

IMPACT OF CLIMATE CHANGE ON THE POWER SUPPLY IN FRANCE, GERMANY, NORWAY AND POLAND: A STUDY BASED ON THE IW CLIMATE RISK INDICATOR

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Introduction

The nuclear disaster in Fukushima, Japan, was a result of the strong earthquake on 11 March 2011. It highlighted the fact that both energy production and distribution are exposed to the various impacts of the natural environment. It also showed that politicians react to this interplay of natural environment and energy supply by establishing and changing laws and regulations that strongly influence the composition of primary energy sources.

The impact of the extraction of energy raw materials and of energy conversion on the environment has been investigated intensively. In recent years a large number of publications have dealt with the impact of greenhouse gas emissions on climate change. They have also examined various options to protect the climate throughout the process of energy production – or at least ways to decrease the effects on the climate during these processes (European Commission 2011; International Energy Agency 2010; TÜV NORD 2010). Ultimately, energy production causes by far the largest emissions of carbon dioxide and other greenhouse gases. In Germany, it accounted for over 40 percent of such emissions in 2008 (Umweltbundesamt 2011a). However, the energy sector itself is also affected by progressive climate change.

This study aims to show the impact of climate change on energy supply in France, Germany, Norway and Poland as examples of different energy systems. As an aggregation of its impact, a climate risk indicator was developed. This indicator makes it possible to analyse the impact of climate changes depending on changes in the energy mix. The prediction of future developments in energy demand (De Cian *et al.* 2012) is beyond the scope of this paper.

Climate change and climate scenarios – changes that are relevant to energy supply

In general, climate change in Europe means an increase in average temperatures and a shift of precipitation from summer to winter. Extreme weather events like storms and heavy rain, as well as heat waves and droughts, which are difficult to predict, should also be more frequent. All of these events have an impact on water resources. While extreme weather events will occur more often, periods of sunshine and average wind speeds will only increase slightly. In France a decrease in summer precipitation of some 20 percent is expected, while Norway will face an increase in precipitation throughout the year. The change will be much smaller in Germany and Poland.

In order to take precautions, developments have to be analysed on a small scale. We also need to consider that, because of intensive linkages with other countries, climate change will also have repercussions on pricing and volume structure, as well as on innovation, and perhaps even on migration. In the future, government and private business will experience a growing need to adapt to climate change (Mahammadzadeh *et al.* 2013).

Climate change and its consequences are significant to the energy industry. Its influence varies by primary energy sources, secondary energy carriers and conversion technologies (Umweltbundesamt 2011b). Infrastructure is especially threatened by storms: the pressure of the wind on power lines will become stronger, and bent or damaged trees could fall on streets and tracks. Power lines are also endangered by



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snow (Makkonen and Wichura 2010), while hail is a threat to the production of biomass. A lack of cooling water in hot summers can become a problem for thermal power plants if no cooling towers exist to reduce the heat. Additionally, there are regulations (e.g. *Hydrological Projections for Floods in Norway under a Future Climate*) that define a maximum temperature for watercourses in order to guarantee good water quality (Rothstein *et al.* 2008; Rothstein and Parey 2011). Another problem is that the power transfer capability of power lines falls at high temperatures. This article explores these different types of impact and their dimensions. From these changes, we have developed a matrix, which shows the overall measures of change.

Method

Expert interviews serve as a data basis for this study. Experts on the key resources from research institutes and universities, as well as experts in power plant technology and networks were all interviewed. They were asked questions about energy production processes and the respective strength of the impact of climate change. Afterwards, the results were discussed and modified during a workshop with scientists and representatives from the energy sector. The value-added chain is differentiated into the following steps:

1. Extraction and availability of resources
2. Transportation of energy sources
3. Energy conversion
4. Transmission and distribution.

Climate change not only has negative, but also positive consequences on energy supply. That is why we differentiated between the different types of impact of climate change into risks and potential. They can partly be interpreted in terms of costs and gains. Experts' responses were classified on a scale from -5 (great risks caused by climate change) to $+5$ (great potentials caused by climate change) to facilitate comparison of them. This makes it possible to consider each individual type of impact of climate change on the energy supply separately. The following sections present the results of the expert interviews. Table 1 displays the figures of the expert ratings within a matrix. The aggregation of climate risks and potentials is determined by the weight of the energy mix. It is thereby possible to create a climate risk indicator with a range of -5 to $+5$ once again.

Interview results

Extraction and availability of resources

As far as the extraction of fossil energy sources is concerned, climate change is more of a chance than a

Table 1

Risks and potential of energy sources by stages of added value												
Scale from -5 (high risk) to $+5$ (high potential)												
Energy sources	Extraction & availability of resource			Transport			Energy conversion			Transmission & distribution		
	Risk	Potential	Balance	Risk	Potential	Balance	Risk	Potential	Balance	Risk	Potential	Balance
<i>Fossil fuels</i>												
Oil	-1	2	1	-2	0	-2	-2	0	-2	-2	0	-2
Natural gas	-1	2	1	-1	0	-1	-3	0	-3	-2	0	-2
Hard coal	-1	0	-1	-2	0	-2	-2	0	-2	-2	0	-2
Lignite	-1	0	-1	0	0	0	-1	0	-1	-2	0	-2
<i>Nuclear energy sources</i>												
Nuclear energy	0	0	0	0	0	0	-2	0	-2	-2	0	-2
<i>Renewable energy sources</i>												
Solar energy	0	0	0	0	0	0	-1	0	-1	-2	0	-2
Biomass	-3	0	-3	-1	0	-1	0	0	0	-2	0	-2
Water power	0	0	0	0	0	0	-2	0	-2	-2	0	-2
Wind power	0	0	0	0	0	0	-2	1	-1	-2	0	-2
Geothermal energy	0	0	0	0	0	0	0	0	0	-2	0	-2
Average	-0.7	0.4	-0.3	-0.6	0.0	-0.6	-1.5	0.1	-1.4	-2.0	0.0	-2.0

Source: Cologne Institute for Economic Research.

threat. The *onshore* production of oil and natural gas is hardly affected by climate change. Several sources that could be used *offshore* when the pack ice melts, on the other hand, have been inaccessible to date. Offshore platforms, on the other hand, will have to be lifted when the sea level rises. All in all, the risks of climate change related to the extraction of oil and natural gas are low, according to the experts.

There is another energy source that may play a more important role in the future: methane in a hydrate form that lies on the sea floor. Experts do not expect any complications with the extraction of methane hydrate caused by climate change. Instead, bigger deposits will be accessible because of the reduction of ice – as in the case of oil and natural gas. The targeted extraction of methane hydrate also makes it possible to stop the release of methane hydrate deposits due to the warming of the sea bed. Therefore, by extracting methane hydrate, it is possible to counteract the speed of climate change. Since the material handling systems are similar to the systems used to extract oil and natural gas, no essential problems caused by climate change are expected.

Generally, yields of oil, natural gas and methane hydrate will only decrease a little because of climate change. The given infrastructure is sufficient to compensate bottlenecks.

The extraction of hard coal will not be affected by climate change – positively or negatively. However, since imports are very important for this sector, it is necessary to think about climate change's potential impact on world production. For example, the global market price for coal increased at the beginning of 2011 after the disastrous flood in Australia that flooded several big coal mines. The extraction of coal is not affected negatively by climate change in Europe, but it is the case in other regions of the world.

According to experts, there may be a stronger dust formation when extracting lignite at an open pit mine during periods of drought. In order not to endanger the health of the area's residents, the lignite has to be moistened. Generally speaking, however, longer periods of drought are positive for the production of energy from lignite because it burns easier when it is dry. Heavy rain that can cause landslides at open pit mines is also expected. However, short-term restrictions do not lead to bottlenecks due to sufficient stocks.

Extraction of uranium for the use of nuclear energy also takes place in open pit mines. Experts classify the impact of climate change on the extraction of uranium and its possible bottlenecks as very low. Even in the past, there have been no serious disturbances in the production of the resources.

Biomass is another energy source. The larger part is extracted from plants like corn, the smaller part from waste products such as liquid manure and straw. In view of competition from food cultivation and other uses, the vegetable part is very likely to decrease in the future. There may be bottlenecks in the production of biomass, but they are more likely to be due to fluctuation in prices in the global markets than to the consequences of climate change. For this reason, smaller power plants had to be shut down for a short time in the past. The use of these resources is affected by climate change as reflected in changing precipitation patterns and extreme weather events. But if these resources are stored in the right way, it is possible to prepare for production losses.

Transportation of energy sources

Climate change can heavily impact the transportation of energy sources when they are shipped by sea. Such energy sources include oil, natural gas and methane hydrate, and also (because of high imports) hard coal and biomass. Costs are likely to increase because of the interruption to business caused by the growing number of storms and their increasing intensity. The same is applicable to transport on rivers: in periods of drought their navigability is limited due to low water levels. The impact of climate change on transportation is negative, but does not carry too much weight.

Energy conversion

Taking a closer look at the influences of climate change on energy production, it is important to realize that it is not the resources used that are relevant for the study, but the type of power plant. According to the experts, climate change has the biggest impact on steam power plants, which are used to generate power from oil, natural gas, methane hydrate, hard coal and nuclear energy. Sinking river water and groundwater levels, as well as the rising temperatures of watercourses, restrict the availability of cooling water during heat waves. During these times power plants often have to reduce their output or shut down in order to protect the environment. That is why in the future

stronger seasonal variation in the energy production from affected power plants is expected. The risks still remain in a medium range, because most of the time only certain power plants are affected by these extreme conditions. That is why there is no threat to the power supply as a whole. Moreover, most of the newer power plants do have cooling towers, which makes them less vulnerable to climate change anyway.

The problem with the cooling water rarely applies to lignite fuelled power stations, because most of them are not cooled by water from a river anyway. Instead, they use drained water from the open pit mine for cooling. Should outdoor temperatures be high, efficiency might be reduced. The loss of efficiency is not very high, but still economically noticeable.

Increased outdoor temperatures play a role when it comes to power generation from natural gas. The higher the outdoor temperature, the lower the possible efficiency of common power plants using cycle gas turbines. That is why the power generation by gas power plants is more influenced by climate change than other types of power plants. Yet one advantage of gas power plants is that it can bridge short-term bottlenecks in the energy supply. But energy production from fossil fuels is not the only form of energy production to be affected by climate change: the latter will also have an impact on renewable energies.

Solar energy is the renewable energy with the biggest variations in yields. Solar thermal plants are highly dependent on the sunshine, while photovoltaic systems can still supply energy when the sky is cloudy. Due to climate change, the output of these plants in Europe is expected to be low in the winter months and high during the summer months. It is possible for the use of solar energy to react to shifts in demand caused by climate change: less heat demand in the winter and more demand for cooling in the summer. Moreover, there are fluctuations of 15 percent in the use of solar energy due to fairly unstable weather conditions. However, long term fluctuations of the same scale caused by astronomical effects, like changes in the sun, are of prime importance because there are no other plants that can compensate for them. An important factor in the yields from solar energy is global radiation. This includes direct solar radiation, as well as radiation components like scattering, which strike the earth and are caused by clouds. Despite local differences, global radiation in general will not change because of climate change. Variations in temperature are

not very likely to have major implications for plants either. Technically, the potential of solar energy is well-known and will not be considerably altered by climate change. Plants nevertheless remain slightly vulnerable due to extreme weather events like storms and hail.

Wind power stations are directly affected by climate change. To date some plants have had to be switched off in storms so as not to endanger their functionality. These problems only occur for two or three hours a year, which is economically irrelevant. Nowadays engineers are working on techniques that make it possible to let the systems run on a lower capacity during a storm. The impact of climate change on the energy supply from wind power stations is generally limited.

Biofuel plants are also only slightly affected by higher outdoor temperatures. The same types of bio fuel plants are operated in different climate zones. Bio gas plants are more sensitive to storms than others, but even this susceptibility is low and can be neglected. There are only problems with cooling water in very complex systems, because others do not need much of it. That is the reason why the risks cannot be compared to the cooling water requirements of other steam power plants.

In the case of low water levels, river power plants are estimated to render only roughly half of their usual service. However, since annual fluctuations are common, changing water levels are already taken into account and can therefore be compensated for throughout the year. Moreover, there is always a basic amount of water *via* the supply of cleaned water from the sewage plant. There are also potential ways of bridging bottlenecks, especially through pumped-storage power plants. The drawbacks in this case are that pumped-storage power plants mean high initial investments and storage power plants produce less electricity during heat waves than usual. In general, however, the impact of climate change on the energy supply from water power is low.

The use of geothermal energy as an energy resource is quite climate robust. In our latitudes, we do not expect any noticeable impact on power plants due to climate change. There may be fluctuations in the energy production from geothermal energy in certain regions where less precipitation is expected. In Kenya, for example, deep droughts may cause problems in energy production.

Transmission and distribution

The distribution of electricity from energy conversion to the end consumer is one part of the process that is very susceptible to weather, and therefore to climate, change. Ice, hail, snow and storms may either affect conductivity, or power lines and masts might be damaged. However, the costs of the alternative, namely laying underground cable, are supposed to be even higher than the losses caused by these weather events. Changing the nationwide power supply system is therefore a disputable option.

In the future, electrical distribution will be increasingly exposed to the climate due to the growing amount of renewable resources. Wind power and the integration of the European power market in particular will mean that power has to be transported over long distances. All over Europe supply and demand for power from renewable resources can be compensated for. Another example is Germany, where energy needs to be transported from offshore wind power plants in the North Sea to industrial plants in the south.

In general, even these risks are low to moderate because the infrastructure of the power lines is designed for wind and snow. Weak points can be eliminated when renewing the power lines. Complete safety in extreme weather, however, cannot be guaranteed.

Climate risks in the energy/electricity mix

For the power supply, it is important that the whole production chain is considered for each energy source (Wachsmuth *et al.* 2012). This includes the availability of raw materials, as well as the availability of the energy source, transports, the actual electricity production in energy conversion, and the transportation of the electricity through the networks.

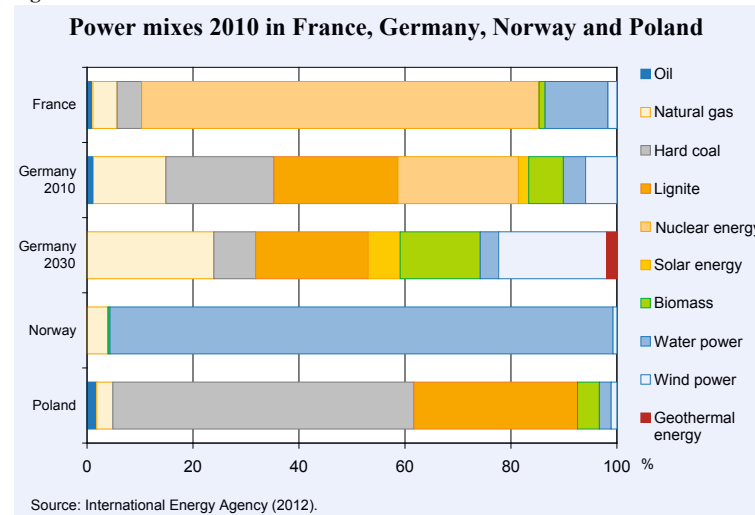
For all energy sources the sum of the risks and potentials – each weighted equally – is negative. It is least negative for water power (followed by biomass and nuclear energy) and most negative for hard coal. No strategy is able to reduce the risks to zero, and most

countries are not able to base their energy system purely on water. On the other hand, in many countries it is possible to use more than one energy source, which also means not relying solely on hard coal. Additionally, there are country-specific risks and potentials. For example, power plants at the coast are not exposed to the risk of a lack of cooling water, but are exposed to rises in sea-level.

The impact of climate change on the energy supply can only be judged summarily after a double aggregation. On the one hand, we need to summarize all the risks and opportunities related to each relevant stage of the value-added chain for each energy source. The result is a risk profile for each energy source. On the other hand, it is necessary to summarize the risks of the different energy sources according to their weight in the respective energy mix. For Germany, it is also possible to derive whether the expected changes in the energy mix in the decades ahead will lead to an energy supply with bigger or smaller climate change risks. That is to say, whether the German energy turnaround (*Energiewende*) also constitutes an adaptation to physical climate risks, or whether it tends to strengthen these risks.

Figure 1 shows the different types of electricity mixes in France, Germany (before and after the turnaround in 2030), Norway, and Poland. Norway has the least diverse primary energy mix, while Germany's energy mix is the most diverse both today and in 20 years. In contrast to France, favourable natural circumstances in Norway allow the usage of an energy source without risks at the stage of energy conversion.

Figure 1



France

The French power mix relies heavily on nuclear power: three quarters of electricity in France is generated in nuclear power plants. Water power is used to produce about 11 percent of the electricity, and hard coal and natural gas each have a share of nearly 5 percent. As nuclear power plants are concentrated at sites on just a few rivers, especially the Rhône, we alter the value – 2 to – 3 for the energy conversion for this type of power plants. This strong bias towards nuclear power leads to a medium vulnerability of the French power generation system, as in hot, dry summers, cooling water is restricted physically and by law. It is responsible for about 75 percent of the climate change related risks to power supply in France. Nearly all of the other energy sources in use are based on water as well. The climate risk indicator (the sum of the risks) is – 1.24. This shows that the size of the risks is moderate, but considerably different from zero.

Germany

Germany is an example of a country that uses a broad energy mix, currently based on lignite, hard coal and nuclear power. The so-called energy turnaround – meaning the restructuring of the power generation and shift towards renewable and low carbon energy

Figure 2

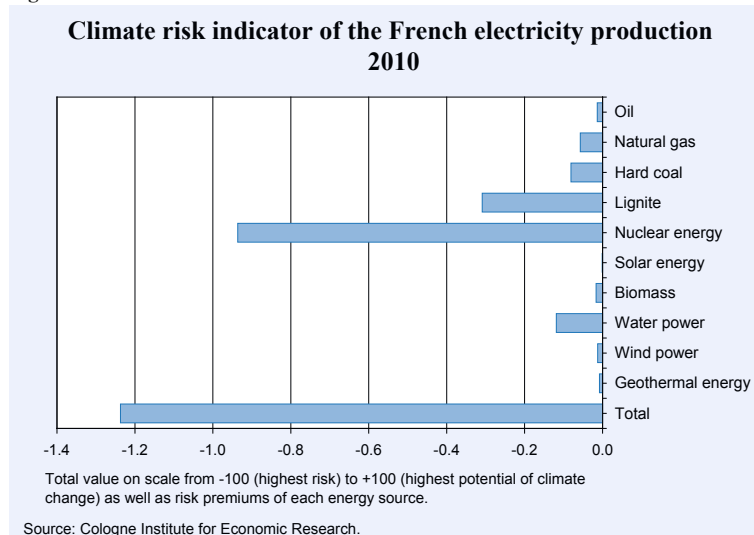
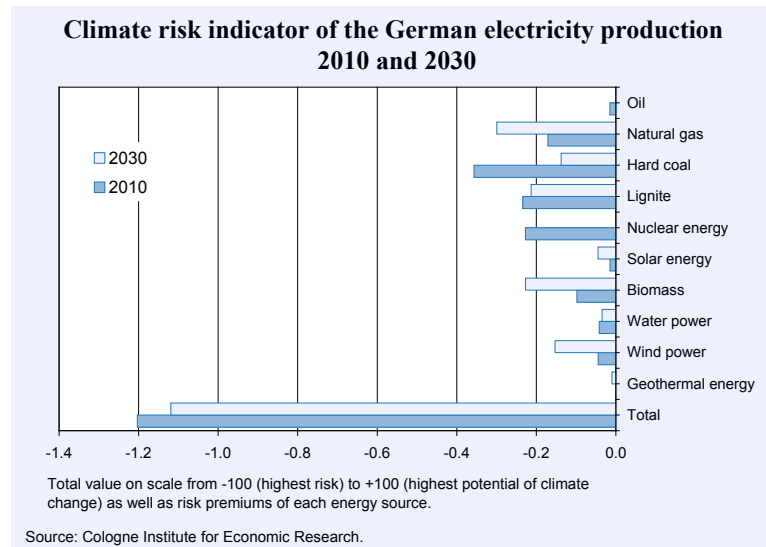


Figure 3



sources by the middle of the century – is a big challenge to the power supply, as well as to the whole energy infrastructure and demand patterns. The power mix will change a lot in the next 20 years (Figure 2). With nuclear power, one of today’s strongest pillars of power supply will disappear. The proportion of fossil fuels such as natural gas, hard coal and lignite will remain constant at about 60 percent as predicted by the Federal government (ewi, gws and prognos 2011). Renewable energy sources, especially biomass and wind, will continue to increase. Solar energy and geothermal energy will only increase on a low level.

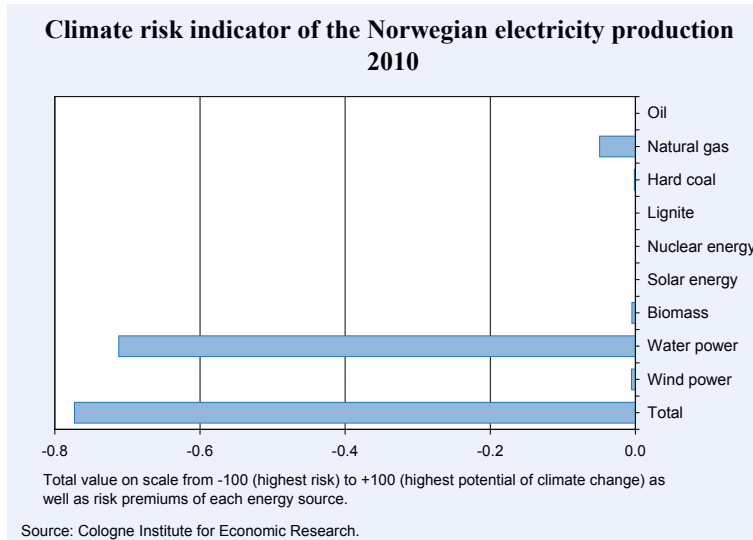
Figure 3 shows the results of the climate risk indicator for the power supply in Germany at today’s energy mix and at a possible energy mix of the energy turnaround for 2030. In total, the risks caused by climate change

will add up to a total value of – 1.20, if the composition of the power generation does not change.

Within this low risk level, the highest risks are related to the power generation of hard coal, nuclear energy and lignite. Natural gas only represents a small risk, as biomass also does. All the other energy sources virtually do not play a role with regard to the overall risk of climate change.

A changed energy mix will not lead to any noticeable change in overall climate risk. The value of

Figure 4



er the value -1 for Norway. As a result, the risks of water power in Norway will not increase significantly due to climate change. There is only a very slight total increase of -0.77 . As shown in Figure 4, this slight increase mainly takes place in the area of water power and only to a small degree in the area of natural gas.

Poland

Nearly 90 percent of the power generation in Poland is derived from coal – hard coal and lignite. These energy carriers depend on cooling water. Poland used to be one of the traditional coal producers in Europe, which made it one of the key suppliers of the global coal market. It benefits from rising world prices (Ritschel and Schiffer 2007). As Poland uses its own coal, the hard coal related risks are also quite small. The country specific value for extraction and transport are coded as zero. As a result, the climate risk indicator is -1.03 . A shift towards renewable energy to protect the climate would therefore result in hardly any further reduction in risks.

the climate risk indicator should only decrease slightly to -1.12 points. The energy turnaround will neither change the climate risks of power generation nor reduce risks by 2030. The structure of risks, however, will change. By phasing out nuclear energy, former climate risks will be replaced by new risks arising particularly from wind power, biomass and natural gas. Biomass is – among the renewable energies – most affected by the risks of a changing climate. But the changes to the risk structure remain at levels that do not endanger the power supply because of physical climate risks.

Norway

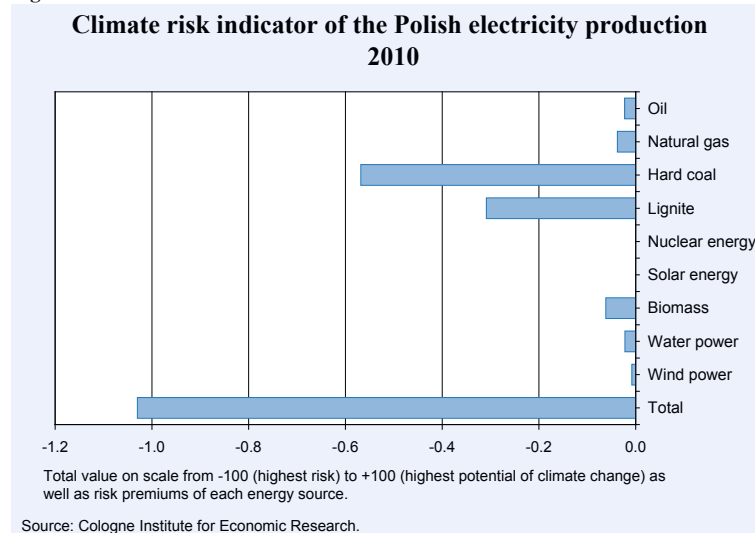
Norway’s power generation system is quite different to that of France and Germany. Its main base is water power, which accounts for 95 percent of the total electricity production. As precipitation in Norway will rise in both summer and winter, the risk at the stage of energy conversion should be considered to a lesser extent than in the average case (Table 1). In parts of Norway, the probability of floods that might endanger power generation will rise, while it will diminish in other areas (Lawrence and Hisdal 2011). Floods are predicted to increase – among other areas – on the east coast, which is mostly relevant to water power generation. Instead of the normal value of -2 , we consid-

er the value -1 for Norway. As a result, the risks of water power in Norway will not increase significantly due to climate change. There is only a very slight total increase of -0.77 . As shown in Figure 4, this slight increase mainly takes place in the area of water power and only to a small degree in the area of natural gas.

Climate change versus other factors influencing energy supply

Climate change is only one of many factors that influence the energy supply. One important question is

Figure 5



whether the energy supply in global markets can match rising demand for energy? This is indicated by rising prices, which lead to an expansion of the energy supply *via* developing new stocks of raw materials and using more expensive mining and generation technologies. The climate, structural and demographic changes in Western and Northern Europe point in the opposite direction, namely towards a further fall in energy demand. This is particularly applicable to thermal energy and less to electricity.

The energy supply is also strongly influenced by regulations on climate protection (Stecker *et al.* 2011). Adaptations to climate change in the energy sector should not further stimulate energy supply, but climate regulations should not make it more sensitive to climate change either.

The purpose of the energy supply is to meet users' energy demands in the required form and in the suitable combination of time and quantity. It is a special challenge to guarantee complete coverage demand for electrical energy. In a power industry based on fossil fuels and discounting the impact of climate change, it is already necessary to complement the base load by providing power plants with variable power plants in order to cover peaks in demand. In view of the increasing use of renewable energies, it is important to consider whether they are able to cover the supply needs and are suitable for filling accruing gaps.

The growing proportion of electricity production accounted for by renewable energies magnifies the need for mechanisms that balance supply and demand, such as demand management, the use of backup power plants and the expansion of network or energy storage. The balance in the European power network is currently more important than the balance over demand-side reactions or the use of storage. Efforts to achieve the functional integrity of the energy supply have to be redoubled. This leads to cost burdens. The core elements of future strategies should be research and development in this area, as well as an economically justified selection of options.

Conclusions

Climate change has many different types of physical impact. It can lead to weather events that have a negative impact on energy supply. At the same time, it is important to note that these negative effects are main-

ly no new phenomena, but known risks that will merely occur more frequently. This applies to all possible bottlenecks in the provision of cooling water for thermal power plants or the danger of wind throw for power lines. There are additional risks for the supply of biomass arising from deteriorated growth conditions caused by extreme weather events. At the same time, it is possible to gain access to new deposits of fossil fuels thanks to the global melting of ice layers.

On the whole, climate change has a negative impact on the power supply: the risks clearly outweigh the potential. The risks can still be seen as moderate and the climate risk indicator remains within the very moderate range. While for France risks are clustered, for Norway, Germany and Poland no dangers to the energy supply are expected as a result of climate change, which cannot be addressed.

Changes in the climate will be noticeable in several decades. Over the same period of time the energy supply in Germany will shift to a renewable energy based supply. There is a change in situation caused by the shift: certain risks will gain importance, especially with the availability of biomass. The German energy turnaround can generally be seen as neutral in terms of climate risks. It does not increase the climate exposure of the energy system, but cannot be interpreted as an independent adaptation to climate change. Even with the energy turnaround and possibly decreasing energy consumption, it is still necessary to sustain an efficient and securely operating energy and power supply system.

Climate risks are more or less related to the energy source in question. This depends on the accumulation of risks through the value chain, which is highest for fossil energy, clustered risks and the climate risks specific to a country or a region. As far as transportation is concerned, climate related risks are very small if, as in Poland, local energy sources are available. Clustered risks remain a challenge in France and, to a small degree, in Norway. Heterogeneity in the power supply, compensation *via* energy storage and/or interregional transmission and, finally, increasing demand management options help to guarantee power supply where it is needed most.

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