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Abstract

The option of adapting to climate change is becoming more important in climate change policy. Hence, responding to climate change now involves both mitigation to address the cause and adaptation as a response to already ongoing or expected changes. These changes are also of relevance for the energy sector in Germany. An energy sector that in the course of the German "Energiewende", also has to deal with a fundamental shift in energy supply from fossil fuel to renewable energies in the next decades. Based on a synthesis of the current knowledge regarding the possible influences of climate change on the German energy sector along its value-added chain, the paper points out, that the possible impacts of a changing climate should be taken into account in the upcoming infrastructure projects in the course of the Energiewende. The main question here is, whether adaptation options will be implemented voluntarily by companies or not. The paper argues that this has to be the case, when the measure is a private good. If, on the contrary, the measure is a public good, additional incentives are needed. For the German energy sector, the paper shows, that governmental intervention are for example justifiable regarding measures to adapt the grid infrastructure as a critical infrastructure that needs to be protected against current and future impacts of climate change.

Keywords: adaptation, climate change, critical infrastructures, environmental policy instruments, energy sector, energy transition, market failures, mitigation, private goods, public goods.

JEL-Classification: A11, H20, H41, L94, Q40, Q48, Q54, Q58.

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1. Introduction

The option of adapting to climate change is becoming more important in climate change policy. Hence, responding to climate change now involves both mitigation to address the cause and adaptation as a response to already ongoing changes (IPCC 2014). These changes are also expected to have relevance for the current and future energy sector in Germany.

When talking about climate change impacts and the energy sector, it is important to have in mind, that Germany has to deal with a fundamental shift in energy supply – the so called "Energiewende".[2] The current energy system – mostly still based on nuclear power, coal, oil, and gas – will be replaced by an energy supply based on renewable energies. This issue of energy supply has been a controversial political issue in Germany for a long time – in its beginnings even back to the 1970s (Leidreiter et al. 2013). In particular, the use of nuclear energy has been the subject of intense controversy for decades. But since the 2011 policy decisions in the wake of massive public outcry after Fukushima, both the phase-out of nuclear energy by 2022 and specific targets for renewable energy development in the electricity sector are fixed by law (Leidreiter et al. 2013). The Energiewende's main targets in the power sector are an electricity supply that will consist of at least a share of 80% of renewable energies by 2050. Intermediate targets are a share of at least 35% by 2020, at least 50% by 2030, and at least 65% by 2040. Furthermore the primary energy consumption should – compared to 2008 – be reduced by 20% until 2020 and by 50% until 2050. Additionally supporting this renewable energy commitment are the "Integrated Energy and Climate Programme" (German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety 2007) as well as ambitious greenhouse gas reduction targets of 40% until 2020 and 80-95% until 2050 compared to 1990.

The Energiewende in the power sector is mainly a result of the expansion of wind and solar energy production, making it the second largest source of electricity in 2012 (23.6% share in gross electricity

[2] A very good overlook on the Energiewende is prepared by "Agora Energiewende", a German think tank and policy laboratory that focuses on dialogue with energy policymakers regarding the energy transition in Germany: http://www.agora-energiewende.org/topics/the-energiewende/

consumption).[3] Their share of renewable electricity production in 2020 will be around 70%, and after that rise to 80 to 90%. This development will fundamentally change Germany's power system and the electricity market, because wind power and photovoltaic are fundamentally different from conventional energy sources. Their production of electricity depends on the weather and is changing during the day, whereby they have relatively high investment costs, but almost no operating costs (German Federal Ministry for Economic Affairs and Energy 2014).

Thereby it needs to be considered that the energy sector is one critical infrastructure in the European Union that needs to be protected (EC 2008). Critical infrastructures can be defined as "organisations or facilities of special importance for the country and its people where failure or functional impairment would lead to severe supply bottlenecks, significant disturbance of public order or other dramatic consequences." (German Federal Office of Civil Protection and Disaster Assistance 2014). Energy supply is a central area of critical infrastructures which, in case of breakdown or disruption, can also have an immediate and high impact on other sectors and the whole society. Therefore also the German Federal Office of Civil Protection and Disaster Assistance – responsible for critical infrastructure protection – points out that, in the event of a serious nation-wide longer interruption of the energy supply, appropriate prevention and reaction strategies should be available in order to keep consequences to a minimum and to reduce the society's vulnerability. In addition, existing weaknesses and vulnerabilities should be identified and analysed with respect to the resulting risk. In this context, appropriate and universal safety requirements should be developed accompanied by the suggestion of concrete policies for the reduction of existing vulnerabilities. Thereby also in Germany the focus currently still is on dangers of terrorist attacks (German Federal Ministry of the Interior 2006), but other dangers like natural disasters are already briefly mentioned.

Regarding the adaptation to climate change, the main question is, whether adaptation options will be implemented voluntarily by companies or not. This will be the case, when the measure is considered a

[3] All of the other renewable-energy technologies in Germany are either more expensive or have only limited potential for expansion.

private good and is economically beneficial (i.e. benefits outweigh costs). If, on the contrary, the measure is considered a public good, additional incentives are needed. Additional incentives could either be legal obligations or other governmental interventions like subsidies, taxes etc.

The paper discusses the need for government interventions and legal obligations regarding adaptation strategies within the framework of the German "Energiewende". It is structured as follows. In the second section, current knowledge of possible vulnerabilities of the energy sector is briefly described along its value-added chain. In the third section the concepts of mitigation and adaptation are introduced and it is argued when, and under which conditions, adaptation measures are taken voluntarily, and when additional regulations and incentives are both needed as well as justified from an economic point of view. The fourth section discusses whether actors in the energy sector should be confronted with government interventions regarding their efforts to adapt to climate change, whereby some possible examples will be briefly outlined. Section five concludes.

2. Vulnerabilities of the energy sector in Germany

According to current projections the major trends of several different climate models show an increase in annual mean temperatures by 1.0 to 2.0 °C for the 30 year period from 2021 until 2050 and 2.2 to up to 4.0 °C for the period from 2071 until 2100 in Germany. It is expected to be wetter during winter and drier during summer, while the annual mean precipitation remains almost constant. Increases of extreme weather events like storms, heat waves, droughts, lightning and heavy rains are to be expected in occurrence and intensity (Jacob et al. 2013). These climatic changes will have several impacts on energy infrastructures, i.e. power plants, distribution facilities like grids and pipelines, and extraction facilities like offshore platforms or opencast pits (Cortekar and Groth 2013).

The first part of the value-added chain – extraction and transport of primary energy sources to the power plants – is only slightly affected by climate change. Occurring phenomena like low (or high) water levels on rivers might hamper resource transports to power plants via ship but power plants are usually holding reserves and, in addition, resources can be transported on roads or railways. The energy sector will most likely be affected on the second and third part of the value-added chain, in particular power generation in thermal power plants and almost all parts of distribution facilities like overhead transmission lines, utility poles, and power transformers (Cortekar and Groth 2013).

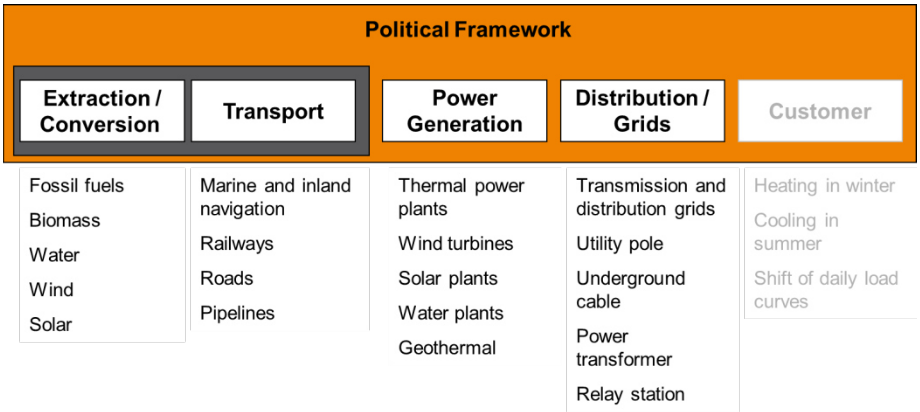

Figure 1: Energy sector – value-added chain (Cortekar and Groth 2013).

Thermal power plants will particularly be affected by the ambient air temperature of a power plant as well as the availability and temperature of cooling water (Altvater et al. 2012). The ambient air temperature negatively influences the degree of efficiency of thermal power plants in general. This effect, however, appears highest considering gas-fired power plants. Even though, efficiency losses are low, they are economically perceptible. Besides efficiency losses due to high ambient temperatures, thermal power plants are prone to the availability and temperature of cooling water which is mostly taken from rivers. Lignite-fired power plants are an exception since the cooling water in their cases is mostly groundwater taken from the usually nearby opencast pits which makes them independent from fluvial water. Hard-coal fired plants, gas-fired plants and nuclear power plants in contrast usually take their cooling water from rivers. These kinds of power plants are affected in two ways during heat waves: firstly, water availability decreases in general and secondly water temperature increases. This is problematic since the discharged cooling water is not allowed to exceed a specific temperature. The combination of these two effects can result in curbing power plants. Even though modern thermal power plants are usually equipped with own cooling facilities like cooling towers, most of the older power plants are not (Cortekar and Groth 2013).

The third part of the value-added chain is consistently attributed the highest vulnerability. Direct physical impacts and damages to the transmission and distribution grids, utility poles, power transformers, and relay stations are expected, due to more intense extreme weather events like storms, floods or thunderstorms. Furthermore fundaments of utility poles can be eroded and relay stations or power transformers can be flooded, which might cause short circuits etc. Besides these impacts causing damage to the physical infrastructure, there might also occur efficiency losses in electricity transmission due to very high or very low temperatures. While vulnerabilities in power generation primarily result in efficiency losses, interferences on the grid level could cause power outages with cascade effects influencing other sectors of society and economy (Cortekar and Groth 2013). At best these outages are limited to a small region and a short time. But at worst they can affect very large regions and last for several days, like in 2003 in Canada and the United States. Even though the outage was not caused by climate change in this case, it shows the vital energy sector importance as a critical infrastructure. What happened? On August 14 2003 large portions of the Midwest and Northeast United States and Ontario, Canada, experienced an electric power blackout. The outage affected an area with an estimated 50 million people and 61,800 megawatts (MW) of electric load in the states of Ohio, Michigan, Pennsylvania, New York, Vermont, Massachusetts, Connecticut, New Jersey and the Canadian province of Ontario. The blackout began a few minutes after 4:00 pm, and power was not restored for 4 days in some parts of the United States. Parts of Ontario suffered rolling blackouts for more than a week before full power was restored. Estimates of total costs in the United States range between $4 billion and $10 billion (U.S. dollars). In Canada, gross domestic product was down 0.7% in August, there was a net loss of 18.9 million work hours, and manufacturing shipments in Ontario were down $2.3 billion (Canadian dollars) (U.S.-Canada Power System Outage Task Force 2004).

3. Economics aspects of adapting to climate change

There are two important questions under the prevailing circumstances: how can facilities be adapted to climate change impacts, and will measures be taken voluntarily or are additional incentives necessary and justifiable? From an economic point of view, markets are considered a superior coordination instrument, also recognizing uncertainties and changing conditions. Under specific conditions, however, the market fails to do so; forms of market failure are for instance public goods, externalities, institutional or behavioral barriers and regulatory barriers (Heuson et al. 2012).[4] If one or more of these economic reasons occur, the market is not able to provide the right information for individual decision-making and, in our case, could result in non- or maladaptation.

In politics, adaptation is often seen as opposite to climate protection (aka “mitigation”). Mitigation aims to implement policies that stabilize the concentration of greenhouse gas in the atmosphere by reducing their emissions and enhancing greenhouse gas sinks (IPCC 2007a). There are two major differences between adaptation and mitigation in terms of their spatial and time scales. While adaptation actions are taken on a local and regional level to prevent something that will probably happen in the future, mitigation efforts have to be taken on a global scale to reduce emissions today. This, from an economic point of view, has an important implication: While mitigation is a public good – measures will be implemented by one economic actor or a group of actors (e.g. the whole energy sector) which have to carry all costs, while the effects benefit the society as a whole on a global scale – adaptation mostly is a private good. This will be made clear referring to what is stated in chapter two, i.e. power generation and grids.

There are different measures available to adapt power generation facilities to the cooling water issues and make them independent from the availability and temperature of fluvial waters. New power plants can be planned and built with different cooling technologies; older and still operating plants can be retrofitted. These measures are considered private goods because the power plant operator has to carry

[4] For a more detailed analysis of the different types of market failures in the context of adaptation see Heuson et al 2012, chap. 4.

the costs but also all benefits (i.e. reduced efficiency losses) resulting from these measures will occur to him. Thus, it is in his interest to keep the efficiency losses as low as possible. The decision to be made is limited to the question, whether the benefits outweigh the costs or not. While numerous studies are available in which costs for power outages are approximated (not necessarily related to climate change impacts), only one study has been conducted for Germany so far, in which costs and benefits had been taken into account. Calculations suggest that overall cost for additional cooling systems in Germany are expected to be between €4 and €8 million annually while benefits are expected to be €10 to €20 million resulting in a cost-benefit-ratio of about 2.5 (Tröltzsch et al. 2012).

In comparison to power generation, the different measures available to adapt grids to climate change are usually (national[5]) public goods (Cimato and Mullan 2010). While costs incur by grid operators, the measures are beneficial to customers, i.e. private households, business companies etc. since they do not have to suffer climate change related power outages. According to economic theory supply with public goods is suboptimal because private companies – i.e. grid operators – have no possibility to re-finance all adaptation investments since no customer can be excluded and thus will not make specific monetary contributions to the provision. Consequently, no adaptation measure will be implemented privately leading to a suboptimal level of autonomous adaptation. Additionally, costs for adapting existing grids (without building new power lines) in Germany are calculated to be around €1 billion annually while benefits are calculated between €10 to €200 million, leading to a cost-benefit-ratio of about 0.01 to 0.2 (Tröltzsch et al. 2012). Thereby adapting energy infrastructure to climate change needs to be considered in different ways. When it comes to building up new infrastructure, its resilience can be ensured by locating, designing and operating an asset with the current and future climate in mind. This is particularly important in the case of large infrastructure with a long lifespan and investment decisions also influencing future generations. Existing infrastructure can be made more climate-resilient by retrofitting and/or ensuring that maintenance regimes incorporate resilience to the impacts of climate change over an asset's lifetime. Possibly adaptation options or strategies are

[5] Cimato and Mullan (2010) differentiate between global, national and local public goods.

for example the strengthening of overland lines to make them better able to withstand extreme weather events or to speed up investment in underground cables to replace overhead transmission lines (EC 2013).

While talking about cost-benefit-assessments of adaptation measures, it becomes clear that economic science plays a key role in providing policy makers with data on the costs and benefits of adaptation measures in order to create a sound decision-making basis for efficiently using scarce budgets. However, so far, the bulk of cost and benefit assessments pursues a top-down-approach. That is, the required data is generated by downscaling cost and benefit estimations of global impact assessment models to a specific region. However, this procedure is often criticized for being inappropriate and vague, since it does not account for the heterogeneous and highly context-dependent character of adaptation measures and adaptation costs and benefits. In this regard, bottom-up assessments seem to be a promising alternative, as they address the specific local or regional problem-setting in which the adaptation takes place. Since the bottom-up approach is in a rather early stage and thus faces various methodological problems, there is a strong need for synthesizing and advancing the respective research efforts, or even more, for developing a proper research strategy (Heuson et al. 2012).

For this reason, the Climate Service Center, the Helmholtz Center for Environmental Research (UFZ) and the Federal Environment Agency of Germany (UBA) initiated two workshops in Germany on the economics of climate change adaptation. These workshops brought together participants from science, policy and other stakeholders. By comparing and analyzing the case-studies, three major overarching methodological challenges could be identified. First of all, there is no comprehensive concept for evaluating and quantifying the economic vulnerability of specific regions or sectors, which is however a prerequisite for identifying, assessing and prioritizing adaptation measures. Existing approaches either try to estimate the vulnerability on the basis of qualitative plausibility checks or refer to the economic importance of the sectors (in terms of their contribution to the GDP) and their dependence on water and energy inputs, because those usually are especially affected by changing climatic conditions. While the first approach fails to produce reliable numbers, the second tends to neglect highly vulnerable sectors, such as the insurance industry. Thus, there is a strong need for advancing research in this field. Another very fundamental challenge comes up with the question how to exactly define adaptation measures and how to isolate them from other (policy) measures, e.g. in terms of infrastructure or nature conservation. Knowing the precise adaptation part of any measure is of vital importance for optimally allocating resources across the various political fields of actions. Finally, the analysis has underlined the limits of the cost-benefit-analysis, stemming from information problems and methodological shortcomings in evaluating the costs and benefits of non-market goods, such as health or biodiversity. Nevertheless, the cost-benefit criterion will still play an important role in providing guidance for the ranking and prioritization of adaptation measures. But it has to be combined with other criteria, e.g. in terms of specific policy goals or robustness and flexibility, in order to create a sound basis of decision-making.[6]

To sum up, according to the current state of knowledge and based on general economic arguments, adaptation measures will most probably be implemented voluntarily by power plant operators, measures to adapt grids will not. Governmental interventions in this case are justifiable. The question to be asked is what instruments and government intervention are available?

There are several systematisations for instruments and governmental interventions in the field of climate. OECD (2008) for example categorize according to purpose or intention of the intervention. Cimato and Mullan (2010) differentiate by types of interventions; others do so by the underlying climate change impact and others by sector (IPCC 2007b). Anyway, the catalogue of (economic) instruments and governmental interventions itself is as long as the approaches to systematize them and includes market-based instruments like subsidies, taxes, licenses, or more recent ones like the payments for ecosystem services approach, financial instruments like loan guarantees, public private

[6] The workshop documentation and all presentations (in German) are provided online: http://www.climate-service-center.de/033252/index_0033252.html.de

partnerships (especially for large infrastructure projects), and risk financing instruments. Besides these economic approaches, legal obligations and other regulations could be used to foster adapting grids to possible climate change impacts.

4. Government interventions and legal obligations to foster the adaptation to climate change

4.1 The political framework

Currently, various countries have already initiated a process of adaptation by drafting strategies or catalogues of measures. Climate change is viewed as a complex set of risks and opportunities, the impacts of which vary between regions and sectors. The aim of climate adaptation is to reduce the related negative costs and impacts of climate change and to take advantage of any new potential opportunities that may by adjusting to a changing climate (Heuson et al. 2012). The growing relevance of adaptation is also reflected in new regulations addressing critical infrastructures. For example, in the "Council Directive on the Identification and Designation of European Critical Infrastructures and the Assessment of the Need to Improve their Protection", the European Council identifies the energy sector as one critical infrastructure in the European Union (EC 2008). The sector thereby can be split into subsectors like the electricity subsector, which includes infrastructures and facilities for generation and transmission of electricity in respect of supply electricity.

For the case of adapting to climate change, the "EU Strategy on Adaptation to Climate Change" builds the framework on the ***European*** level. The intention is to encourage and support action in three priority areas: promoting and supporting actions by member states, promoting adaptation in key vulnerable sectors at EU level, and ensuring better-informed decision-making. The strategy builds upon the 2009 white paper on adaptation, which foresaw the elaboration of an EU-wide strategy by 2013. Most actions included in the white paper had been implemented by the end of 2012. The adaptation strategy is a package of documents and takes stock of these initiatives and seeks to build on them. The main political document is a communication that sets out actions to be taken in the three priority areas mentioned above.[7] The energy sector infrastructure is part of the working document "Adapting Infrastructure to Climate Change" (EC 2013). Besides an overview of climate risks and impacts on the energy infrastructure in Europe, the paper also discusses instruments and financings provided by the European Union to make Europe's infrastructure more climate resilient. Thereby mentioned as the most important type of instrument used to regulate infrastructure sectors are standards at EU level taking into account possible impacts as well as guidelines for climate-proofing infrastructures. Financing the adaptation of existing and the climate-resilient construction of new infrastructure is seen by the EU as a major challenge since this investment need cannot be met by traditional sources of public financing alone. The EU identifies a significant infrastructure investment gap and points out the need to bridge it by both the public and the private sector, including institutional investors. Most interesting is the EUs will to step up its efforts in financing climate-resilient infrastructures in the current budgetary period. Thereby a minimum of 20% of the overall 2014-2020 EU budget will go in climate-related investments. The proposed funding plan is intended to speed up long-term investments in roads, railways, energy grids, pipelines and high-speed broadband networks.

Regarding the adaptation to climate change, the political framework in ***Germany*** mainly consists of the "German Strategy for Adaptation to Climate Change" (The German Federal Government 2008). and the "Adaptation Action Plan for the German Strategy for Adaptation to Climate Change" (The German Federal Government 2012). The "German Strategy for Adaptation to Climate Change" creates the framework for a medium-term national adaptation process, in which the risks of climate change will be progressively identified, the actions that may be necessary specified, appropriate objectives defined, and possible adaptation measures developed and implemented. It aims to reduce the vulnerability to the consequences of climate change, to maintain or improve the adaptability of natural, social and economic systems, and to take advantage of opportunities. To facilitate a precautionary approach to sustainable planning and action in the private, scientific, business and public sectors it

[7] The full EU Adaptation Strategy Package is available at:
http://ec.europa.eu/clima/policies/adaptation/what/documentation_en.htm

points out the need to i) improve the knowledge base by better defining and communicating opportunities and risks as well as options for action, ii) create transparency and participation by means of communication and dialogue as well as decision support, iii) support public awareness raising and information, iv) develop strategies for dealing with uncertainty (The German Federal Government 2008).

The “Adaptation Action Plan for the German Strategy for Adaptation to Climate Change” describes the objectives and options for action laid down in the “German Adaptation Strategy” with specific activities to be carried out by the German Federal Government in the years to come. Regarding the creation of frameworks by the Federal Government it points out, that many adaptation measures are directly or indirectly influenced by the framework conditions put in place by the German Federal Government. Therefore suitable framework conditions can help to develop and strengthen adaptive capacities. By the “Adaptation Action Plan for the German Strategy for Adaptation to Climate Change” the German Federal Government points out that it aims at strengthening of adaptive capacities and self-provision, and ensuring that existing instruments for the creation of frameworks are improved appropriately. Furthermore it will seek to ensure that the requirements of adaptation are taken into consideration by the self-regulating bodies responsible for standardization and the development of technical rules (The German Federal Government 2012).

However, as of now, there are currently no actual government interventions by legal obligations or economic instruments implemented in Germany regarding the adaptation to a changing climate within the energy sector or within the existing framework for the German Energiewende.

Within its “Climate Change Act 2008” (UK Government 2008) the ***United Kingdom*** makes legal arrangements about climate change mitigation and adaptation. It sets the requirements for the “Climate Change Risk Assessment“ (Defra 2012a), the “National Adaptation Programme” (Defra 2013a) and the “Adaptation Reporting Power” (Defra 2014). Within Part 4 – impact of and adaptation to climate change – of the "Climate Change Act 2008" the Secretary of State has been conferred powers by section 62(1) to direct certain persons or bodies – so called reporting authorities – to give reports about adaptation to climate change. This applies to organizations that are responsible for essential services and infrastructure, like energy or transport companies. So the government argues that it is important to know that these organizations are planning to respond to climate change as part of their risk management processes. Obligations for the energy sector as critical infrastructure are to prepare reports on how they assess and act on the risks and opportunities from a changing climate. The reporting mainly covers an assessment of the current and predicted impacts of climate change in relation to the reporting authority's functions, as well as a statement of the reporting authority's proposals and policies for adapting to climate change in the exercise of its functions and the time-scales for introducing those proposals and policies (Hendel-Blackford 2012).[8] In the first round of reporting the strategy focused on major infrastructure providers from the energy, transport and water sectors. It was completed in March 2012, and the related reports have been published (Defra 2012b). The energy sector was a crucial sector in the first round of reporting. It includes organizations responsible for electricity generation, transmission and distribution, as well as gas transportation, and the sector regulator Ofgem.

The adaptation plan reports from key infrastructure providers in response to directions to report under the "Climate Change Act 2008" show, that they made a contribution to raising understanding of adaptation and increasing action. It raised adaptation to the board level and in many cases embedded climate change risks within organisations' corporate risk management procedures. It also shows that organisations are already adapting to climate change and mitigating their specific climate change risks.

In the current second round, however, the government is now using a voluntary approach to reporting. The Secretary of State will invite key organisations to report an assessment of their current and predicted climate change risks and opportunities as well as a programme of adaptation measures. The

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[8] Information on guidance for climate change adaptation reporting is provided online: https://www.gov.uk/government/publications/climate-change-adaptation-reporting.

invitation process started in winter 2013-2014 and reports will be delivered until 2016 in accordance with individual agreed timescales (Defra 2013b).

Some general challenges that remain are the fact that the reportings still only comprises the risks and opportunities the organisations identified themselves. There is no cross-check if this actually fits with climate change impacts to be expected on a scientifically sound basis. So companies might also use the reportings to present themselves in a most positive way, without reporting about all of the real impacts they are and will be confronted with. Also the plans for monitoring and evaluating adaptation effectiveness are still not clear. There still is a need to explore interdependencies to a greater extend (Hendel-Blackford 2012). Furthermore it now becomes quite obvious in this second phase, that the "Adaptation Reporting Power" no longer remains a legal obligation, since it is now a voluntary approach to reporting. And therefore it actually is more like what the CDP does for investors.[9] Hence it will be interesting to analyse how the reportings will change from the first to this second phase until 2016.

4.2 Possible government interventions and legal obligations

As pointed out above, it is the energy infrastructure that will mainly be influenced by climate change impacts. But if we now talk about possible incentives or regulations for adapting to climate change, it is important to understand the regulatory background regarding grids in Germany. While the German energy sector was characterized by economic protectionism for the majority of the 20th century, statutory orders of the European Union require free access and non-discriminatory prices for grid-based transport of energy since the 1990s. The resulting regulatory tasks are managed by the Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway (Bundesnetzagentur, BNetzA) which holds all national grid-related competencies since 2005. The corresponding law (Anreizregulierungsverordnung, ARegV) came into force in June 2007 (German Federal Ministry for Economic Affairs and Energy 2007). Aim of this legally codified regulatory regime is the

[9] The climate change program reports by the CDP are provided online: https://www.cdp.net/en-US/Results/Pages/All-Investor-Reports.aspx.

determination of prices, which were achieved as a result of competition. The regulated revenues are supposed to provide cost coverage plus a pre-defined return on equity on the one hand, and to stimulate efficiency gains and further investments in the grid industry on the other hand. Therefore one possibility to be discussed would be a regulatory government intervention by including incentives for investments in order to build up a more resilient and climate-proof infrastructure. Since the Federal Network Agency is required to submit a report containing an evaluation and suggestions for further refinement of the current incentive regulation to the German Federal Ministry of Economics and Technology until the end of 2014, also new criteria taking into account the adaptation to climate change should be discussed from the beginning of 2015 on.

Additionally discussed in the near future should also be the use of the current German solidarity surcharge (Solidaritätszuschlag) for financing the specific parts of critical infrastructure investments related to climate change adaptation. The solidarity surcharge is an additional fee on income tax, capital gains tax and corporate tax in Germany. It is a direct federal tax, so the tax revenue is fully available for the Federal Government. The solidarity surcharge is to be paid by every natural and legal person that owes one of the above-mentioned taxes in Germany. The solidarity surcharge currently is 5.50% of the tax payment for all taxpayers, which sums up to a specific tax revenue of about €14 billion per year. It was introduced in 1991 and was mostly justified by the costs of German reunification and was introduced as a temporary additional tax. It has also often been the subject of proceedings, where its constitutionality was always confirmed, even with regard to a permanent existence. For its initial purpose it will run out in the next years, but there are clear politic signs that this surcharge at principle will not be abolished. For a long time now there has been a controversial discussion in Germany about ending the solidarity surcharge. The question is for what purposes it will be used in the future. One might be supporting the provision of a climate resilient energy infrastructure (as well as other critical infrastructures) in Germany. Thus, it would have to be paid by every natural and legal person whereby the progressive effect of the income tax rate could be used. The question remains, if it would be possible and politically acceptable to earmark the tax revenue to be spent for this specific purpose. Furthermore it has to be made clear, that no private sector responsibilities would be financed.

Also to be used to finance the provision of climate resilient critical infrastructures is the German Energy and Climate Fund ("Energie- und Klimafonds"), a facility fed by revenues from the European emissions trading scheme. Currently funds are spent for various support programmes relating to energy efficiency, renewable energy, energy storage, energy-efficient renovation, national and international climate protection as well as electro mobility – hence to climate change mitigation (German Federal Ministry of Justice and Consumer Protection 2011). Currently there is already a debate going on in Germany about the fund's budget for the next years. This debate should also be used to both think of additional ways of funding the Energy and Climate Fund as well as ways to include the specific needs of climate change adaptation as part of the German Energiewende.

Also obligations for the energy sector to prepare reports on how they assess and act on the risks and opportunities from a changing climate, as initiated in the UK by the "Climate Change Act 2008" could be an appropriate way to prepare an assessment of the current and predicted impacts of climate change for companies in the energy sector in Germany – especially according to the first round of reporting in the UK.

Furthermore and on an informational level, possible climate change impacts for the energy sector and possible solutions should to a greater and more detailed extend be included in future publications, recommendations and guidelines for companies and government authorities provided by the German Federal Office of Civil Protection and Disaster Assistance (2006; 2008).

5. Conclusion

The option of climate change adaptation is becoming more and more important in climate change policy. Especially in view of the failure of international negotiations on climate protection and the improbability of a trend reversal in the climate changes that have already occurred, responding to climate change now involves both mitigation to address the cause and adaptation as a response to the changes.

Since the paper mainly deals with government interventions and legal obligations it is important to finally underline the necessity of government intervention as well as the role of policy makers on different governance levels in the adaptation process. Adapting to changing framework conditions is surely not a novel phenomenon, but rather an ongoing task for all societies and economic players. Governments and specifically national policy makers therefore play a key role in elaborating adaptation strategies for the energy sector and support the implementation of measures against a regional background of expected climate impacts. They need to ensure that mitigation targets and according energy mixes are climate proofed and promote energy efficiency and sufficiency by environmental policy instruments. On the European level, political decision makers must set a clear focus on the European transmission grid safety, sufficient redundancies and cross-border connections. Likewise, research on the energy sector vulnerability, measures to increase energy sector resilience (e.g. investment in research on alternative storage technologies) and climate-proofing energy supply should be promoted. Finally, it is important to mainstream adaptation of concrete measures into mitigation policies.

Thereby the German energy sector is facing specific challenges and opportunities in the course of the Energiewende. As it progresses towards an energy system more and more based on renewable energies, it is reasonable to expect that risks related to climate change will generally decrease. Unlike centralized conventional power plants, which can take days or weeks to power up after a storm, most renewable power technologies can be turned on nearly immediately. The problem of cooling water for thermal power plants will be reduced by modern renewable energies, many of which use little to no water and none of which pollute water with warming or contaminants. With the exception of biomass, which is affected by climate change due to effects on vegetation growth, and hydropower, which may be impacted by climate related drought, renewable energy sources also are not at risk of diminishing significantly in a changing climate. Moreover, renewable energies can be implemented successfully in every region, as Germany has shown with its rapid uptake.

However, the paper shows that the German energy sector is – and will be in the future – influenced by climate change along its value-added chain. Therefore specific actors should in the near future be confronted with new or increasing legal obligations and other government interventions regarding their efforts to adapt to climate change. Thereby governmental interventions are for example justifiable regarding measures to adapt the grid infrastructure. How these government interventions, legal obligations or economic instruments should be designed and implemented, still remains highly relevant future need for research.

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