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Which Incentives Does Regulation Give to Adapt Network Infrastructure to Climate Change? - A German Case Study

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Abstract

Climate change poses a new challenge in particular to long-lasting electricity networks. At the same time, this industry is highly regulated, which greatly affects the behavior of network operators. In this paper, the impact of regulation in general and of the German electricity grid regulation in particular on anticipatory adaptation investments is analyzed.

The qualitative analysis shows that in general a whole set of elements of the regulatory model and their coordination influence the decision of ex ante adaptation to climate change. A careful and balanced design, e.g. of efficiency and quality measurement, is thus crucial to avoid inadequate adaptation. The regulation in Germany discourages flexible adaptation to extreme weather events (EWEs). For irreversible adaptation of new and existing infrastructure to EWEs, the incentives highly depend on the cost approval of the regulator. Currently, the regulation discourages this type of adaptation. But if the additional costs can be claimed, the network operator is indifferent to adapt. Similarly, incentives to irreversibly adapt existing and new infrastructure to slow onset events (SOEs) range between excessively high and undistorted depending on the regulator's discretion. Undistorted means that the decision to implement adaptation measures is not biased by regulation. Undistorted are also the incentives for flexible measures to adapt to SOEs. Only in the undistorted cases, the risk of inadequate adaptation are borne by the network operator.

Keywords: Electricity Networks, Regulation, Climate Change, Germany

1 Introduction

Climate change poses a new challenge in particular to electricity system operators: they dispose of assets with long life-times (e.g. 30-100 years), parts of which are highly exposed to weather and climate changes, e.g. more frequent and severe storms, flooding, excessive icing. Owing to the far reaching consequences of disruptions for economy and society, the infrastructure is classified as critical (BMI, 2009). To protect the network infrastructure and its services, substantial investments to counter the effects become necessary. Stern (2007) roughly estimates the aggregate annual cost for infrastructure adaptation in OECD countries at US$ 15-150 billion.

Adaptation measures, e.g. use of different materials or an increase of redundancies, aim at making the current system more robust. They are successful if negative impacts do not materialize in the future. This is different to conventional investments that predominantly expand the grid or reduce operating costs. In addition, most current regulations of electricity system operators aim at increasing productive efficiency and were not explicitly designed to enhance the robustness of the systems.

In the literature, two strands analyze the impact of regulation on corporate investment behavior, in particular with regard to sunk costs and uncertainty. One analyzes the implications of the regulatory content on investment (e.g. Guthrie, 2006; Helm, 2009; Sappington, 2005; Dobbs, 2004), and the other focuses on the governance of economic regulation based on institutional theory (cf. Levy and Spiller, 1994; Stern and Holder, 1999). Due to its sunk and long-term investments, the theoretical findings have been applied particularly to the electricity sector. For instance, several studies recently analyze the impact of regulation on investments for the grid integration of distributed generation (Niesten, 2010; Cossent et al., 2009; Nykamp et al., 2012)). The effect of institutional endowments of a country on the investments of electric utilities has been assessed empirically, too (e.g. Bergara et al., 1997; Levy and Spiller, 1994; Stern and Holder, 1999). An application to the case of adaptation of infrastructures has not been undertaken yet. In the literature on adaptation to climate change, Inderberg (2012) and Inderberg and Løchen (2012) analyze the influence of regulation on the adaptive capacity of the Norwegian and Swedish electricity sector from an organizational perspective. They conclude that regulation plays an important role in explaining firms' reaction to extreme weather events (EWEs). Their conclusion that efficiency oriented regulation diminishes the regulatee's adaptive capacity has, however, not been analyzed economically.

This paper tries to close this gap by means of a qualitative analysis of the impact of economic regulation on adaptation investment based on the two strands of literature. In particular, it analyzes whether the existing regulatory institutions in Germany give incentives for adaptation of the electricity grid, and if so what type of adaptation is favored. We also deal with the question of who – consumers or investors – bears the risk of climate change impacts and the costs of inadequate adaptation.

In the following, the impacts of climate change on network infrastructure and possible adaptation measures are outlined. In Section 3, the theoretical and empirical insights on the influence of regulation on investment are applied to adaptation to climate change and in Section 4 to the German electricity grid regulation. In Section 5 the findings are discussed and concluded.

2 Impacts on and Adaption of Network Infrastructure

A number of studies show that weather conditions, both normal and extreme, significantly influence the quality of supply of electricity networks (e.g. Coelho et al., 2003; Domijan et al., 2005; Yu et al., 2009). The impacts of a changing climate on electricity infrastructure have also been analyzed in several studies of recent years (for an overview see Schaeffer et al., 2012; Mideksa and Kallbekken, 2010). Electricity transmission and distribution grids are especially vulnerable to more frequent and/ or severe storms (including also falling trees), change in air temperature, flooding, excessive icing or other EWEs. Underground lines, which are common in distribution systems, can be affected by changes in soil temperature and soil moisture[1], but little research has been conducted on this issue so far. Little quantification exist for these effects to date (Mideksa and Kallbekken, 2010). One exception is Peters et al. (2006), who estimates that storm-induced transmission outages durations could double annually in the United States due to

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[1] According to Oeding and Oswald (2011) for instance, soil temperature influence the dimensioning of cable sections.

climate change, which they monetize with US$ 3.3 billion additional costs.

For an operator the damage from EWEs can materialize in reduction of service quality/ security of supply (e.g. interruptions, blackouts) and a loss of physical assets. In the aftermaths of an extreme event, capital expenditures (Capex) and operational expenditures (Opex) are necessary for damage remedy and restorations. The operator can also be made liable for damages that are caused by power interruptions. Slow onset events (SOEs) can lead to a more rapid wear and tear and a reduced transmission capacity of power lines e.g. in case of extreme heat, which can compromise service quality in extreme situations. As a consequence, Capex could increase due to premature replacements or repair, and Opex might also rise due to increased need for congestion management. In the following, damage costs will be abbreviated *D-Capex* or *D-Opex*, depending on the type of costs incurred.

To reduce future impact cost and or maintain/ increase future service quality, network operators can adapt to these impacts. Adaptation to climate change can be differentiated according to diverse categories, such as temporal scope or timing (for an overview see Smit et al., 2000). In the following, we focus on planned, ex ante measures. With regard to long-lived infrastructure such as the electricity grid, one can differentiate between flexible and irreversible adaptation investments (Hallegatte, 2009). Flexibility means that the measure can be canceled without a great loss when developments turn out differently than anticipated. Examples for this category are increased maintenance (e.g. vegetation management) and process innovations (e.g. climate adjusted steering of the grid or change in feed-in management) (Dunkelberg et al., 2009). Irreversible measures include climate proofing (retrofitting) of existing infrastructure (e.g. pylons) and of new infrastructure, increase of redundancies or product innovations (development of more climate robust material), as well as choice of site. Figure 1 gives an overview on the climate change impacts, related damage effects on the grid infrastructure and ex ante adaptation measures.

Flexible adaptation measures mostly incur Opex (*A-Opex*), whereas irreversible measures incur mainly Capex (*A-Capex*). While irreversible measures for new infrastructure such as safety margins do not necessarily incur high additional costs, climate proofing of existing infrastructure comes at high costs (Fankhauser et al., 1999; Hallegatte, 2009). After a storm-event in 2005 revealed, for instance, the vulnerability of Thomas steel pillars, the necessary reinforcement of 28,000

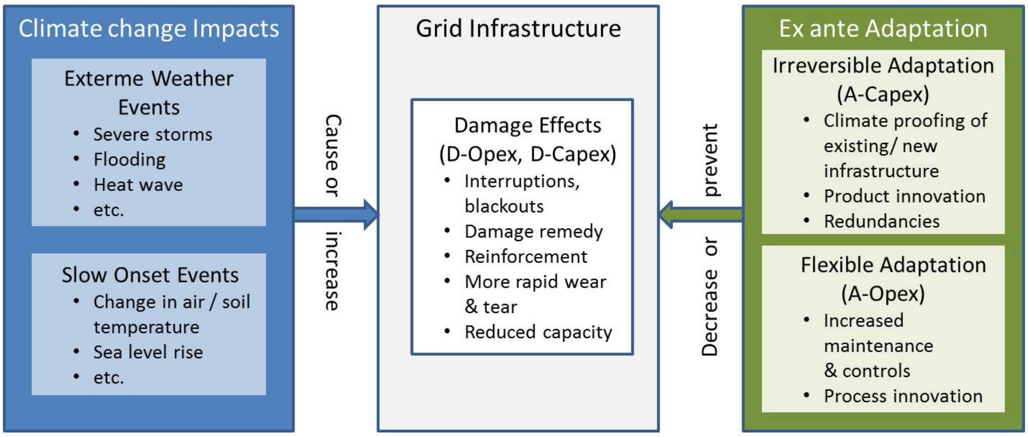

Figure 1: Overview on climate change impacts, damage effects and ex ante adaptation for grid infrastructure

pillars was estimated to amount up to €500 m (Eskeland et al., 2008), which is about a quarter of the annual investments of all grid operators in Germany. Van Ierland et al. (2007) indicate that the cost of climate-proofed poles and lines are twice as high (about €2 m/km) as costs for conventional ones. In relation to this, A-Opex such as additional maintenance can be expected not to amount to high expenses: the German TSO 50hertz declares that yearly maintenance and inspection costs aggregated to about €1.4 m in 2012 (50hertz, 2013).

The network operator will balance damage and adaptation costs against each other. If the firm seeks to maximize its profit[2], then it will only invest if the net present value of the investment is positive, i.e. if the expected (discounted) sums of damage costs that can be foregone by the measure (in addition of further expected benefits) are greater than the costs of it. However, regulation greatly influences the decision on adaptation spending (Cimato and Mullan, 2010; Heuson et al., 2012). For instance, Opex and Capex are often treated differently and thus incentives to alter one or the other form of costs are given. A regulated operator will base the adaptation investment decisions on how it affects the allowed revenue, its actual costs and hence its actual revenue. A closer look at the key elements of regulation that drive or hamper anticipatory adaptation investment is hence necessary. The credibility of the regulator and the predictability and transparency of the regulation have a significant influence on the operator's behavior, too. Finally, regulation also determines which market side bears costs of inadequate adaptation (cf. Guthrie, 2006).

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[2] If other or additional goals are pursued, this might not apply (Guthrie, 2006).

3 Influence of Regulation on Adaptation Investment

The relationship between regulator and network operator can be understood as contractual (Williamson, 1976; Goldberg, 1976) [3], in which the regulator defines which prices the operator may charge or which revenue s/he is allowed to make. The specific design of such a contract, e.g. price flexibility and cost assessment, influences the investment incentives resulting for the network operator (Guthrie, 2006). In addition, the governance of the contract influences investment decisions.

3.1 Regulatory Content

Regulation of monopolistic markets has been introduced to promote allocative efficiency. Basically two different regulatory regimes have evolved in this context: cost-based regulation and incentive-based regulation. The particular design of the regulatory scheme is often a hybrid of the two extreme forms (Bauknecht, 2012; Cambini and Rondi, 2010). A closer look at the key elements of regulation that drive or hamper anticipatory adaptation investment is hence necessary.

3.1.1 Price Flexibility and Length of Regulatory Cycle

A network operator, who is confronted with the decision to adapt the infrastructure to an uncertain climate and impact development, can choose to wait and see how the climate develops instead of adapting ex ante. In this case, s/he might experience higher D-Capex/-Opex (= cost of waiting). These losses can be compensated, if the operator can adjust the price accordingly. As a consequence, with price flexibility the need to adapt ex ante is lowered (Guthrie, 2006; Dobbs, 2004). Under incentive regulation the price is only limited at a certain stage, meaning that the operators can partially compensate this cost of waiting by increasing prices until the cap is reached (Guthrie, 2006). The degree of price flexibility is limited by the level of the cap: if it is set to become binding when climate impacts become more severe, it can spur ex ante adaptation (Guthrie, 2006).

If the operator decides to adapt ex ante, new Capex are not considered by the reg-

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[3] Goldberg (1976) describes regulation as an administered contract.

ulator until the end of the regulatory cycle, except for pure incentive regulation. This means that the cap remains fixed in case of A-Capex during the ongoing period. As a consequence, total costs are not fully covered by the capped revenue, unless prices can be adjusted accordingly. If the cycle is long, there can be a considerable time lag between Capex and their consideration in the regulatory asset base. This phenomenon is known as negative base or delay effect (cf. Stronzik, 2011; dena, 2013), which is illustrated in Figure 2. It reduces the incentive to invest especially at the beginning of a regulatory period.

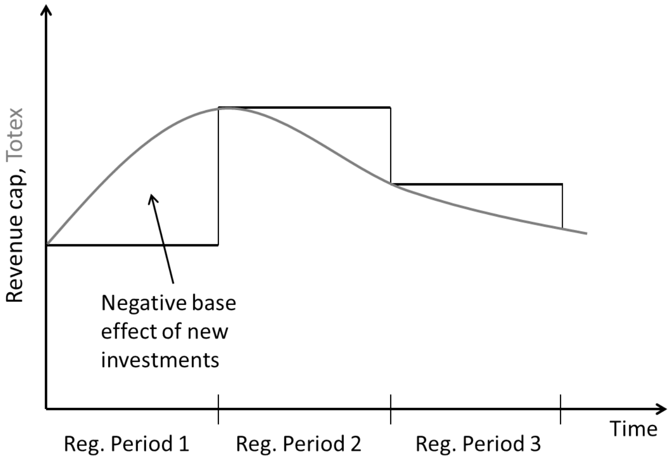

Figure 2: Negative base effect of new investments [own illustration based on dena (2013)]

A-Capex investments may, however, be able to prevent or reduce damage costs already in the ongoing period. The longer the cycle length and the more rigid the price, the higher is the sum of expected damage costs that can be mitigated by adaptation, which renders A-Capex more attractive. Even though also A-Opex can negatively influence the revenue with a fixed cap, the cycle length is not decisive due to the reversibility of such measures.

Adjustment or exemption clauses can lever the price rigidity to a certain degree. When such clauses are in place, the network operator is able to automatically adjust the cap upwards when predefined cost parameters increase during the ongoing cycle (Pfeifenberger and Tye, 1995). Depending on which type of costs (damage or adaptation) the adjustment clauses account for, respective incentives result.

3.1.2 Regulation of Capital Costs

The regulatory asset base is a central feature of the regulatory setting. Under incentive regulation, it determines the level of the initial price (or revenue) and the efficiency factor (Joskow, 2008). It is the sum of the actual costs of the physical capital of a company, adjusted for depreciation, upon which the company is allowed to earn a certain return (Guthrie, 2006). Different valuation approaches exist to determine the asset base: Under historical cost accounting, all actual costs incurred by the operator for the investment are approved without exemptions. A limitation of this approach is the "used-and-useful" criterion, where only the costs of assets are approved that are judged to be necessary, based on ex post information (Guthrie, 2006). If an asset is not approved, the operator bears the costs, but misses out on the return of investment. The higher the risk of ex post disallowance by the regulator, the lower is the incentive to invest in the first place, especially in long regulatory cycles.

The risk of cost disallowance can be assumed to be low for D-Capex even under strict cost evaluations, if the replaced asset had been approved used and useful before. A-Capex are spurred under historical cost accounting. Under more strict cost valuation schemes, these investments will only be undertaken, if they "have a relatively low potential for bad news" (Guthrie, 2006, p. 956), e.g. if the measure entails additional benefits in any case. This is for instance the case for climate-proof new infrastructure, which also expands the network.

3.1.3 Efficiency Assessment

Under price or revenue cap regulation, the regulator adjusts the cap during the regulatory period for inflation and an individual efficiency (x) factor[4]. It can be applied to the entire costs or certain costs categories, e.g. Opex. The x-factor expresses the expected productive efficiency gain of the individual operator during the regulatory period. The greater x, the greater is the measured inefficiency and the lower is the allowed price or revenue. If higher efficiency gains can be made than prescribed by the x-factor during the regulatory period, the profit can be kept. Theoretical insights are that slight increases of the x-factor increase the investments in cost reduction, but if x is set excessively high, no investments in

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[4] For instance, the revenue cap in period 1 is: $R_1 = (1 + RPI - x)R_0$, where RPI is the retail price index and R_0 is the revenue of the previous period.

cost reductions are undertaken (Cabral, 1989). Empirically, it was found that the level of the x-factor negatively influences (mostly cost reducing) investment in the electricity sector (Cambini and Rondi, 2010; Nagel and Rammerstorfer, 2009).

Different methods exist for calculating the x-factor, which relate inputs to outputs of operation. The choice of input and output variables determines, which adaptation activities of the network operator and also which exogenous factors such as weather impacts influence the efficiency value (Jamasb and Pollit, 2001). If the efficiency assessment is based on Opex as inputs, then A-Capex as well as D-Capex would have no affect on the measure, unless they influence the output side, too. Furthermore, these expenditures would not be subject to the efficiency target. Based on Totex instead, the efficiency measure would register an increase in inputs for all types of damage and adaptation expenses. If this cannot be compensated with either increasing the output or reducing another input category, the measured inefficiency increases.

In case benchmarking is applied, the efficiency score also depends on the exposure and behaviour of other operators (cf. Poudineh and Jamasb, 2013). Consequently, single operators may be disproportionately advantaged or disadvantaged due to the local conditions. In addition, operators can also show freeriding behaviour. To account for structural, inherent differences, comparative factors can be included, as is already often the case for e.g. topography and customer density (Jamasb and Pollit, 2001). Empirical studies show that including weather parameters can have (small) significant effects on the efficiency ranking (Yu and Pollitt, 2009; Growitsch et al., 2012; Korhonen and Syrjänen, 2003). Yet the influence of weather conditions on efficiency scores can also be covered by other variables in the comparison (Korhonen and Syrjänen, 2003; Yu and Pollitt, 2009)[5].

Accounting for quality of service (e.g. duration of interruptions) in the assessment, would lead to a correction of the efficiency score for quality. Adaptation measures could thus also cause an increase of efficiency in the future.

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[5] For instance, network length as an output factor can partially reflect the weather effect (Yu et al., 2009).

3.1.4 Reward of Quality

Since incentive regulation has been criticized to encourage quality deterioration, additional regulatory instruments have been implemented to counter this effect. This is mostly done via an additional factor to the regulatory formula (e.g. minimum quality standards, investment budgets etc.) or in few cases via integration in the formula (Elliott, 2006; Sappington, 2005). Besides financial incentives to increase service quality, the regulator can also use indirect instruments such as reputational incentives by publishing the quality of all operators (Bliem, 2005). For ex ante adaptation, it matters whether or not weather related disruptions show in the quality measurement. Quality rewards are additional benefits that the operator can gain, even if the investment made is not approved as “used and useful”.

3.2 Regulatory Governance and Opportunism

Since contracts are by nature incomplete, regulated agents run the risk of governmental opportunism, i.e. some form of appropriation by the regulator or government (Stern and Holder, 1999). With a high risk of regulatory opportunism, the operators will refrain from undertaking any investments. The characteristics of public utilities render them particularly vulnerable to governmental opportunism (Bergara et al., 1997).

Several studies identify key aspects of the regulatory governance that facilitate private investment by restricting the regulator’s opportunities to behave opportunistically (Levy and Spiller, 1994; Stern and Holder, 1999). Two central issues are: (1) the relationship between the government and the regulatory agent or the “formal aspects of regulation” (Stern and Holder, 1999, p. 42), i.e. the autonomy of the regulator, its accountability and the clarity of roles and objectives between the government and regulator; (2) the practice of regulation, i.e. its transparency and predictability and thus credibility of the regulator. Regulatory credibility and predictability matter especially for decisions on long-term, irreversible investment (Henisz, 2002). Once undertaken, the investments need to pay off over a lengthy period of time. The risk of administrative expropriation of any kind causes the regulated firm to refrain from any long-term investments (e.g., Baumol and Klevorick, 1970). Empirical studies support this hypothesis (e.g.,Levy and Spiller, 1994; Bergara et al., 1997).

In the context of adaptation to climate change, central entry points for regulatory opportunism are the predictability of A-Capex allowance and the handling of D-Capex/-Opex. No A-Capex will be undertaken, if the risk of disallowance is high and/or if the cap can be easily adjusted for damage costs.

To sum up, the analysis shows that a whole set of elements of the regulatory content and their interplay influence the decision of ex ante adaptation to climate change. In addition, the final incentives depends also on political independence and credibility of the regulator.

4 Electricity Grid Regulation in Germany

In the course of the German electricity sector reform, the electricity grid operation was unbundled from other steps in the supply chain. At the transport level, four private companies manage the grid in four different control areas. The distribution of power is currently carried out by 897 companies (as of 2013) in their regional monopolies; about 90 % of these have less than 100,000 customers (Bundesnetzagentur, 2014). A considerable share of them is owned by municipalities.

Transport system operators (TSOs) and large distribution system operators (DSOs) are regulated by the Federal Network Agency (*Bundesnetzagentur*, BNA), which is subordinate to the Federal Ministry of Economics and Energy (*Bundesministeriums für Wirtschaft und Energie*, BMWi) and in part to the Federal Ministry of Transport and Digital Infrastructure (*Bundesministerium für Verkehr, und digitale Infrastruktur*, BMVI). Small and medium DSOs (less than 100,000 customers) operating in only one federal state are regulated by the regulatory authority of the federal state[6]. In addition, energy supervisory authorities of the federal states are responsible for the approval of network operations. With the amendment of the Energy Economy Act (*Energiewirtschaftsgesetz*, EnWG) in 2005, the access to the electricity network is regulated and replaces a system of negotiated access.

The basis for network charge calculation is the Electricity Network Fee Regulation Ordinance (*Stromnetzentgeltverordnung*, NEV) of 2005, which was comple-

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[6] Except for five federal states (Bremen, Mecklenburg- Western Pomerania, Lower Saxony, Schleswig-Holstein and Berlin) where part of the regulation is managed by the BNetzA. If the area of control by the DSO crosses the frontier of a federal state the BNetzA takes over, too.

mented by an incentive-based regulation (*Anreizregulierungsverordnung*, ARegV) that came into force on January, 1st 2009 and replaced a cost-based regulation. With the ARegV, a revenue ceiling is determined that grid operators are allowed to gain from the network charges. The revenue cap is transformed into maximum network charges, which are still calculated according to NEV. The revenue ceiling in year t is based on different cost categories of that same year and of a photo year ($t = 0$), which is the penultimate year of the previous regulatory period (2006 for first period). The formula is as follows [7]:

$$\overline{R}_t = F_t + e_t(cpi_t - x_{gen,t})(K_0 + (1 - x_{ind,t})C_0) \pm q_t$$

where

- $\overline{R}_t$: revenue ceiling for income from network charges in year t;
- F_t: permanently non-influenceable share of costs of year t;
- e_t: network extension factor for year t (for DSOs only);
- cpi_t: change in consumer price index (CPI) compared to photo year;
- $x_{gen,t}$: sectoral productivity factor for year t;
- K_0: temporarily non-influenceable share of costs of photo year;
- C_0: influenceable share of costs of photo year;
- $x_{ind,t}$: individual efficiency target for year t based on costs in photo year;
- q_t: quality factor (introduced in 2012 for DSOs only);

4.1 Regulatory Content

Significant changes in any of these variables influence the allowed maximum revenue of a network operator as will be analyzed in the following.

4.1.1 Price Flexibility and Investment Regulation

The regulated operator in Germany has certain flexibility in setting the network charges within the bounds of the revenue ceiling. The ceiling is "automatically"

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[7] Two components are excluded: volatile share of costs (V_t) and yearly surcharges or reductions resulting from minor deviations from the yearly ceiling (S_t) are not relevant for the analysis

adjusted at the first calendar day of each year if CPI, non-influenceable costs or the quality measure have changed (see § 4 ARegV):

$$\overline{R}_t = \boldsymbol{F_t} + e_t(\boldsymbol{cpi_t} - x_{gen,t})(K_0 + (1 - x_{ind,t})C_0) \pm \boldsymbol{q_t}$$

Permanently non-influenceable cost shares, F_t, contain besides others approved investment budgets (for TSOs) and lump-sum investment allowances (for DSOs). Any investments costs incurred after the photo year that do not fall into these categories are not taken into account until the next cost review. Since the photo year is the antepenultimate year of the last regulatory period, the delay can last up to seven years (negative base effect) (Nykamp et al., 2012).

In contrast, investment budgets and lump-sum allowances are added to the revenue cap without delay and are not subject to an efficiency factor until the end of the regulatory period in which they are finalized (see § 4, 3 ARegV). Investment budgets are limited to measures for extension and restructuring of the transport system, for the stabilization of the entire system, and transport system specific measures[8] (see § 23 ARegV). Several rule examples are given for such authorized investments. They explicitly include extensions of high-voltage lines underground, and the implementation of temperature monitoring of transmission lines. Even though these two measures were not introduced with climate change in mind, they can also serve to adapt the electricity grid. Another rule example covers substantial and costly restructuring measures to improve the technical security of the grid. A change of technical standards is not a mandatory prerequisite for this, but the necessity of such investments need to be approved or ordered by the energy supervisory authority of the respective federal state (BR-Drucks. 417/07 (Beschluss)).

For DSOs a surcharge for grid extensions is captured in the factor e_t of the formula. In addition, they can apply for lump-sum investment allowances before a regulatory period starts, which may not exceed the current capital costs by 1 % each year.

Additional, extracurricular adjustments of R_t can be requested by the network operator during the regulatory period (once a year), if the supply task has changed or in case of an unforeseeable incident that would impose an unreasonable burden on the firm (see § 4, 4 ARegV). In the ordinance's explanatory statement, the

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[8] DSOs can only apply for such investments approvals in exceptional cases.

government states natural disasters and terrorist attacks as examples for such incidents (BR-Drucks. 417/07, p. 45).

In brief, the price flexibility is limited. The regulation does not facilitate the immediate pass through of damage costs. Yet, the adjustment option for unforeseeable incidents grants leeway for the pass-through of damage costs resulting from EWEs. Any A-Capex are discouraged especially early of the period that cannot be posted under either lump-sum allowances or investment budgets, respectively, due to the negative base effect of up to seven years. Currently, replacement investments are excluded from any kind of investment budget (**?**). Exempted is retrofitting that includes structural changes or that is substantial, needed to improve technical security and approved by the federal state authority. For TSOs, A-Capex for new infrastructure depends on the approval of the budget by the regulator. New pylons and lines need to be built in accordance with the latest technical standards (see § 49, 1 EnWG). Any more costly design outperforming the standard needs to be justified and, if not approved, the residual costs need to be covered by the operator. Approved A-Capex are revenue neutral, unless they have additional positive/ negative effects on Opex. For DSOs, A-Capex for new infrastructure can in principle be posted under the lump-sum investment allowances and have a positive impact on revenues. Yet they compete with other investments due to the limit of allowance. As a consequence, even efficient adaptation measures may not be undertaken, if they have lower rates of return than other investments.

4.1.2 Cost Review

To determine the base level for the revenue ceiling the regulatory authority identifies the total expenditures (Totex) of a grid operator in the photo year. These comprise operating and capital costs. In general, any type of costs is only to be included that is comparable to network costs of an efficient and structurally comparable network operator (§ 4, 1 NEV) and that would be incurred to a comparable extent by a firm in competition with others (see § 21, 2 (2) EnWG). Approved cost shares are included in the revenue cap formula as highlighted:

$$\overline{R}_t = F_t + e_t(cpi_t - x_{gen,t})(\boldsymbol{K_0} + (1 - x_{ind,t})\boldsymbol{C_0}) \pm q_t$$

The more costs approved, the higher is $\overline{R}_t$. The division in K_0 and C_0 depends on the efficiency assessment (see Section 4.1.3). Costs that are considered a "particularity" of the base year are excluded from the approved costs (see § 6, 3 ARegV). If for instance maintenance expenditures have increased significantly in the photo year compared to the precedent years, this can be considered a particularity and not taken into account for the revenue cap[9].

The residual asset value is calculated differently for old (activated before January 1st, 2006) and new operating assets. For new assets, which are of interest here, the calculatory residual value is assessed based on historic costs. The current assets considered to determine the capital costs are restricted to assets "necessary for operation" (*betriebsnotwendig*, NEV). This term has the connotation of a "used- and useful" criterion.

In sum, the main limitation of cost pass-through of adaptation expenditures and restoration costs is given by the qualification of incurred costs to be comparable to network costs of an efficient and structurally comparable network operator. This puts all A-Capex at regulatory risk, unless they have been approved in investment budgets beforehand. For D-Capex (replacements of damaged assets) the risk of disallowance is low, given that the replaced assets had been approved before. D-Opex and A-Opex are only considered in the review, if incurred in the photo year. Even then both can be considered a particularity of the photo year and hence be excluded from the cap, which is most likely for D-Opex caused by EWEs. D-Opex and A-Opex that arise outside the photo year are not taken into account for the revenue cap, unless the operator can prove unreasonable economic burden (see Section 4.1.1).

4.1.3 Efficiency Assessment

The efficiency factor is divided into two parts in Germany: the sectoral productivity factor $x_{gen,t}$ and an individual efficiency target $x_{ind,t}$. The first applies to all grid operators equally and embodies the general sector efficiency in comparison to other sectors. The second is based on benchmarking (for DSOs and TSOs separately). The revenue cap decreases the higher $x_{gen,t}$ and $x_{ind,t}$:

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[9] Cost disallowances in such a case have already happened in the past (Bundesnetzagentur, 2011b).

$$\overline{R}_t = F_t + e_t(cpi_t - \boldsymbol{x_{gen,t}})(K_0 + (1 - \boldsymbol{x_{ind,t}})C_0) \pm q_t$$

The individual efficiency is estimated by means of two efficiency analysis methods[10] based on the approved Totex (net of F_0) and standardized Totex, as well as a defined set of output and comparative variables. The output parameters include e.g. the length of the lines/ cables and annual maximum load. Comparative variables are included to correct for exogenous or structural influences, such as the size of the area supplied. Weather or climate conditions are not considered. The efficiency score of a network operator may be corrected upwards, if s/he can prove that the supply task comprises particularities that are not sufficiently covered by the structural variables (see § 15, 1 ARegV)[11]. Due to the limited number of TSOs, the efficiency comparison is conducted internationally with the so called E3-Grid-Modell, i.e. taking into account TSOs from other European member states (see § 22 ARegV).

Operators that are considered technically efficient have a $x_{ind,t}$ target of 0, all others have a higher target respectively[12]. The individual efficiency score is also applied to divide Totex (net of F_0) into C_0 and K_0[13]. The lower $x_{ind,t}$ the more costs are accounted in K_0, which is not subject to the individual target.

Since the benchmarking method is based on Totex, not only adaptation measures affect the efficiency score, but also damage costs. Except for grid losses, the output parameters do not include quality indicators. This means that additional expenses for quality management are penalized given that other operators do not invest. In addition, the efficiency factor is not corrected for weather or climate conditions. Thus, network operators that operate in areas with more impacts can be discriminated against, unless a network operator can prove that a certain impact or adaptation measure is a particularity of its supply task and substantially influences its costs.

In sum, A-Capex for existing infrastructure, A-Opex and D-Opex incurred in the photo year increase $x_{ind,t}$, if they are not considered a particularity. For A-Capex for new infrastructure the effect is ambiguous since it increases both input

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[10] Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) are applied for DSOs; for TSOs the assessment is based on DEA only.

[11] The associated costs of the particularity need to increase the total costs by at least 3 %.

[12] A maximum target of 0.4 or an inefficiency of 60 % is determined in case of the DSOs.

[13] $K_0 \leq (1 - x_{ind,t})(Totex - F_0)$ and $C_0 \geq x_{ind,t}(Totex - F_0)$.

and output side, again given that they have been approved as network costs. D-Capex should have no significant effect on the efficiency score since they simply replace former assets and annuities are being correct for. Due to the benchmarking method, the total effect of each expenditure also depends on the behaviour and vulnerability of other network operators.

4.1.4 Quality Factor

Since January 1st, 2012, the additive q-factor has been introduced for DSOs ($\succ$ 30,000 customers) with a reward/ penalty system.

$$\overline{R}_t = F_t + e_t(cpi_t - x_{gen,t})(K_0 + (1 - x_{ind,t})C_0) \pm \boldsymbol{q_t}$$

The system is based on the System Average Interruption Duration Index (SAIDI) for low voltage networks (weighted by number of end users), and the Average System Interruption Duration Index (ASIDI) for medium voltage networks (weighted by rated apparent power of the affect power transformer). For the calculation of the index the network operator adds up planned interruptions and three categories of unplanned interruptions[14]; i.e. atmospheric influence[15], actions of third parties, no apparent reason/ responsibility of operator. Exogenous structural differences of the network operators are taken into account as done in the efficiency comparison. Not considered are interruptions due to acts of god/ force majeure, which are defined as events caused (besides others) by exceptional elementary natural forces that are unforeseeable and unpreventable, and which the affected firm cannot be bounded to consider due to the events' (low) frequency (Bundesnetzagentur, 2011a). Examples given are heavy storms ("unless preparations had to be done"), storms that exceed force 11 and exceptional floods.

The reward or penalty is calculated depending on the DSO's quality level and a weighted reference level of all DSOs. The difference is multiplied with the number of end users and a monetizing factor, which is based on value of lost load calculations. To even out volatility, the three year mean of the SAIDI/ASIDI values is taken as the operator's quality level. The resulting rewards or penalties

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[14] Only interruptions that exceed 3 minutes are taken into account.

[15] Atmospheric influences comprise for example storms with forces below 10, floods, hail and snow. Actions of third parties include line contact with trees.

are constant for half of a regulatory period.

Due to this calculation method, any improvements or declines in quality are rewarded or penalized with a delay of three to five years, i.e. in general only in the next regulatory period. They are capped at ± 4 % of the revenue cap of the previous year less permanently non-influenceable costs (Herrmann, 2012)[16].

On an overall basis, the quality regulation does not give incentives to adapt to EWEs, since any related service interruptions are excluded from the comparison. Impacts from other atmospheric influences are penalized, if they cause interruptions of service. However, interruptions due to singular events are evened out by averaging.

In addition, in case of damages caused by supply interruptions, the liability of DSO is limited according to the regulation on low voltage connection (*Niederspannungsanschlussverordnung*, NAV). In case of simple or gross negligence, the compensation of property losses is limited to € 5,000 per user and also in total (depending on the size of the operator) (see § 18 NAV).

Table 1 summarizes how damage and adaptation costs affect the operators' revenue via the specific elements of the German regulation. If the respective cost influences the element positively (+) it has also a positive impact on the revenue cap. Hence, it facilitates the cost pass-through. Vice versa, if costs have a negative impact (–) or no impact (0) on the respective element, the pass-through is restricted. In other cases, the effect on the element may be ambiguous (am). In some cases, an expenditure may only affect the element positively, if the respective measure becomes effective ([+]). Shaded fields highlight results that depend on the discretion of the regulator.

4.2 Regulatory Governance

Several legal measures have been taken that safeguard the autonomy and independence of the Federal Network Agency. For instance, the members of the Ruling Chambers (Beschlusskammern) of the BNetzA cannot hold any position in an energy company or in any executive or legislative body of the federal government or the federal states (see § 59 EnWG). Yet, the BNetzA is de jure subject to

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[16] In 2012 the mean q-factor was about 0.18 % of the revenue cap. Most of the operators received surpluses on the cap. The maximum values were approximately ± € 1 million (Herrmann, 2012).

	D-Opex/-Capex from SOEs	D-Opex/-Capex from EWEs	A-Capex for existing infrastructure	A-Capex for new infrastructure	A-Opex
Immediate effect on $\overline{R}$ during the period					
F: adjustment clauses for unforeseeable events & investment budgets	0	$+$	$+$ or 0	$+$ or 0	0
Effect on $\overline{R}$ at next review, incurred in photo year					
$K_0 + C_0$: comparable to efficient operator & non-particularity	$+$ or 0	0	$+$ or 0	$+$ or 0	$+$ or 0
$(1 - x_{ind,t})$: based on Totex, not accounting for quality, not controlling for weather/ climate conditions	$-$ or 0	0	$-$ or 0	am or 0	$-$ or 0
q_t: excluding EWEs (DSOs only)	$-$ or 0	0	[+]	[+]	[+]
Effect on element: +: positive; [+]: positive if effective; 0: no effect; -: negative; am : ambiguous					
Dependent on regulator's decision					

Table 1: Overview on how the elements of German regulation affects the pass through of damage costs and adaptation expenses [own illustration]

directives from the BMWi (see § 61 EnWG), which are addressed to the president (Ludwigs, 2011; Ruhbaum, 2011). The independence of the Ruling Chambers from these instructions is not clearly regulated (Grashof, 2007). The Ministry can further take influence on personnel decisions, e.g. it approves the members of the Ruling Chambers. The political independence of the ten federal state regulatory authorities has been limited, too, due to organizational dependency on the federal state ministries of economics (Monopolkommission, 2009). By now, some federal states have established organizationally independent regulatory entities.

The role of the BNetzA and its key powers and duties are clearly outlined in the EnWG (see §§ 29-35) and the ARegV (see § 32). The role and competences of the federal state regulatory authorities and the cooperation with the BNetzA is clearly described, too (see § 54, 2, § 55 EnWG). In addition, a number of aspects constitute the accountability of the BNetzA. For instance, a formal mechanism is established for parties involved in the regulatory process that want to challenge the decisions of the BNetzA (see § 75 EnWG).

In general, the transparency of the regulatory setting is ensured by the availability of all regulatory documents and of all major decisions including the reasons behind them in the public domain. The regulatory details e.g., the regulatory formula or the results of the efficiency comparison, are made available, too, which ensures the predictability of regulation. Since the introduction of the incentive regulation, several guidelines have been published that clarify formerly unclear procedures. An aspect that could dampen the general predictability is the fact that the regulatory authorities have some leeway with regard to e.g., the determination of revenue caps, the set-up of the regulatory account, the method for efficiency comparison, etc. (see § 29 EnWG; § 32 ARegV). In fact, it has been criticized that the federal state regulatory authorities and the BNetzA do not always decide consistently, causing planning uncertainties for the companies (Monopolkommission, 2009).

In the regulatory content outlined above, the handling of unforeseen events in the adjustment clause and in the quality target, as well as the approval of adaptation costs stand out as plausible entry points for regulatory opportunism. For the quality target, the Bundesnetzagentur (2011a) has published a statement on the treatment of force majeure events. This includes the definition "'[...] event that is unforeseeable by human judgment and experience [...]"'(Bundesnetzagentur, 2011a, p. 2) [17] , as well as concrete examples of inclusion and exclusion. For the adjustment clause, the definition of an unforeseeable event is less precise, but also specifically includes natural disasters (see above). Hence, the predictability and transparency on the handling of damage costs from EWEs is high.

With regard to the approval of adaptation costs in the review, the regulatory content entails uncertainties due to the qualification of incurred costs to be comparable to network costs of an efficient and structurally comparable network operator. The predictability of which costs fall into this classification is not very high, and no reference cases exist so far for adaptation expenses. This is also the case for the approval of new infrastructure with additional climate-proofing expenses. Retrofitting of existing infrastructure could in principle be posted under investment budget as restructuring measures, if they demonstrably improve the technical security of the grid. The approval depends on the consent of the federal state supervisory authorities. In the past, the restoration of Thomas steel pylons has been approved, but only after about 80 pylons of this material had collapsed in a winter storm in 2005 and caused a blackout.

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[17] Own translation of "'*[...]Ereignis, das nach menschlicher Einsicht und Erfahrung unvorhersehbar ist* [...]"'.

Another aspect where transparency and predictability are needed is the correction of the efficiency score in singular cases, if particularities of the supply task or supply area can be proven that are not captured by the environment variables. The Federal Supreme Court has determined that these include any exogenous requirements that the operator cannot evade without unbearable effort. This includes all basic conditions that affect the operation and that the operator cannot influence directly (Bundesgerichtshof, 2012). Based on this definition, network operators will not face high risks in proving a particularity due to weather related impacts, if substantial additional costs have been incurred.

5 Implications for Investment in Adaptation in Germany

Since grid operators balance the revenue effect of damage and adaptation costs against each other, the effects of both need to be contrasted to assess whether biases towards precautionary over- or under adaptation are introduced. Biases are introduced, if only one cost category affects the revenue cap. In the undistorted case, the expected net benefits of adaptation only depend on the climate developments. Table 2 gives an overview on the influence of regulation on adaptation and damage costs.

		Impact of A-Capex/-Opex on cap	
		positive	no or negative
Impact of D-Capex/-Opex on cap	positive	indifferent to adapt; risk of inadequate adaptation on demand side	overly low incentives to adapt; risk of inadequate adaptation on demand side
	no or negative	overly high incentives to adapt; cost of inadequate adaptation on demand side	undistorted incentives to adapt; risk of inadequate adaptation on supply side

Table 2: Overview on impact of regulation on ex ante adaptation [own illustration]

The previous analysis shows that the main regulatory uncertainty exists with regard to the allowance of adaptation expenses. Therefore we differentiate between two cases: a high predictability that (1) A-Capex and A-Opex are neither approved during the period nor the review or (2) A-Capex for new infrastructure are approved during the period and A-Opex as well as A-Capex for existing infrastructure during the review.

In the first case, A-Opex and A-Capex both for new and existing infrastructure do not affect the revenue cap or only marginally positively, if they effectively increase the quality factor for (DSOs). Since damage costs from SOEs have no or an ambiguous (depending on the effect on x-ind and quality) effect on the revenue cap, the decision to adapt to such events depends only in the expected extent of both types of costs. In any case, the risk of inadequate adaptation is on the supply side. In contrast, the damage costs resulting from EWEs have a positive effect on the revenue cap. Therefore, the German regulation introduces a bias towards overly little adaptation to such events and shifts the risk of inadequate adaptation to the demand side.

In the second case, the picture is different: since approved in the review, A-Opex and A-Capex for existing infrastructure have an ambiguous (depending on the effect on x-ind and quality) effect on the revenue cap, whereas A-Capex for new infrastructure has an immediate positive effect on the cap and an ambiguous effect in the subsequent review (depending on the effect on x-ind and quality). Since the effect of damage costs from SOEs on the cap has not changed, the decision for A-Opex and A-Capex for existing infrastructure is still undistorted. However, overly high incentives for A-Capex for new infrastructure exist. In the latter case, the risk of too much adaptation is shifted to the demand side. For adaptation to EWEs, also in this second scenario overly low incentives exist to spend A-Opex or A-Capex on existing infrastructure. Again the risk of too little adaptation is on the demand side. Since not only damages from EWEs but also A-Capex for new infrastructure have a positive effect on the revenue cap, the operator is indifferent to this kind of adaptation. The risk of inadequate adaptation is borne by the demand side.

For TSOs the regulation does not reward the quality of service. That’s why, any form of ex ante adaptation is less attractive for them. This is particularly striking, since their infrastructure is mostly overground and thus more exposed than the infrastructure of DSOs.

6 Discussion and Conclusions

The electricity grid regulation in Germany differentiates between impacts from extreme weather events and from slow onset events. For the former, it gives disincentives for flexible adaptation and incentives for irreversible climate proofing of infrastructure depend on the approval by the regulator. Currently, the the eligibility of adaptation costs in the review year is uncertain, which discourages investment. In the German Action Plan on Adaptation the German Government proposes to consider whether adaptation related additional expenses can be claimed by the network operators Bundesregierung (2011). If this was the case, the network operator would be indifferent to irreversibly adapt to extreme weather events since both types of costs could be passed through to customers. For slow onset events the picture is different: climate proofing of infrastructure to such events is either undistorted or overly encouraged in case of cost disapproval or approval, respectively. Undistorted means that the expected net benefits of adaptation only depend on the climate developments. Undistorted are also the incentives for flexible measures to adapt to SOEs.

Another source of uncertainty affects the decision making on adaptation besides uncertain climatic changes and regulatory decision-making: the behavior of other network operators. In the current setting, network operators that are either particularly more affected by weather related impacts or that take preventive measures are discriminated against in the efficiency comparison. Under the current climate conditions, this may still only be a marginal effect. However, it grows substantially with ongoing climate change and should be considered in future adjustments of the regulatory design. An approach to correct for such a bias could be to introduce weather or climate variables in the efficiency comparison. Further research in this area is needed to analyze the effects of such adjustments.

In addition, the results hold for profit-maximizing network operators. For operators that are have strong regional ties and are to some extent owned by municipalities, the behaviour may diverge. In this case reputational concerns, for instance, may dominate the decision-making on adaptation. Hence ownership may play an important role.

In the current set-up, technical security is to a great degree the self-responsibility of the network operators. The energy supervisory authorities of the federal states only control for it in the plan approval procedure before the initial operation of the assets. Not only can climate change considerations be integrated in this early phase of set-up (e.g. site approval), but also periodical controls could be conducted by the authority. The latter would, however, increase transactions costs of regulation to a great degree.

An important political question that precedes the discussion on whether the regulatory design gives the right incentives to adapt to climate change impacts is the question of what level of robustness wants to be achieved. A related question is who should carry the risk of (too) little adaptation. In a competitive setting it can be assumed that a firm will adapt as long or as much as the marginal benefits outweigh the marginal costs of adaptation. For critical infrastructure, whose failing has a strong effect on society, it may be of particular interest that a higher level of robustness is maintained. As Brunekreeft (2013, p.13) puts it in a similar context: “the ’cost of doing it wrong’ may be significantly higher than the ’benefits of doing it right.”’ On the contrary, due to the uncertainty of climatic developments, it may be a political objective to maintain enough leeway for learning and later adjustments of infrastructure. Related to this aspect is also the issue of budget restrictions and opportunity costs of investment. Due to limited financial resources, a trade-off between adaptation of existing and building of new infrastructure exists. At a time of great transformations of the German energy sector, the reinforcement of existing infrastructure may counter these attempts.

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