generation. Yet, as has been mentioned earlier, heat generation constitutes 75% of total energy consumption in residential buildings in Germany and therefore, it is unlikely that even a large increase in the share of gas for electricity generation will completely outweigh the effects of the latter [Schuler et al., 2000].

As a result, it can be deduced that the overall predicted increase in the demand for gas will be due to an increase in demand in other sectors.

Moreover, the primary energy carrier which is likely to gain most in the future is renewable energy as has been seen which will greatly increase its share in heat generation and is also predicted to do so as a part of electricity generation [AG Energiebilanzen, 2010].

On the other hand, the primary energy carrier which seems likely to experience the greatest losses within the coming decades based on this analysis is coal which is likely to be replaced by fuels which place a less intensive strain on the environment [Beggs, 2002].

Overall, however, one important factor that must be mentioned is that all of these changes seem to be more related to the effects of legislation induced by climate change rather than to be direct effects of climate change itself. This claim is further supported by the fact that, for instance, the decreasing share of gas in heat generation had already become obvious in the reference scenario while the scenarios assuming a temperature increase had only shown that the total amount of gas demanded will increase further, yet, the share of gas as a part of heat generation will remain the same. Consequently, it could then be argued that potential changes in the fuel mix of the German energy sector will to a large extent be brought about by the indirect consequences of climate change while the direct effects of climate change itself only further intensify the latter.

VI.2 Implications for German energy companies

Based on the analysis provided in the previous section, it seems fairly obvious that these changes will also affect the conduct as well as the success of the majority of German energy companies.

With regard to the direct effects of climate change therefore a general decrease in demand for energy regarding heating as well as electricity was observed based on the model calculations. This decrease in demand then is also likely to lead to a decrease in revenues of energy companies unless prices rise high enough to make up for the latter. Consequently, it could be argued that the direct effects of climate change will negatively affect German energy companies by decreasing demand and thereby leading to shrinking revenues.

Moreover, potential future electricity and gas price developments which could revise these losses are difficult to predict due to the complexity of developments in these sectors. With regard to electricity it, at first, seems unlikely that prices will increase in the future considering that since the liberalization of the electricity sector the prices of the latter are determined according to supply and demand which in a case of decreasing demand would lead a decrease in prices [Schiffer, 2008].

Yet, developments concerning prices are often more complex and a variety of other factors need to be taken into consideration.

So, for instance, most previous studies predict that prices for electricity will actually rise in the future due to a lack of generation capacities since the profitability of investments in the energy sector has become increasingly difficult to predict [Jobs, 2009]. However, it is not entirely clear whether this prediction takes potential future decreases of demand into account. Therefore, based on the forces of supply and demand no conclusion can be drawn with regard to future electricity prices since it is unclear whether a decrease in supply will be large enough to offset the decrease in demand or whether the latter is likely to prevail. However, another factor of importance that should be taken into consideration concerning electricity is that the share of renewable energies in electricity generation is assumed to rise substantially in the future [IER et al., 2009].

Due to the high price of current renewable energy this could then be considered as the potentially most important factor which could influence electricity price development in the future and would indeed lead to an increase in electricity prices.

In addition, with regard to gas potential future prices seem even more difficult to determine since price developments for the latter are bound to the development of the oil price [Schiffer, 2008].

Yet, the price for gas is also predicted to increase in the future [IER et al., 2009].

However, concerning the latter predictions it needs to be taken into account that with the liberalization of the gas markets gas prices will also increasingly become subject to the rules of supply and demand [Haas et al., 2009]. This in turn would then lead to the conclusion that if demand for heating and electricity decreases gas prices will also decrease. However, before concluding an important distinction needs to be made. Gas unlike electricity is a primary energy carrier which can be used to generate end products for consumers like heat or electricity [Schiffer, 2008].

While it has been established that the share of gas in heat generation will decrease this might be offset to a certain extent by an increase in the share demanded for electricity generation. Yet, as was mentioned, this is unlikely to outweigh the decrease in demand for gas for heating and as a consequence prices would still decrease, however, to a lesser extent.

Nevertheless, the most important point that needs to be repeated hereby is that these figures only concern energy consumption in the residential building sector. However, price formation will take place based on overall demand which is predicted to increase and therefore, would also lead to an increase in prices [IER et al., 2009].

Consequently, it is possible that gas and electricity prices might increase further in the future. Moreover, as was mentioned, other factors also play an important role in price formation and so an increase in the share of renewables for heat and electricity generation could also lead to increasing prices [Schlandt, 2010]. However, with regard to an increase in prices due to increasingly feeding-in renewables big companies such as RWE will not profit since the higher revenues due to renewables will solely benefit the generators of renewable energy rather than energy distributing companies [Sensfuß et al., 2008].

As a result, energy companies should therefore take into account that demand with regard to heating and electricity in residential buildings is likely to decrease, yet, could be outweighed by an overall increase in prices. Furthermore, if overall demand for gas should really increase as predicted by other studies this would have to be due to increasing demand from other sectors such as industry and consequently industrial consumers would become more important so that business strategies such as marketing tactics should be adapted accordingly.

Moreover, while it has also become obvious that generators of renewable energy are favored by the legislations implemented due to climate change coal-fired generation plants will be disadvantaged by the latter. Especially considering, as was mentioned, that an increase in prices of CO_2 led to increased Dutch-German cross-border trade due to the Dutch energy economy being based on gas-fired power plants this could become problematic for German generators employing coal-fired power plants [Delarue et al., 2008]. If, for instance, the majority of electricity previously generated by coal-fired power plants was to be substituted by imports from gas-fired plants in the Netherlands this could lead to large-scale job losses in the German energy sector.

Additionally, energy companies will also have to cope with the indirect effects of climate change which are likely to lead to a change in the fuel mix underlying heat and electricity generation. In order to understand the effects thereof, however, it is firstly important to look at the structure of the German energy market in which companies can be divided into three broader categories, namely national companies, regional companies and local companies. Thereby it is mainly national operators which conclude contracts with domestic and foreign energy generators and afterwards sell the demanded capacities to regional and local companies. The latter in turn then take on the responsibility of the direct provision of power to consumers [Mez, 2001].

What is most important hereby is the difference in the nature of contracts which underlie these interactions. For instance, regional and local companies mainly use future and forward contracts in order to ensure that there will be sufficient supply of gas or other fuels for heat generation as well as supply of electricity in the future to satisfy the demand of their customers. In those contracts the buyer usually agrees that a certain amount of power will be purchased at a certain point in time for a previously determined price. The importance hereby lies in the fact that these contracts can refer to time periods of up to six years but are usually used for shorter periods. Moreover, a smaller amount of trade also takes place on spot markets in order to assure a better balance of supply and demand, especially during peak times. Capacities purchased on the spot market are usually distributed during the following day and sometimes also on the same day of purchase [Huisman, 2009].

In consequence, it can be seen that the contracts used by regional and local suppliers are generally of a more short-term nature. Therefore, considering that the changes in demand and fuel mix will develop slowly over time adaptation to these changes will be facilitated for these companies due to the nature of the contracts on which their interactions are based.

National companies, on the other hand, often conclude long-term contracts with domestic and foreign generators which can last up to 20 years and longer in some cases. Moreover, these contracts usually contain "take-or-pay" obligations according to which companies have to pay for the amount contracted regardless of changes in demand [Mez, 2003]. While this does not mean that national companies are entirely inflexible to adjust to changes in demand it will be much more difficult for them to do so. Therefore, it is necessary that potential long-term changes such as the effects resulting from climate change are taken into consideration when developing strategies for future supply in order to avoid potential losses in revenue.

Yet, other developments within large national companies like RWE have taken place which might help bigger companies to deal with the effects of fuel switching. So, for instance, a "convergence" of the electricity and gas sectors has taken place with large national companies which were previously specialized on the provision of gas incorporating electricity into their portfolio. This, especially in light of the aforementioned developments, can facilitate a switch of gas previously used for heating purposes to be used for electricity generation [Künneke, 2009; Mez, 2003].

Furthermore, it also gives companies an advantage with regard to trade due to a strong presence in both markets [Bernotat, 2009]. While this might make it easier for companies to deal with underlying changes in the fuel mix it only applies to companies that have integrated branches of gas and electricity. For other companies which specialize on the supply of gas for heating purposes this might make it even more difficult since integrated companies will want to redirect their own gas supplies towards the generation of electricity and might therefore attempt to restrict access for the former.

Concluding this section, it should be pointed out that the direct effects of climate change on energy consumption as well as measures such as improved energy efficiency are likely to harm companies in the German energy sector since they lead to a decrease in demand for energy. However, potential changes in the fuel mix underlying energy generation might benefit some companies which have widened their focus from the sole provision of gas to also include electricity. Similarly to the previous section, generators of heat and electricity operating coal-based power plants will be the ones likely to make the biggest losses while renewable energy generators are likely to profit.

VI.3 Implications for consumers

The effects of climate change and legislation related to the latter seems to be twofold in the case of consumers in which the rationale seems to run directly opposite to that of energy companies. So, for instance, the STE building simulation model has shown that consumption of heating and electricity will decrease until 2050 which can be considered to be mainly due to improvements in building energy efficiency but is further intensified by the direct impacts of climate change, more precisely by rising temperatures. Therefore, the direct implications of climate change for building energy consumption seem to be clearly beneficial since a decrease in consumption will also lead to a decrease in expenditure which currently constitutes 7.2% of total household expenditures [BMU & BMWi, 2006].

The indirect effects of climate change asserted through, for example, legislation, however, seem to have different effects depending on the individual measure implemented. In this case measures such as the improvement of building energy efficiency are proven to have reduced energy consumption drastically in the past and are likely to continue doing so [Geller et al., 2006].

As a result, a thorough implementation of the measures established as part of EnEV 2009 would benefit consumers since it would reduce consumption and thereby reduce costs.

Yet, other measures such as the feeding-in of renewable energy seem to have negative or at best ambiguous effects on consumers. So, for instance, it is expected that in 2011 an increasing amount of solar energy will be fed into the grid due to a large-scale extension of solar energy capacities. However, it is predicted that this will increase electricity prices by about 10% in 2011 which would result in an expenditure increase of 100 € for single family homes that use on average 5000 kWh of electricity or more per year. These increases have even led experts to argue that the costs associated with a feeding-in of renewable energy are becoming unbearable for consumers [Schlandt, 2010].

This would then result in a situation in which less energy will be consumed in the future but in which this decrease in consumption will not lead to a reduction in expenditures due to rising prices associated with renewables. Consequently, this would mean that the direct effects associated with climate change such as rising temperatures as well as certain measures implemented due to climate change like building energy efficiency improvements are offset by other measures like the feeding-in of renewables in the case of consumers.

Yet, it needs to be mentioned that the overall effect of the feed-in tariff on electricity prices can also be debated. For example, a study by [Sensfuß et al., 2008] which takes a more in-depth look at the effects of feeding-in renewables on the merit-order effect argues that due to the long-term nature of contracts underlying the purchase of renewable energy and the specified quantity which needs to be purchased less electricity will be purchased on the spot market in the end. This decrease in demand will also lead to a decrease in prices since within the merit-order of power plants only the relatively cheaper plants will be employed to generate the amounts requested on the spot market. Considering this the decreases in spot market prices as well as the relatively high market value of renewable energy are argued to outweigh the increases in price due to the feeding-in of renewable energy [Sensfuß et al., 2008].

However, it needs to be kept in mind that prices for household consumers are determined by a variety of factors and include several components which could explain why this effect seems to apply less to household consumers and is therefore not reflected in current or potential future prices [Schiffer, 2008; Schlandt, 2010]. Therefore, an increase in prices for household consumers should still be expected.

In consequence, it is therefore difficult to determine whether consumers will experience a net benefit or net loss due to the direct and indirect effects of climate change since it cannot be determined whether the increase in prices will outweigh the decrease in demand. Yet, it should be kept in mind that the effects of climate change on consumers vary according to which effects and measures are taken into consideration and do not follow a singular linear direction.

VI.4 Geopolitical Implications

In terms of geopolitics total overall consumption as well as the importance of individual energy carriers also play an important role. Taking into consideration past examples of measures implemented in order to reduce dependence on foreign energy imports it becomes clear that reducing domestic energy consumption was among the most frequently implemented measures [Dirk, 2008].

Therefore, it can be argued that a decline in energy consumption in the residential building sector brought about by the direct effects of climate change will also lead to an overall decline in dependence on imported fossil fuels. Moreover, however, in this case it will again be the indirect measures like improved building energy efficiency which have a larger influence with regard to reducing import dependency by leading to a greater reduction in energy consumption. Additionally, a potential decrease in dependency could further be supported by the fact that the share of renewables as part of the energy mix is predicted to increase. This in turn could also lead to a relative decline in the importance of imported fossil fuels as compared to domestically generated renewable energy [AG Energiebilanzen, 2010].

Yet, fossil fuels will still remain of importance and it is therefore necessary to analyze in how far the indirect effects of climate change affecting the fuel mix will influence dependence on these fossil fuels. More specifically the focus hereby will be on gas considering that it is the most important fuel underlying residential energy consumption as well as the fact that gas as a primary energy carrier has led to geopolitical difficulties and disagreements between different European countries in the past [Schiffer, 2008; Noel, 2008].

With regard to gas Russia is the most important supplier for the majority of European countries including Germany. Yet, the security of supply with regard to Russian gas has been a topic that has been hotly debated among several European countries. Incidents in the past such as Russia cutting off gas to Ukraine in 2006 have fueled these discussions and have led many to argue that Russia uses gas as a “political weapon”, in this instance trying to pressure Ukraine into distancing itself from the EU and NATO with which it had been establishing closer ties [Stern & Honoré, 2009; Noel, 2008].

However, others argue that the problem lies not so much within malign intentions on the Russian side but in the fact that European countries do not pursue a uniform policy towards Russia. In fact larger European markets such as the German one import the majority of gas from Russia, yet, have a more diversified portfolio of sources. Since these countries are not entirely dependent on Russia the latter cannot afford to antagonize them which so far has led companies in the German, Italian and French markets to maintain good relations with Russia. Smaller, mainly Eastern European countries, on the other hand, rely entirely on Russian gas and therefore are at the mercy of Russian policy makers. It is argued that this could be avoided if there was a single European market so that resources could be redirected between markets if necessary, yet, developments in these directions have been slow and have been blocked by larger member states like Germany in order to not jeopardize relations with Russia [Noel, 2008].

Therefore, it needs to be reviewed in how far a potential increase or decrease in gas consumption could influence the dependence on Russian gas and in how far this might change German policy choices with regard to other European countries.

Another factor which is of importance hereby is that in order to circumvent some of the aforementioned problems such as a sudden lack of supply in Germany due to cutting off power to Ukraine as well as for economic reasons the Nordstream project was started which is supposed to connect oil fields in the Barents Sea directly with

North Western Germany and was predicted to start operating in the second half of 2010 [Warning, 2009; Lochner & Bothe, 2007].

This project could then lead to Eastern and Central European countries becoming even more vulnerable since they would further lose their importance as transit countries. Indeed the following was also suggested by a study conducted by [Lochner & Bothe, 2007] at the Institute of Economics at the University of Cologne (EWI) which argues that after the termination of the Nordstream pipeline the use of many pipelines through transit countries will greatly decrease. However, Nordstream will not have the capacity to completely satisfy demand in Western countries and therefore, transit countries will not entirely lose their status in the future. More importantly for Germany, however, the model employed in the study suggests that Nordstream would lead to Germany importing more gas from Russia and less gas from other countries like Norway. This then would indeed lead to Germany becoming more dependent on Russia as an energy provider. Yet, it should be considered that hereby only economic factors and not political decisions are taken into account and therefore policy decisions might be taken which could prevent further reliance on Russian gas [Lochner & Bothe, 2007].

Most importantly hereby therefore seems to be that there seems to be a problem with the supply of Russian gas being tied to political conditions. While this has not affected countries like Germany so far this could change in the future if Germany relies too heavily on imports from Russia. Considering that the STE building simulation model predicts a decrease in total energy consumption as well as in the demand for gas this might point against Germany becoming overly dependent on Russia and might even weaken current dependency structures.

On the other hand, as was discussed, if total energy demand in Germany is considered it is unlikely that gas will become less important in the future and decreasing reserves in other European countries like the UK and the Netherlands might even increase the importance of Russian gas in the future [Lochner & Bothe, 2007; Correljé & van der Linde, 2006]. Therefore, it is highly likely that German dependence on Russian gas could increase in the future and could further be intensified through "overreliance" on the Nordstream pipeline. Consequently, conscious policy decision will need to be taken in order to avoid the latter and thereby ensure that Germany will not risk facing problems similar to those of many Eastern European countries in the future. If these measures should not be put into place and Germany would face similar supply problems as a result this might, however, lead to Germany becoming more cooperative with regard to liberalizing the gas market and consequently the supply situation for Germany as well as some of the highly dependent Eastern European countries might improve. Yet, this is highly speculative and likely to be tied to a variety of more complex underlying factors which cannot entirely be discussed here.

Overall, therefore, the direct effects of climate change which would lower demand for gas due to lower consumption improve Germany's geopolitical position. Yet, other policies, such as substituting gas for coal in electricity generation in order to reduce emissions further seem to offset these effects. In combination with a potentially rising demand in other sectors this might actually increase reliance on gas which could lead to difficulties in the relations with Russia if the latter decides to continue tying the provision of gas to political conditions.

VII Reversed Impacts on Climate Change

In this last section it shall be briefly discussed in how far the results of this study produce an adverse effect on climate change itself. With regard to the fact that 25% of total energy consumption in Germany is consumed in the residential building sector it seems fairly obvious that a reduction of energy consumption in this sector would in turn lead to a significant reduction of emitted greenhouse gases [Industrie-Initiative für effizienten Klimaschutz in Deutschland, 2008].

However, the direct effects of climate change and rising temperatures associated with it would be rather small in this regard considering that they only seem to intensify previous reductions induced by improved building efficiency measures and other socio-economic factors. So, for instance, an increase of 3℃ would only reduce consumption further by 11.7% while energy efficiency improvements and socio-economic factors already reduce consumption by 34.5% until 2050 as seen in the reference scenario.

Yet, taking into consideration that the aim is to limit the rise in global temperatures to a maximum of 2℃ the reductions achieved by the direct effects of climate change would be even smaller [Watts, 2009].

As a result, it can be seen that while climate change to a minor extent contributes itself to its own solution policy measures such as improving the energy efficiency of buildings are necessary in order to reduce energy consumption and thereby greenhouse gas emissions to a level that is substantial enough to achieve emission reduction targets and to limit the warming of global temperatures to below 2℃.

VIII Conclusion

In conclusion, it can be said that energy consumption in Germany is likely to follow a trend similar to that of other countries due to the effects of climate change. Thereby total energy consumption in residential buildings in Germany is likely to decrease in the future brought about by a variety of factors. In more detail heating energy consumption is predicted to decrease substantially whereas cooling energy demand is likely to rise, yet, the latter will not be able to offset the effects of the decrease in heating energy demand.

Moreover, the fuel mix underlying heat and cooling energy generation is also likely to change until 2050. In terms of heat generation the STE building simulation model clearly shows that the share of gas in heat generation, which has so far been the most important energy carrier for the generation of heat, will greatly decrease to almost half of its current share. Additionally, the share of fossil fuels in general will be reduced with other fossil fuels such as oil also being reduced while the share of renewable energy in heat generation will largely increase.

On the other hand, the model does not account for changes in the fuels underlying electricity generation which is the main source for cooling energy. Considering, however, that overall gas consumption is predicted to increase in the future and is also considered as a cleaner energy carrier than coal which is currently used to a great extent for the generation of electricity it is likely that gas will become more important in electricity generation and thereby, in combination with potentially rising demand from other sectors, still remain one of the most important primary energy carriers underlying the German energy economy. Furthermore, renewable energy sources are, similar to the heating sector, also likely to become more important for electricity generation in the future.

However, analyzing these results further, this study has shown that the majority thereof will be derived from the indirect impacts of climate change rather than direct changes brought about by an increase in temperatures. So it could, for instance, be seen that while rising temperatures have an influence on the total energy consumed and thereby also on heat and cooling energy as a part of the former they largely only intensify already existing trends caused by other factors. These other factors mainly seem to be constituted of predicted future socio-economic developments as well as the political framework and environmental or energy policy in Germany. Moreover, the effect of the latter seems to be much more extensive than effects caused directly by climate change. So, for example, will improved building energy efficiency measures reduce total energy consumption and heating energy consumption to a much greater extent than warming temperatures. In addition, the changes in the underlying fuel mix can be entirely assigned to legislative measures which, for instance, prescribe a feeding-in of renewable energy and therefore explain the stark increase in the share of renewables as a part of heat as well as electricity generation.

Yet, considering that these legislative measures were passed as a result of the increasingly imminent threat of climate change the effects of the former can be considered as indirectly accruing due to climate change and are therefore referred to as the indirect effects of climate change.

These indirect effects then have shown to have a much more decisive impact and can be considered as only being intensified by the direct effects of climate change. The only area in which the direct effects of climate change, meaning the effects resulting from rising temperatures, seems to be the main cause for change is the increase in the demand for cooling energy which has so far not proven to have been influenced by any other factors. However, this could be a potential topic for further research.

Within the frame of this study the impacts on several areas were outlined and evaluated thereby taking into account the direct and indirect effects of climate change and analyzing their impacts on the underlying fuel mix of the German energy economy, which was already summarized above, as well as on energy companies, energy consumers and the geopolitics of energy.

As for German energy companies it was found that they will be directly affected by climate change in that it lowers consumption further which will also influence the revenues of the latter unless prices rise high enough to offset the effects of decreased consumption. However, as was mentioned, also in this case it could be argued that the indirect effects of climate change such as improved energy efficiency measures have a more significant effect since they lower consumption by a larger extent. Moreover, energy companies will also be affected by changes in the fuel mix whereby, however, different types of companies could develop different adaptation strategies. For instance, regional and local companies are likely to face less severe problems due to the short-term nature of the contracts which found the basis for their interactions with energy suppliers. Therefore, it could be argued that it will be easier for them to adapt to the slowly unraveling consequences of climate change and make more accurate predictions about potential future demand of consumers. National companies, on the other hand, are bound to long-term contracts concluded with domestic and foreign suppliers and are therefore, more vulnerable even to long-term changes. Yet, national companies increasingly integrate gas and electricity provision and might therefore find other outlets for the contracted amounts of power.

In the case of energy companies it is then again generators which are mostly affected with generators providing renewable energy mostly benefiting while generators relying on coal-based power plants are likely to experience the biggest losses. This again is an effect of climate change induced legislation and therefore more of an indirect than a direct consequence of climate change.

In contrast, consumers are directly adversely affected meaning that most of the effects negatively influencing energy companies will be of benefit to consumers. Consequently, consumers are likely to benefit due to reduced consumption resulting from the direct and indirect effects of climate change since reduced consumption will result in lower expenditures for consumers. Yet, indirect measures such as an increased feeding-in of renewables are likely to lead to an increase of prices which might outweigh the positive effects of reduced consumption on consumers. However, the magnitude of these effects is not entirely clear and as a result it cannot be clearly determined whether consumers will experience an overall net loss or net benefit due to the effects of climate change.

Thirdly, climate change is also likely to have geopolitical effects. By lowering consumption it will thereby reduce dependence on fossil fuel imports which could affect current debates among European countries on how to handle Russia as one of the main energy suppliers, especially with regard to gas. Yet, as was also discussed, overall gas is unlikely to lose in importance due to potential changes with regard to the fuel mix underlying heat and electricity generation as well as potential increases in demand with regard to other sectors. Therefore, the indirect effects of climate change on which the switch between different fuel types is mainly based combined with increasing demand from other sectors could again have a larger effect and in combination with other factors such as decreasing reserves in other European countries like the UK and the Netherlands or an "overreliance" on the newly built Nordstream pipeline lead to an increased dependence of Germany on Russian gas.

If German dependence on Russian gas should increase it should be investigated in how far these developments would influence the bilateral relations between these two countries. Considering that Russia is often charged with tying political conditions to the provision of energy resources especially with regard to smaller Eastern European countries which entirely rely on supplies from Russia it could be investigated whether an increased dependence on Russian gas could have the same effects on Germany or whether Russia would not risk jeopardizing relations with Germany due to the size of its market as well as to maintain good relations in other fields. Moreover, it could further be looked at in how far a potentially increasing dependence on Russian gas would change Germany's attitude and political behavior towards the currently affected Eastern European states as well as towards overall developments within the European gas market. Yet, these are all issues that will not be answered within the scope of this study but might be suggestions for possible future research.

Lastly, this study also briefly investigated how the effects of climate change on energy consumption will affect climate change in return and found that the direct effects of climate change will help to reduce the emission of greenhouse gases by lowering energy consumption and thereby be of potential help in slowing climate change itself. However, the direct effects of climate change will not be sufficient to reduce climate change to a significant level and as a result supporting measures such as legislation to reduce energy consumption remains necessary.

Overall, these effects therefore do not only show that the indirect effects of climate change in most cases have much larger impacts on energy consumption and changes in the fuel mix and are only intensified by the direct effects of climate change but more importantly also illustrate that the effects of different measures sometimes have contrary effects. While the direct effects of climate change are thereby mainly complemented by an improvement in building energy efficiency since both aim at reducing total energy consumption other measures with the aim of achieving a more environmentally friendly fuel mix often have contrary effects and thereby offset the consequences of the former. However, it was not investigated within this research which of these contrary effects will prove to have a larger impact in the end and whether either of them will produce a net gain or net loss for consumers or companies. This again could be a potential topic for further research.

While this provides a detailed summary and analysis of the findings of this study the limitations of the latter should also be pointed out.

Firstly, while the model tried to take into account as many factors as possible which could potentially influence future energy consumption such as population or price developments there are other factors which cannot be clearly quantified and could therefore not be taken into consideration. One of these factors is consumer behavior which is generally difficult to predict and might be influenced by the improvements in building energy efficiency by leading consumers to actually consume more energy and thereby limiting the effects of technological improvements.

Furthermore, it is unclear in how far certain factors that the model accounted for such as improved building energy efficiency according to the EnEV standards will develop in practice since there is still much debate on in how far the standards prescribed by the EnEV regulations are actually being implemented in reality. Since the model assumes a “perfect” implementation of the standards it might thereby overstate the gains in reducing energy consumption that might be derived from the EnEV regulations as compared to the magnitude of the reductions which might take place in reality.

Another factor which should be taken into consideration is that while energy consumption in German households constitutes a significantly large share of total energy consumption in Germany it can only provide an indication but not the full picture of how energy demand and especially the demand for individual fossil fuel will develop in Germany. Due to the fact that other sectors such as industry and transport are also large-scale consumers of energy and particular types of fossil fuels an analysis for the latter would have to be added to provide a more accurate picture of potential developments regarding the entire German energy economy. While an attempt was made at including these effects no concrete figures and estimations could be provided which could be an idea for potential future research but could not be realized within the scope of this study and due to limitations of the model at hand.

Moreover, as was mentioned above, with regard to the potential future fuel mix the model did not provide exact information on changes regarding the fuel mix underlying electricity generation. Therefore, an analysis of the potential changes had to be based on other current research which, however, also does not provide concrete figures but only gives an indication regarding potential changes. As a result, it was not possible to directly compare whether the decrease in the share of gas with regard to heat generation will be outweighed by the increase in the share of gas used for electricity generation. In general, this is unlikely considering that total energy consumption in residential buildings constitutes to a much larger extent of heating consumption. Yet, overall future predictions show that the importance of gas will increase in the future and consequently the ensuing analysis was based on these predictions.

In addition, only the potential developments until 2050 were investigated within this study. However, expanding the time frame might lead to entirely different results, for instance, due to an even larger increase in future temperatures. Yet, since the possible increase in temperatures is based on current research which does not take adaptations to climate change into consideration the actual increase in temperatures might also be lower than initially expected.

Lastly, considering as we have seen that the negotiations on a follow-up treaty for the Kyoto protocol and thereby on potential greenhouse gas reduction targets and measures to reduce climate change are still in progress it is unclear in how far currently existing targets will be revised. Yet, taking into account the fact that climate change seems to be becoming an increasingly imminent threat and that the public is becoming increasingly aware of the issue it is highly likely that further legislative measures will be added or that the currently existing ones will become more stringent. However, since these developments lie in the future and any assumptions would be highly speculative only the currently existing legislation could be accounted for. Yet, if changes will occur it is likely that they will significantly affect future energy consumption in reality.

To sum up then, while this research cannot provide concrete predictions regarding future energy consumption in Germany it answered the questions aimed at within the scope of this study. Thereby it showed that residential building energy consumption will change significantly in the future due to the effects of climate change whereby the indirect effects brought about by legislative measures clearly seem to outweigh the direct effects. However, future research could take up some of the questions which have been posed throughout this study or could potentially revise some of the limitations this study has faced. Furthermore, it could also extend the scope of this study further and focus on total energy consumption in Germany thereby including further sectors such as industry or transport.

IX Referenzen

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