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The Costs of Power Interruptions in Germany - an Assessment in the Light of the Energiewende

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The German Energiewende's potential effects on the reliability of electricity supply as well as the corresponding economic consequences have recently entered both the political and scientific debate. However, empirical evidence of power outage costs in Germany is rather scarce. Following a macroeconomic approach, we analyse the economic costs imposed by potential power interruptions in Germany. Investigating a rich data set on industry and households we estimate both Values of Lost Load (VoLLs) and associated costs of power interruptions for different German regions and sectors and every hour of the year. This disaggregated approach allows for conclusions for optimal load shedding in case of technical necessity and the economic efficiency of measures to improve security of supply. We find that interruption costs vary significantly over time, between sectors and regions. Peaking on midday of a Monday in December at 750 Mio€ per hour, the average of total national outage costs amount to approximately 430 Mio€ per hour. The industrial sectors facing the highest outage costs are the machinery and transport equipment sectors. Their aggregated hourly outage costs average out at approximately 20 Mio€. Our results emphasize the prominent regional aspect of the German Energiewende as the regions with the highest estimated cost of interruptions in South and West Germany coincide with the areas which face nuclear power plant shut downs in the near future.

Keywords: Security of Supply, Value of Lost Load (VoLL), German Energiewende, Electricity outage costs

JEL classification: Q40, Q41, D61, L94

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1. Introduction

In 2011, the German government decided to radically change national energy policy. After the events in Japan's Fukushima, a nuclear moratorium was determined and, in summer 2011, a set of new energy and climate policy laws putting a strong focus on renewable energy promotion enacted. Germany introduced the so called Energiewende: beside the confirmation of the target that renewable energy should contribute 35% to overall electricity consumption in 2020, the government ordered the immediate shutdown of eight existing nuclear power plants and declared to decommission the remaining nine German nuclear power plants until 2022. Next to the economic challenges – additional costs for the Energiewende are projected to be more than 250 billion Euro up to 2030 (Pesch et al., 2012) – security of electricity supply will increasingly become an issue: the major source of renewable generation will be in Northern Germany, from both on- and offshore wind generation. This electricity needs to be transported to the centres of electricity demand in Southern Germany. Now, the high-voltage transmission lines for this purpose have not been built yet and current grid extension realisation gives serious doubt that the necessary connections from Northern to Southern Germany will be accomplished before the rest of the nuclear plants in the South of Germany will have been decommissioned. Since South and West Germany are the industrial centres of Germany and have the largest population among the German federal states the Energiewende might put a majority of German citizens and industry under the risk of insecurity of supply of electrical energy. This risk can be separated into two aspects. The first is a technical one and can be described as the technical probability of a service interruption. The second aspect relates to the economic damage a customer has to take in case of interruption. This damage is equivalent to the opportunity cost of alternative (economic) activity or the Value of Lost Load (VoLL). In this paper, we estimate the costs of power interruptions based on the VoLL in Germany to identify potential additional cost of the Energiewende induced by an increasing economic risk of insecurity of electric energy. Given Germany's regionally heterogeneous population, industry structure, demand patterns as well as the regional effect of nuclear power plant decommissioning we put a special focus on regional economic vulnerability imposed by potential power interruptions. Therefore, we estimate the costs of power interruptions for different German regions and sectors for any hour of a year. Our analysis allows us to investigate the economic risk of potential power interruptions and, by that, conclusions for optimal load shedding in case of technical necessity - or, more generally put, information about economically efficient solutions how to deal with shortages of electricity supply.

Methodologically, three different approaches have been applied in previous research to derive the economic costs of power interruptions. First, some studies have drawn upon historical blackouts to infer outage costs from available data (see Corwin and Miles (1978) or Serra and Fierro (1997). Second, surveys were used to investigate the willingness to pay for the avoidance of an interruption among different groups of customers (see, among others, Balducci et al. (2002) or LaCommare and Eto (2006)). While the obvious advantage of this methodology is the independence from actual power outages that are rare in developed countries, a clear shortfall is that customers may not state their true willingness to pay.[1]

The third methodology used to obtain estimates of welfare losses caused by interruptions in electricity supply is the macroeconomic approach. Within this framework, electricity is interpreted as an input factor both for firms and private households. The approach seeks to derive economic costs of electricity outages from the loss in output generated by these two groups. To calculate the costs of outages, we first estimate the VoLL, defined as the loss in output resulting from not supplying one unit of electricity and measured in Euro per kilowatt hour (€/kWh). We then multiply the VoLL with hourly regional and/or sectoral demand (in GW) to obtain the costs of power interruption for any hour of the year.

A crucial advantage of the macroeconomic approach, especially in comparison to surveys, is the estimate of outage costs based on an objective measure. Moreover, as the method relies on publicly available data, it represents a more feasible approach than studies based on historical outages in which the results are rather case-specific and hence suffer from a lack of generalization (Linares and Rey, 2012).

However, the benefits of the macroeconomic methodology also come at a cost, since the approach only captures losses in output while disregarding instantaneous damages caused by the supply interruption. Another critical aspect of the macroeconomic approach is the implied assumption of linearity among electricity input and generated output. An immediate consequence of this supposition is that the relation between outage duration and interruption costs is also characterized by linearity. This may be considered a shortfall, as any adjustment of electricity customers to outages is neglected. Hence, the methodology is particularly suited for the assessment of economic costs resulting from short-term power interruptions. Moreover, the shortcomings of the macroeconomic approach seem to be rather small compared to those of the alternative methodologies, while the benefits discussed above are appealing for the purpose of our study. Thus, we utilize the macroeconomic approach to investigate the economic risk of insecurity of electric energy in Germany. Our findings show relatively higher costs of power interruption for South and West Germany, indicating relatively higher welfare losses if these regions will be affected by insecure electricity supply.

The remainder of the paper is structured as follows. Section 2 discusses previous research. Section 3 presents the methodological approach. Results from the empirical analysis are discussed in Section 4. Section 5 concludes.

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[1] An illustrative example is the case of industrial customers with interruptible contracts: There is clearly an incentive to overstate willingness to pay since customers seek high discounts on the tariffs paid. On the other hand, as many customers are not used to power outages, some of them may underestimate the induced losses in utility.

2. Previous research

Several studies have relied on the macroeconomic approach to determine the economic value of a secure electricity supply. Bliem (2005) investigates the economic costs of power interruptions for Austria. He derives VoLLs for both households and economic sectors based on electricity dependent leisure activities and sector specific gross value added. Beyond the sectoral disaggregation, the research also accounts for demographic and economic structures of various regions through the derivation of regional VoLL-figures. Overall, Bliem concludes that outage costs within the residential sector and the aggregated outage costs within the economic sectors have comparable magnitude. On national average the VoLL amounts to 8.60€/kWh.

de Nooij et al. (2007) analyze the economic value of supply security in the Netherlands. They calculate sectoral VoLLs accounting for day of the week effects and construct estimates of aggregated hourly outage costs. On national average, they estimate the economic cost of one kWh electricity not supplied to be 8.56€. In an extension of this work, de Nooij et al. (2009) advocate, from a welfare perspective, the superiority of rational rationing, i.e. curtailing regions with low VoLLs first, compared to a random selection of curtailed regions in case of an outage.

Following a similar approach, Leahy and Tol (2011) investigate the value of secure electricity supply in Northern Ireland and the Republic of Ireland. They estimate the economic costs of a one-hour blackout with respect to different times of day, days of the weeks and groups of customers. Their findings reveal that the residential sector exhibits the greatest VoLL over all sectors in both countries.

Linares and Rey (2012) explore national as well as regional outage costs in Spain. Their study stresses both regional and sectoral heterogeneity of power interruption costs. On an aggregated level, they estimate the average VoLL for Spain to be 6.35€/kWh. Moreover, the authors argue that electricity market regulation in Spain does not provide appropriate incentives to prevent electrical power outages. Thus, they conclude that the Spanish level of electricity system reliability is not optimal from a welfare point of view.

In the context of Germany's nuclear phase out, Praktiknjo et al. (2011) estimate the economic value of supply security within Germany for the residential sector. The authors rely on numerical simulation and are therefore able to account for uncertainty regarding consumer preferences, marginal wages and time use. The result of their Monte Carlo approach yields a right-skewed distribution of residential VoLL estimates, with average economic costs of 15.70€/kWh electricity that is not supplied to the customer. Moreover, they investigate the additional economic costs that would arise if the German System Average Interruption Duration Index (SAIDI) was increased to the European average. Praktiknjo et al. (2011) conclude that such a decrease in the level of service reliability in Germany would cause significant economic costs.

However, previous research on outage costs in Germany has neglected the investigation of outage costs on a disaggregated sectoral level as well as the combined effects of regional and sectoral effects. Our paper contributes by identifying sectoral and regional VoLLs and thereby gives important additional insight in the economic risk of the Energiewende.

3. Methodological Approach

For the derivation of electrical power outage costs within the residential sector, it is important to consider the kind of output generated by households. People gain utility from leisure activities. However, the relation between availability of electricity and leisure activities is not straightforward: While some leisure activities directly or indirectly depend on electricity (e.g. watching television), others do not (e.g. reading in times of daylight). This reasoning suggests that the correlation of leisure-induced welfare and electricity consumption may neither be zero nor one, but rather in the range between these two values. Since substitutability between electricity-based leisure activities and non-electricity-based leisure activities is likely to exist, we follow the approach as advocated by Bliem (2005) and assume a coefficient of substitution equal to 0.5. In other words, power outages reduce the amount of welfare households gain from leisure activities by 50%.[2]

In order to determine the amount of time households dedicate to leisure activities we take advantage of labour market data and available information regarding the shares of time assigned by households to different activities. Computing the annual amount of leisure across all households and multiplying by the factor of substitutability yields the time spent for electricity-based leisure activity.

However, an economic value has yet to be assigned to leisure. The work of Becker (1965) provides an economic framework to derive a monetary value for leisure time. In his model Becker argues that households gain utility from the consumption of goods and from leisure activities. The money for consumption is earned by working. Further, since the marginal utility of both consumption and leisure activities decreases with each additional unit there is an optimal amount of working and non-working hours. Within this equilibrium, the household is indifferent between an additional hour of work and an additional hour of leisure. That is, the value of an additional hour of leisure is equal to the income from an additional hour of work.

However, Becker's approach may not apply to people that are not employed (i.e. unemployed, children, pensioners, sick or disabled persons), as their opportunity costs of leisure are no longer equal to the hourly income. Since leisure time in this case is less scarce than for employed people, valuing leisure by the hourly income may be an overestimation. On the other hand, it is obvious that their leisure time is still valuable. In order to capture the different opportunity costs of leisure for employed and non-employed people, we assume that an hour of leisure is worth half the hourly income to the group of non-employed. This approach is in line with the methodology proposed by de Nooij et al. (2007, 2009) and followed by Linares and Rey (2012).

Once the economic value of leisure is obtained, the VoLL of the residential sector can be calculated as the ratio of this value and the electricity consumption. Since hourly wages and average working hours vary significantly among federal states in Germany, the opportunity costs of leisure as well as the amount of time that is available for leisure

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[2] In particular, long interruptions can also lead to losses in goods; such as refrigerated or frozen food. As a result of missing data these losses are not taken into account.

activities are expected to be regionally heterogeneous. Hence, we specify the residential VoLL-calculations not on a nationally aggregated level, but rather on a state-specific level, explicitly accounting for regional labour market conditions.

The VoLL of the residential sector r in federal state f can be stated as

$$VoLL_{r,f} = \frac{VL_{r,f}}{EC_{r,f}}, \tag{1}$$

where $VL_{r,f}$ is the federal state's (annual) economic value of leisure and $EC_{r,f}$ is the federal state's (annual) residential electricity consumption. The VoLL, as calculated in Equation (1), is by construction a static value as it normalizes the annual residential output to the use of one unit of electricity. However, leisure activities enjoyed by households are unarguably not equally distributed throughout the day. Thus, outage costs differ with respect to the moment the interruption occurs. Moreover, actual economic interruption costs are also determined by the absolute amount of power not supplied. Therefore, for an absolute and time-varying estimate of outage costs, the static VoLL (measured in €/kWh) is not sufficient. In fact, the static VoLL of the residential sector r within a federal state f has to be multiplied by its power consumption $EC_{r,f,t}$ in hour t to yield a proper estimate of time-varying costs. Consequently, the time-varying outage costs can be expressed as

$$OC_{r,f,t} = \frac{VL_{r,f}}{EC_{r,f}} \times EC_{r,f,t} = VL_{r,f} \times lf_{r,t}, \tag{2}$$

where $lf_{r,t}$ denotes the load factor in hour t that can be obtained from a standard residential load profile.[3] In the case of firms, output is measured by gross value added. Hence, the ratio of gross value added to electricity consumption represents a measure of economic output generated by inputting one unit of electricity. The macroeconomic approach implies the assumption that the value adding process of firms fully depends on electricity consumption. As noted by de Nooij et al. (2007, 2009), this linearity assumption may lead to an overestimation of the outage costs. However, other costs from losses in goods and materials or from restart costs in consequence of the power interruption are not included.

As the role of electricity in production processes varies significantly across economic sectors, the same holds true for the VoLL. Hence, the accuracy of estimates regarding economic costs of power interruptions crucially depends on the extent of sector-specific granularity. Following this argumentation, we investigate power interruption cost on a disaggregated sectoral level and calculate VoLLs and time-varying outage costs for a number of economic sectors. Beyond the sector-specific differences, power interruption costs may also depend on the regional economic structure as well as the technologies that are regionally available. Therefore, we additionally differentiate between federal states in our calculations. This makes the obtained VoLL estimates more credible since we

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[3] A standard load profile is a representative load profile, i.e. a representative mapping of electrical load over time.

account for both regional and sectoral heterogeneity. Consequently, the VoLL of sector s in federal state f is

$$VoLL_{s,f} = \frac{GVA_{s,f}}{EC_{s,f}}, \tag{3}$$

where $GVA_{s,f}$ and $EC_{s,f}$ are the (annual) gross value added and the (annual) electricity consumption of sector s in federal state f, respectively. The time-varying outage costs within sector s in federal state f at a specific hour t are

$$OC_{s,f,t} = \frac{GVA_{s,f}}{EC_{s,f}} \times EC_{s,f,t} = GVA_{s,f} \times lf_{s,t}. \tag{4}$$

In other words, the hourly outage costs represent the respective VoLL multiplied by current power consumption. This is equivalent to the annual output scaled by the hourly load factor $lf_{s,t}$, that can be derived from the appropriate standard commercial load profile.[4]

4. Empirical results

4.1. Value of Lost Load

Table 1 presents the estimated VoLLs. The values are sectorally and regionally disaggregated into 15 economic sectors and one residential sector and 16 federal states of Germany. To calculate values, we collect data on electricity consumption from the energy balances for both Germany entirely and each state individually. In a limited number of cases, missing values are replaced by values from Eurostat's energy statistics.[5] The data on gross value added is drawn from the regional economic accounts of the federal states provided by the Statistical Office of Baden-Württemberg (2011). The reference year is 2007. A detailed overview on the utilized electricity consumption and gross value added data is provided in the Appendix (see Table A.1 and Table A.2).

The gaps shown in Table 1 result from missing data on electricity consumption and/or gross value added for some sectors in some states. For four states, namely Berlin (BE), Brandenburg (BB), Saxony (SN), and Thuringia (TH), data for the manufacturing sector was only available on an aggregated level. However, as none of these states are characterized by an exceptionally large or highly industrialized manufacturing sector we consider any bias that may be included in the aggregated manufacturing VoLL of these states as negligible.

Furthermore, for the agriculture and fishing and construction and services sectors, disaggregated data on electricity consumption was only available on the federal level (D). However, as for these sectors, the technological heterogeneity across regions can be

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[4] The assignment of load profiles to the different commercial sectors is discussed in Section 4.2.

[5] The accounting policies for the energy balances of the federal states are defined by the Länderarbeitskreis Energiebilanzen in close cooperation with the Arbeitskreis Energiebilazen e.V., which is responsible for the preparation of the overall energy balance of Germany. For further information, see, www.lak-energiebilanzen.de and www.ag-energiebilanzen.de.

Table 1: Value of Lost Load in €/kWh (2007)[a,b,c]

Sector	BW	BV	BE	BB	HB	HH	HE	MV	NI	NW	RP	SL	SN	ST	SH	TH	D
Agriculture and fishing																	2.49
Manufacturing																	
• Food, beverages and tobacco	2.00	2.58			2.04	2.43	2.61	1.75	1.80	2.05	2.25	2.01		1.42	2.42		2.08
• Textile and leather	3.65	2.42					4.26	11.98	3.71	2.62	2.02			0.62			
• Wood and wood products	2.11				7.81		2.51	0.75	1.24	1.22	1.61	0.57		0.78			
• Pulp, paper and print	1.11	1.06			6.95	19.07	2.26	2.34	0.98	1.15	1.07			0.69	1.41		1.40
• Chemical and petro-chemical	3.25	1.11			2.43	2.94	2.27	1.74	0.48	0.80		0.28		0.51	1.32		1.07
• Rubber and plastic	2.04	1.90			5.21	1.78	1.99	1.77	1.65	1.97	1.17	1.06		1.06			1.75
• Non-metallic minerals	1.32	1.46			0.52		1.74	2.01	1.18	0.75	1.24	2.46		0.81	1.14		1.09
• Basis metals and fabricated metal products	2.30	2.26			0.86	0.29	2.27	2.77	0.77	1.03	1.59	1.32		1.74	3.58		1.30
• Machinery and equipment n.e.c.	7.73	7.26			16.99	13.12	9.76	5.42	8.56	8.46	9.83	5.01		5.22	8.60		7.97
• Electrical and optical equipment	7.16	6.77			24.39	9.30	6.05	6.14	5.25	3.11	9.02	6.37		4.99			
• Transport equipment	4.84	5.95			5.46	6.51	3.12	3.56	3.84	3.49	3.83	3.91		2.98	3.30		4.55
• Manufacturing n.e.c. and recycling	6.33					5.32	3.69	3.96	3.53	4.11			1.85				
Manufacturing total	3.58	2.81	4.65	1.06	2.44	2.23	3.04	2.18	1.58	1.51	2.13	1.87	1.91	1.06	2.21	1.77	2.19
Construction																	102.93
Services																	11.04
Households	14.53	13.77	17.37	12.53	11.96	11.70	14.96	12.40	12.11	13.12	11.93	13.00	12.77	10.86	10.23	9.50	11.92

[a] The state codes represent Baden-Württemberg (BW), Bavaria (BV), Berlin (BE), Brandenburg (BB), Bremen (HB), Hamburg (HH), Hesse (HE), Mecklenburg-Vorpommern (MV), Lower-Saxony (NI), North Rhine-Westphalia (NW), Rhineland-Palatinate (RP), Saarland (SL), Saxony (SN), Saxony-Anhalt (ST), Schleswig-Holstein (SH), Thuringia (TH), and Federal Republic of Germany (D). [b] The sector classification follows the Statistical Classification of Economic Activities in the European Community (NACE Rev.1.1). [c] The reference year for Lower-Saxony is 2006. Source: Own calculations.

assumed to be rather low, we do not consider the lack of regional disaggregated VoLLs for these sectors as a problem. In fact, in order to include these sectors in our regional outage cost calculations, we use the sectors' federal VoLLs and the sectors' regional disaggregated data on gross value added to calculate the sectors' regional disaggregated electricity consumption. By doing so, we are able to calculate regional outage costs that, in terms of gross value added, encompass at least 90% of all economic sectors in the federal states (see Table A.1).[6]

The data on electricity consumption for the household sector is taken from the same sources as for the economic sectors. To calculate the second element of the households' VoLLs, the value of leisure $VL_{r,f}$, we use data on the labor market provided by the regional economic accounts of the federal states and Eurostat, as well as time use data provided by the Federal Statistical Office of Germany. The labor market data includes information on employed and unemployed persons, number of actual hours worked per employee per year and labor costs per hour on the regional level. A detailed overview on this data is provided in the Appendix (see Table A.3). The time use data of the Federal Statistical Office of Germany indicates that the average German person spends around 11 hours per day on personal care such as sleeping, eating, washing and dressing (Federal Statistical Office of Germany, 2003).

The first step in determining our value of leisure requires the derivation of the employees' net hourly income. Given that the employer's average rate of social security contributions amounts to approximately 22% of the labor costs per hour (Federal Statistical Office of Germany , 2008) and that the employees' average rate of income tax and social security contributions amounts to approximately 33% of the gross hourly income (OECD, 2012), we calculate a regional net hourly income equal to around half of the respective regional labor cost per hour (see Table A.3).

Using the information described above, the annual value of leisure of all employed persons in the federal state f can be calculated as

$$\begin{aligned} VL_{e,f} = &((8760 - 365 \times 11 - hours\ work_f) \times net\ hourly\ income_f) \\ &\times number\ of\ employed\ persons_f \times 0.5, \end{aligned} \tag{5}$$

where 0.5 reflects the assumed substitutability between electricity-based leisure and non-electricity-based leisure as defined in Section 2. Similarly, assuming that the hour of leisure for unemployed persons is worth half the net hourly income of that of the employed (see Section 2), the annual value of leisure for all unemployed persons in the federal state f is calculated as

$$\begin{aligned} VL_{u,f} = &((8760 - 365 \times 11) \times 0.5 \times net\ hourly\ income_f) \\ &\times number\ of\ unemployed\ persons_f \times 0.5, \end{aligned} \tag{6}$$

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[6] As can be seen in Table A.1 in the Appendix, the data on gross valued added encompasses 90% of all economic sectors in Rhineland-Palatinate (RP). For all other federal states, a higher percentage is given.

Together, $VL_{e,f}$ and $VL_{u,f}$ add up to the residential value of leisure in the federal state f, $VL_{r,f}$. This value divided by the households' electricity consumption in a given state yields the residential VoLL in the federal state f, $VoLL_{r,f}$.

As can be seen in Table 1, the VoLLs vary significantly between the sectors and the federal states. First, with respect to sector level, the highest federal VoLL, is observed for the construction sector with 102.93€/kWh. This value is much higher than all other VoLLs, which results from a relatively higher gross value added than the level of electricity consumed in this sector. In other words, the construction sector is characterized by an exceptionally low energy intensity (kWh/€) compared to other sectors.[7] At the federal level, the construction sector accounts for approximately 4% of gross value added but only for approximately 0.2% of total electricity consumption in all economic sectors considered (see Tables A.1 and A.2 in the Appendix).

The federal VoLLs for the service sector and for the households amount to 11.04€/kWh and 11.92€/kWh, respectively. Both sectors are large electricity consumers, with the service sector accounting for approximately 36% of total electricity consumption in all economic sectors considered. Moreover, households account for approximately 27% of overall electricity consumption at the federal level. In addition, both sectors also generate a large amount of the total value, i.e. the sum of gross value added from the economic sectors and the value of leisure from the households. At the federal level, the service sector accounts for approximately 69% of gross value added and the households for approximately 43% of total value.

In contrast, the federal VoLLs of the agriculture and total manufacturing sectors are relatively low (2.49€/kWh and 1.62€/kWh). Compared to the service sector, the manufacturing sector consumes even more electricity-approximately 62% of total electricity consumption in all economic sectors considered-but it creates only approximately 24% of gross value added. Finally, for the agricultural sector, both numbers are low. At the federal level, the agricultural sector accounts for approximately 2% of total electricity consumption in all economic sectors considered and contributes approximately 1% of gross value added.

Overall, our sector results are in line with the results from studies of other countries (see, e.g. Bliem (2005), de Nooij et al. (2007), and Linares and Rey (2012)). All studies indicate relative low VoLLs for the agricultural and manufacturing sectors compared to relative high VoLLs for the construction, service and household sectors.

On the regional level, the VoLLs for the federal states indicate a large heterogeneity among states. In particular, the city-states Berlin, Hamburg and Bremen show VoLLs in some sectors that differ significantly from the corresponding VoLLs of the other states. This is due to the fact that in small states, one or just a couple firms with a specific VoLL have a high sectorial impact. For example, the sector pulp, paper and print in

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[7] Although the result that the construction sector has the highest VoLL among all sectors is in line with the results from other studies, the amount is rather high. For example, Bliem (2005) calculates a value of 42.4€/kWh for Austria and Linares and Rey (2012) calculate a value of 33.37€/kWh for Spain. In order to check whether our high VoLL for the construction sector is a result of a one-year effect in the year 2007, we also calculated VoLLs for the construction sector in the years 2001 to 2009. In all years, the VoLL remains quite stable around 100€/kWh.

Hamburg consists mainly of printing and publishing firms rather than any huge pulp or paper production plants. Since printing and publishing has significant lower energy intensity than pulp and paper production, Hamburg's VoLL for this sector is much higher than in other federal states with a different sectorial structure. Similar arguments can be applied to other sectors such as the machinery and equipment n.e.c. sector and the electrical and optical equipment sector. Overall, the heterogeneity in the regional VoLLs shows that there exists large differences in the economic structures of the federal states and it is therefore important to differentiate between regions in order to obtain credible estimates of regional outage costs.

The derived VoLLs constitute a valuable framework to assess the relative economic efficiency of load shedding within different sectors and regions: Economic theory suggests that, in case of a supply shortage, it is welfare-optimal to curtail the customer with the lowest VoLL first. The potential welfare gains of such a rational rationing (i.e. curtailing regions and sectors with low VoLL first compared to a random selection) have been advocated by de Nooij et al. (2009). Hence, the sectoral VoLLs of our study could be used as an indication in which sectors interruptible electricity contracts are comparatively efficient.

4.2. Time-varying Outage Costs

Since output generated by the sectors is not equally distributed over seasons, weeks, and days, the outage costs vary significantly over time. Given the assumed linearity among electricity input and generated output, we scale each sectoral output along the standard load profile that most appropriately reflects the power consumption patterns of the specific sector. For this purpose, we rely on the residential and commercial standard load profiles for 2012, as specified by the German Association of Energy and Water Industries and published by E.ON (2012).

For the residential sector, the choice of a suitable load profile is straightforward, as a standardized profile for households exists. The same holds true for the agricultural sector.[8] The identification of suitable profiles for the other economic sectors is more challenging. Since no public data is available on firm- and sector-specific standard load profiles, we choose the most general standard commercial load profile for sectors when no better guess exists. However, if we assume continuously producing enterprises to prevail within a certain sector, we assign standard load profiles specifically designed for this kind of firms to the respective sector.[9]

Figure 1 and Figure 2 display the structure of the total national outage costs in Mio € per hour, aggregated over all regions and sectors. Total national outage costs exhibit different patterns with respect to time. Figure 1 shows the mean-, maximum-,

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[8] There exist various standard load profiles for the agricultural sector, depending on the type of agriculture. Since we do not have any detailed information on the agricultural structure in Germany, we choose the most general standard load profile for agriculture, "L0".

[9] We assign profiles for continuously producing enterprises to the following sectors: Pulp, paper and print, chemical and petrochemical, basis metals and fabricated metal products, machinery and equipment n.e.c. and transport equipment.

and minimum-hourly outage costs occurring each day throughout the year. The u-shaped curvature of average outage costs illustrates their seasonality since the costs of interruptions are higher during the winter compared to the summer months. Moreover, the intra-weekly fluctuations are reflected in the weekly drops in average outage costs, stressing that the average outage costs are higher on working days compared to weekends. Maximal national outage costs per hour amount to more than 750 Mio € on a Monday in December between 1 p.m. and 2 p.m., while the lowest costs, around 168 Mio €, arise on an early Sunday morning between 3 a.m. and 4 a.m. in September. On average, a nationwide one-hour power interruption causes a welfare loss of more than 430 Mio €.

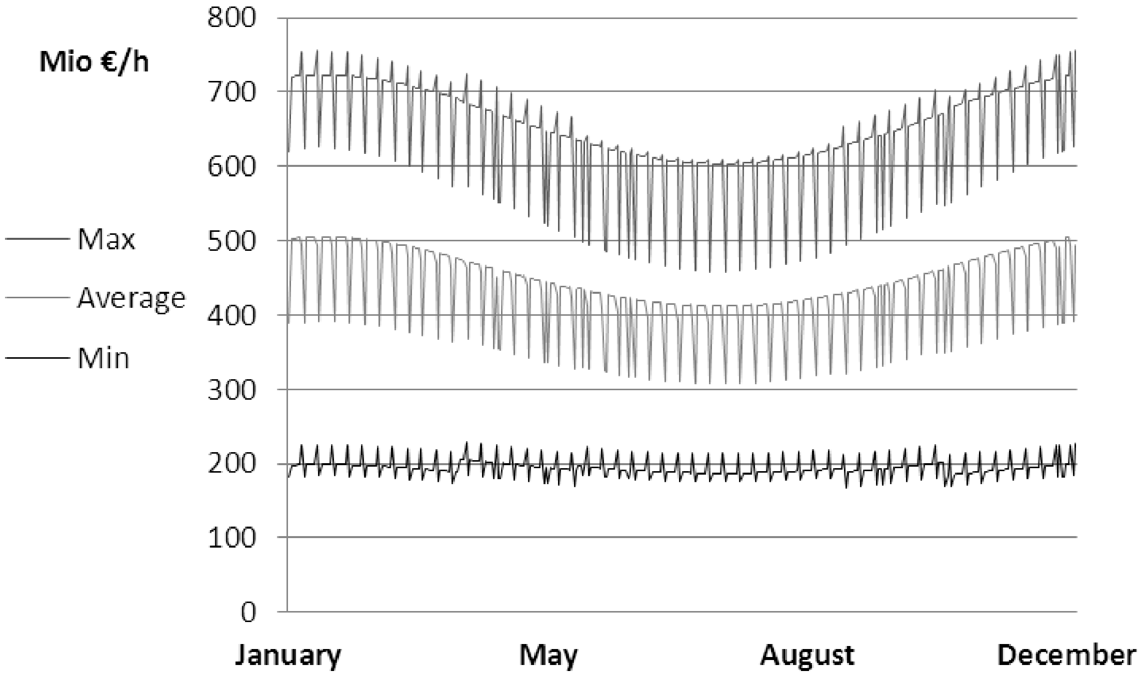

Figure 1: Total national outage costs in Mio € per hour
(Source: Own calculations.)

Moreover, the differences between the three displayed series at each point of time in Figure 1 emphasize the variation of outage costs during the day. This intraday fluctuation of outage costs is presented more detailed in Figure 2. The displayed annual averages of hourly outage costs at a specific time of the day exhibit two distinctive peaks: The greatest total hourly outage costs occur between 11 a.m. and noon and subsequently decline until 4 p.m. From this moment on, average total hourly outage costs start to rise to a second peak, which can be observed from 6 p.m. to 7 p.m. Averaged aggregated hourly outage costs are considerably lower during the night, reaching a minimum between 2 a.m. and 3 a.m.

Beyond the calculation of aggregated national outage costs, it seems promising to investigate the distribution of outage costs among the different sectors. Therefore, we calculate hourly costs of power interruptions on a sectoral level. Table 2 contains mini-

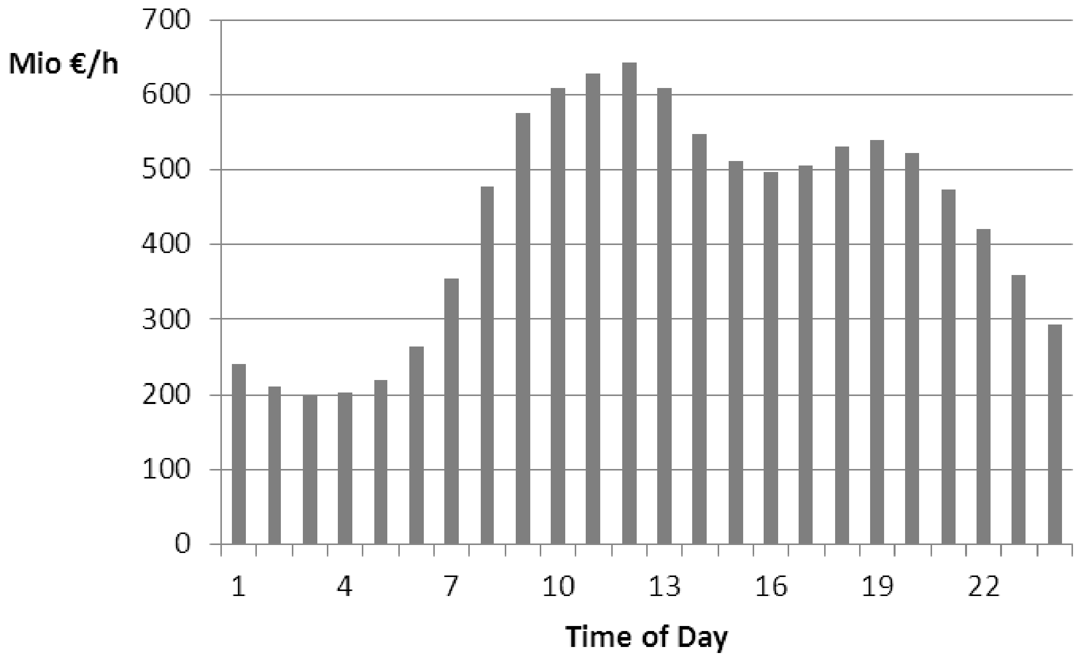

Figure 2: Average total national outage costs for each hour of the day in Mio € per hour (Source: Own calculations.)

mum, maximum and average values of sector shares based on total hourly outage costs as well as information on the moment when the extreme values of sector shares occur.[10]

Table 2: Time-varying sectoral shares based on total national outage costs

	Residential	Agriculture	Manufacturing[a]	Commercial and Public Services
Min Share	31%	0%	8%	18%
Time	Sep/Sat/4 a.m.	Jan/Sat/2 p.m.	Jan/Sun/11 a.m.	Jan/Sun/11 a.m.
Max Share	74%	2%	23%	53%
Time	Dec/Sun/11 a.m.	Nov/Thu/8 a.m.	Jul/Sun/5 a.m.	Nov/Fri/11 a.m.
Average Share	46%	1%	15%	39%
Median Share	43%	1%	14%	39%

[a] Including construction. Source: Own Calculations.

On average, the residential sector accounts for 46% of total hourly outage costs. The service sector ranks second as it captures on average 39% of all hourly welfare losses

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[10] The maximum and minimum values may occur several times throughout the year. The information provided refers to the first time within the year that the respective value can be observed. For the sake of simplicity, a brief notation is used in Table 3: For instance, “Sep/Sat/4 a.m.” indicates that the extreme value occurs on a Saturday in September from 4 a.m. to 5 a.m.

resulting from power interruptions. Aggregated hourly costs in the manufacturing sector (including construction) represent on average 15% of total interruption costs, whereas the welfare losses in the agricultural sector are comparatively small.

However, a remarkable feature of the structure of national outage costs is that the sectoral shares based on total outage costs vary over time: Approximately 74% of aggregated hourly outage costs can be assigned to the residential sector on a Sunday at noon in December, whereas its share decreases to 31% of total hourly costs during nights in September. Within the commercial sectors, the cost share of the service sector varies between 18% and 53%. Our finding of heavily time-dependent sectoral cost shares stresses the fact that, without knowing the exact moment of a power interruption, it cannot be known a priori which sector bears the greatest welfare losses from the outage.

Our extensive data set allows for a more elaborate analysis of the costs arising from an interruption in power supply within the manufacturing sector. We calculate time-varying outage costs for a variety of manufacturing sectors using the standard load profiles discussed above. Based on these sectoral cost estimates, we compute the sectoral shares on total outage costs in the manufacturing sector as well as on total national outage costs for each hour of the year. Descriptive statistics on these shares are shown in Table 3.

Table 3: Time-varying sectoral shares based on total national outage costs

Sector	Share on Manufacturing Costs[a]			Share on Total National Costs		
	Average	Min	Max	Average	Min	Max
Food, beverages and tobacco	6%	3%	7%	0.78%	0.37%	1.01%
Textile and leather	2%	1%	2%	0.23%	0.11%	0.32%
Wood and wood products	1%	0%	1%	0.11%	0.05%	0.12%
Pulp, paper and print	6%	4%	7%	0.82%	0.45%	1.57%
Chemical and petrochemical	9%	7%	11%	1.29%	0.71%	2.49%
Rubber and plastic	4%	2%	5%	0.57%	0.26%	0.78%
Non-metallic minerals	2%	2%	3%	0.35%	0.16%	0.47%
Basis metals and fabricated metal products	13%	10%	16%	1.93%	1.07%	3.73%
Machinery and equipment n.e.c.	16%	12%	20%	2.31%	1.28%	4.46%
Electrical and optical equipment	9%	6%	12%	1.32%	0.61%	1.80%
Transport equipment	16%	13%	21%	2.42%	1.34%	4.67%
Manufacturing n.e.c. and recycling	1%	1%	2%	0.20%	0.09%	0.27%
Construction	16%	10%	21%	2.25%	1.04%	3.06%

[a] Including construction. Source: Own Calculations.

The majority of outage costs within the manufacturing sector can be assigned to four sectors, namely transportation equipment, machinery and equipment n.e.c., basic metals and fabricated metal products and construction. On average, these sectors account for approximately 61% of total hourly outage costs within the manufacturing sector. Their average cumulative share based on national hourly costs is about 9%.

In addition to the presented sectoral heterogeneity, outage costs may also vary significantly across regions. Hence, a more regional, disaggregated analysis on the federal state level is provided in the following section.

4.3. Regional Focus on Outage Costs

Annual averages of total outage costs on the federal state level, aggregated over all sectors are displayed in Figure 3. They are calculated using the detailed regional data described in Section 4.1 and according to the method from Section 4.2. Clearly, the southern part of Germany (Bavaria and Baden-Württemberg) and North Rhine-Westphalia exhibit the highest outage costs, whereas the eastern part of Germany and the federal state Saarland exhibit significantly lower costs from power interruptions. The regional distribution of outage costs reflects the relative economic strength of the aforementioned regions.

It seems worthwhile to contrast the regional distribution of outage costs with the probability of regional supply interruptions, since the product of outage costs and probability of occurrence equals the expected welfare loss. A first approach towards this issue is to investigate the relation of (reliable, i.e. non-intermittent) generation capacity and electricity demand. In Germany, the most significant changes in reliable generation capacity are induced by the shift in German nuclear policy following the events in Fukushima. The implications on nuclear generation capacity can be seen in Figure 3. Five out of the eleven nuclear power plants located in South Germany have been shut down in 2011. The remaining active nuclear plants in Germany are scheduled to follow until 2022. Clearly, South Germany suffers most from the immediate shutdown in 2011 as well as from the intended phase out.

The problem of a decline in reliable generation capacity in South Germany is enforced by the fact that a large share of renewable generation capacity yet to build (in particular on- and offshore wind energy) will be located in North Germany. Since there is no corresponding regional shift in power demand, the regional imbalance of electricity supply and demand between South Germany and North Germany increases. Even as of today, transfer capacity problems occur in extreme conditions, as outlined by the German Federal Network Agency (Bundesnetzagentur, 2012*a*). Hence, a promising approach to account for the changing structure of demand and supply would be to extend the high-voltage transmission grid on north-south routes.

However, the necessary extension projects face significant obstacles to overcome (e.g. environmental concerns and regional opposition) and are not expected to be readily available when most nuclear capacity will be shut down (Bundesnetzagentur, 2012*b*). Therefore, the risk of supply interruptions is likely to grow in South Germany in the near future. To make matters worse, the affected regions (Bavaria and Baden-Württemberg) coincide with the federal states facing comparably high economic cost once the interruption occurs (see Table 2 and Figure 3). Consequently, the expected loss in welfare due to interruptions in power supply is particularly high in South Germany due to comparatively high probabilities of occurrence and substantial regional outage costs.

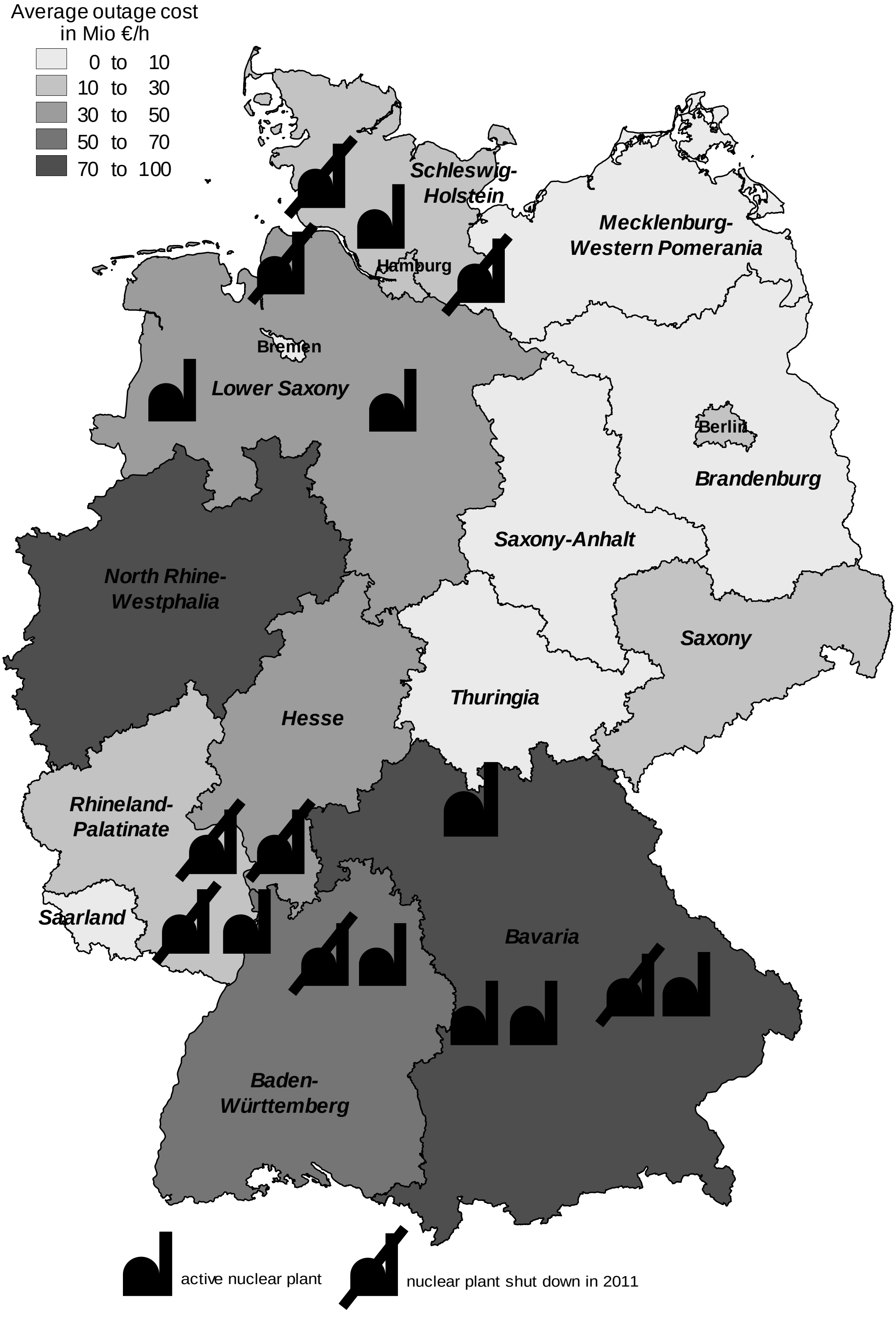

Figure 3: Average total outage cost on the federal state level in Mio € per hour (Source: Own calculations)

We draw upon a similar approach as applied to the national outage costs in Section 4.2 to investigate the time-varying structure of regional outage costs. Again, we find significant seasonal, intra-weekly, as well as intra-daily patterns of fluctuations in interruption costs.[11] Table 4 provides descriptive statistics on the time-varying pattern of total hourly outage costs on federal state level. The figures emphasize the dominance of North-Rhine Westphalia, Bavaria and Baden-Württemberg on national outage costs, since their average cumulative share on national outage costs amounts to around 55% (equal to around 238 Mio €per hour). Therefore, we focus on these three federal states and investigate the sectors that are driving the outage costs within the respective region.

Table 4: Descriptive statistics on total hourly outage costs for the different federal states (Mio €/h)[a]

Federal State	Mean	Median	Min	Max	Standard Deviation
BW	64.8	66.0	26.3	111.1	23.7
BV	74.8	75.5	29.3	129.5	28.2
BE	15.8	16.2	5.6	28.2	6.3
BB	9.1	9.4	3.2	16.2	3.6
HB	4.3	4.3	1.7	7.5	1.7
HH	13.5	13.1	5.1	23.5	5.3
HE	39.0	39.3	14.9	68.0	15.0
MV	6.6	6.6	2.4	11.5	2.6
NI	38.1	39.0	14.6	66.3	14.4
NW	98.3	100.2	38.3	170.8	37.0
RP	19.4	20.1	7.3	34.1	7.4
SL	5.6	5.7	2.2	9.5	2.0
SN	15.0	15.3	5.3	26.6	5.9
ST	9.5	9.7	3.6	16.6	3.6
SH	13.2	13.5	5.0	23.2	5.1
TH	7.8	8.0	2.8	13.8	3.1

[a] The state codes are the same as in Table 1. Source: Own Calculations

Table 5 presents the sectoral shares on total regional outage costs. In line with the analysis on a national level described in Section 4.2, the figures highlight the considerable magnitude of the outage costs within the residential sector. Since the economic structures are heterogeneous across the three federal states, the shares of commercial sectors on total regional outage costs vary significantly. For instance, the manufacturing sector contributes on average 13.73% of total regional outage costs whereas in North

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[11] The time-varying structure of regional outage costs are qualitatively similar to the structure of national outage costs analyzed in Section 4.2: Total regional costs from power interruptions are generally higher during the winter than during the summer, while they are generally lower on working days (compared to the weekend) and in the night (compared to daytime).

Rhine-Westphalia while this sectors contributes on average 20.10% of total outage costs in Baden-Württemberg. The latter figure stresses the economic relevance of the manufacturing sector in Baden-Württemberg. Consequently, the welfare losses implied by power outages are borne to a different extent by the considered sectors in each federal state.

Table 5: Distribution of outage costs across sectors, descriptive statistics

Sector	Baden-Württemberg			Bavaria			North Rhine-Westphalia		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
Residential	44%	29%	72%	44%	29%	72%	46%	31%	74%
Agriculture	<1%	<1%	1%	<1%	<1%	2%	<1%	<1%	1%
Manufacturing	20%	11%	32%	14%	8%	23%	14%	7%	23%
Commercial and public services	32%	15%	46%	39%	19%	53%	38%	17%	52%

Source: Own Calculations.

5. Conclusions

In this study, we quantified the economic costs of power interruptions in Germany. Drawing upon a macroeconomic approach, we derived the VoLLs and outage costs in different German regions and sectors, accounting for regionally heterogeneous economic structures and federal state specific labor market conditions.

On a national level, our empirical findings reveal average total German outage costs of around 430 Mio € per hour, peaking at 750 Mio € per hour on a Monday in December between 1 p.m. and 2 p.m. On average, national outage costs are approximately equally split across residential electricity customers, although the sectoral shares on total costs vary significantly over time.

Our empirical results shed light on the economic efficiency of different approaches to deal with electricity supply shortages. Since economic theory suggests that load shedding (if necessary) should be applied to customers who suffer the lowest welfare losses from an interruption in power supply, our estimates of disaggregated outage cost can be used to assess the economic efficiency of curtailing customers within different sectors and regions at different moments of interruption. Therefore, this piece of work may provide guidance for a concept of rational rationing, i.e. curtailing customers with the lowest outage costs first instead of a random selection, in case of supply shortages. Although the practical feasibility of such concepts has to be considered carefully due to technical restrictions, our finding of strictly heterogeneous outage costs across different sectors, regions and moments of interruption provides an idea about how large the potential welfare gains of an efficient power curtailment may be compared to the benchmark of random load shedding.

However, even if the concept of rational rationing may not be feasible due to physical restrictions or political opposition, our results generate previously unknown insight into the economic efficiency of interruptible electricity contracts since they reveal the regional, sectoral and time-dependent structure of welfare losses due to interruptions in power supply. Assuming that pricing of interruptible contracts will be based on the outage costs suffered, the disaggregated outage cost estimates can be used to approximate the system costs in case demand flexibility will be used to cope with supply shortages. Thus, the estimated outage costs help to identify combinations of sectors, regions and interruption moments, in which interruptible electricity supply contracts may be desirable from a welfare perspective.

With regard to the German Energiewende, we find that South and West Germany will face by far the greatest welfare losses if these regions are touched by interruptions in electricity supply. This regional distribution of outage costs suggests that the respective federal states (Bavaria, Baden-Württemberg and North Rhine-Westphalia) deserve particular attention with respect to measures intended to maintain the current reliability of electricity supply.[12] One crucial challenge in the eye of the Energiewende is the disparity of the main future generation areas in North Germany (with its suitable locations for wind generation) and the centers of electricity demand in South Germany. This imbalance is further exacerbated by the phase-out of nuclear power plants in the south until 2022. Contrasting the regional distribution of outage costs with the decline in reliable generation capacity in South Germany due to the nuclear phase-out, we conclude that the expected welfare losses from interruptions in electricity supply in South Germany will increase. Thus, political efforts to address this problem should be intensified. There is a broad range of possible political approaches that could be applied simultaneously or alternatively to mitigate the increase in expected welfare losses from electricity supply interruptions in South Germany, e.g. acceleration of grid extension projects, changes in the electricity market design to keep fossil power plants in the market despite low utilization rates, or a delay of the nuclear phase-out. Despite the substantial costs and / or the social opposition with regard to these measures, a resolute implementation of at least some of them may be appropriate considering the significant welfare at stake.

The investigation of regional outage risks from a more technical perspective could be a promising branch for further research within the area of welfare losses induced by electricity supply interruptions. The results could then be combined with the disaggregated outage cost estimates of this work to derive reliable expected regional welfare losses from electricity supply interruptions. Moreover, given future data availability, an investigation of one-off outage costs for both industrial and residential customers could complement our research, as this cost component cannot be accounted for within the macroeconomic methodology used in this study.

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[12] Such regional assessments are difficult by nature and have to be interpreted carefully, as power flows are governed by physical laws and do not follow the logic of market flows (possibilities of contagion etc.) in the network considered.

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A. Appendix

Table A.1: Gross value added (GVA) in Mio € and in % of all economic sectors (2007)^{a}

Sector	BW		BV		BE		BB		HB		HH	
Agriculture and fishing	2,315	0.7	4,077	1.0	98	0.1	932	2.0	52	0.2	143	0.2
Manufacturing												
• Food, beverages and tobacco	3,426	1.1	6,525	1.7					877	3.7	1,060	1.4
• Textile and leather	1,912	0.6	1,839^{e}	0.5								
• Wood and wood products	1,110	0.3							31	0.1		
• Pulp, paper and print	5,714	1.8	5,699	1.5					139	0.6	1,354^{j}	1.8
• Chemical and petrochemical	6,744	2.1	6,239	1.6					61	0.3	821	1.1
• Rubber and plastic	4,107	1.3	4,506	1.2					52	0.2	263	0.4
• Non-metallic minerals	1,787	0.6	3,691	0.9					42	0.2		0.0
• Basis metals and fabricated metal products	12,159	3.8	8,291	2.1					909	3.8	746	1.0
• Machinery and equipment n.e.c.	24,841	7.7	17,186	4.4					731	3.0	1,377	1.8
• Electrical and optical equipment	17,062	5.3	8,60^{f}	2.2					171^{i}	0.7	1,321	1.8
• Transport equipment	26,077	8.1	22,734	5.8					1,980	8.3	2,257	3.0
• Manufacturing n.e.c. and recycling	2,402	0.7										
Manufacturing total^{b}	107,342	33.4	85,313	21.9	9,755^{h}	12.6	6,976^{h}	14.6	4,993	20.8	9,199	12.2
Construction	13,935	4.3	15,792	4.1	2,552	3.3	2,487	5.2	651	2.7	1,655	2.2
Services^{c}	190,708	59.4	260,751^{g}	66.9	63,730	82.6	34,816	73.0	17,508	73.0	61,768	82.2
Total	314,300	97.9	365,933	93.9	76,135	98.7	45,210	94.8	23,204	96.8	72,766	96.8
All economic sectors	321,189	55.9	389,522	57.4	77,160	51.7	47,690	53.4	23,984	61.8	75,190	62.5
Households^{d}	253,196	44.1	289,201	42.6	72,037	48.3	41,561	46.6	14,805	38.2	45,079	37.5
All economic sectors and households	574,385		678,723		149,198		89,251		38,789		120,269	

Table A.1: continued

Sector	HE		MV		NI^k		NW		RP		SL	
Agriculture and fishing	1,138	0.6	862	2.8	2,783	1.5	3,002	0.6	1,410	1.5	64	0.2
Manufacturing												
• Food, beverages and tobacco	2,122	1.1	991	3.2	4,907	2.7	7,030	1.5	1,652	1.8	410	1.5
• Textile and leather	430	0.2	24	0.1	579	0.3	2,357	0.5	334	0.4		
• Wood and wood products	431	0.2	261	0.8	423	0.2	1,346	0.3	410	0.4	73	0.3
• Pulp, paper and print	2,381	1.2	248	0.8	2,451	1.4	6,849	1.4	1,393	1.5		
• Chemical and petro-chemical	7,678	4.0	236	0.8	3,239	1.8	15,602	3.3			122	0.5
• Rubber and plastic	2,293	1.2	140	0.4	2,942	1.6	5,311	1.1	1,660	1.8	322	1.2
• Non-metallic minerals	653	0.3	163	0.5	1,315	0.7	3,118	0.7	1,354	1.4	206	0.8
• Basis metals and fabricated metal products	4,191	2.2	440	1.4	4,398	2.4	26,854	5.6	3,104	3.3	2,815	10.4
• Machinery and equipment n.e.c.	5,024	2.6	314	1.0	4,271	2.4	19,575	4.1	3,067	3.3	882	3.3
• Electrical and optical equipment	5,991	3.1	455	1.5	3,538	2.0	11,282	2.4	1,381	1.5	560	2.1
• Transport equipment	4,198	2.2	520	1.7	11,379	6.3	7,935	1.7	2,517	2.7	2,409^l	8.9
• Manufacturing n.e.c. and recycling	649	0.3	103	0.3	761	0.4	3,149	0.7	481	0.5		
Manufacturing total^b	36,041	18.7	3,895	12.5	40,203	22.3	110,408	23.2	17,353	18.6	7,799	28.9
Construction	6,652	3.5	1,692	5.4	7,514	4.2	16,126	3.4	4,105	4.4	1,049	3.9
Services^c	145,126	75.3	24,293	77.7	123,135	68.3	330,944	69.5	61,264	65.5	17,308	64.1
Total	188,958	98.0	30,743	98.4	173,635	96.3	460,481	96.6	84,132	90.0	26,221	97.1
All economic sectors	192,796	55.8	31,247	53.9	180,247	53.0	476,458	54.3	93,470	52.0	27,007	54.7
Households^d	152,712	44.2	26,706	46.1	159,781	47.0	400,678	45.7	86,119	48.0	22,373	45.3
All economic sectors and households	345,508		57,953		340,028		877,135		179,589		49,380	

Table A.1: continued

Sector	SN		ST		SH		TH		D	
Agriculture and fishing	934	1.1	875	1.9	1,047	1.6	716	1.6	20,940	1.0
Manufacturing										
• Food, beverages and tobacco			1,394	3.0	1,322	2.1			35,525	1.6
• Textile and leather			48	0.1		0.0				
• Wood and wood products			186	0.4		0.0				
• Pulp, paper and print			542	1.2	1,192	1.9			31,351	1.4
• Chemical and petrochemical			1,970	4.3	1,500	2.3			55,929	2.6
• Rubber and plastic			554	1.2		0.0			24,665	1.1
• Non-metallic minerals			689	1.5	368	0.6			15,410	0.7
• Basis metals and fabricated metal products			1,582	3.4	733	1.1			73,619	3.4
• Machinery and equipment n.e.c.			840	1.8	1,987	3.1			85,483	3.9
• Electrical and optical equipment			794	1.7		0.0				
• Transport equipment			545	1.2	534	0.8			89,274	4.1
• Manufacturing n.e.c. and recycling			214	0.5		0.0				
Manufacturing total[b]	17,463[m]	20.8	9,358	20.2	7,636	11.9	10,260[m]	23.3	513,266[n]	23.5
Construction	5,248	6.3	2,640	5.7	2,420	3.8	2,591	5.9	87,490	4.0
Services[c]	57,094[g]	68.0	31,106[g]	67.2	48,854	75.9	28,976[g]	65.7	1,502,430	68.9
Total	80,739	96.2	43,979	94.9	59,957	93.1	42,543	96.5	2,124,126	97.4
All economic sectors	83,969	55.4	46,319	54.2	64,398	53.5	44,075	55.2	2,180,730	56.6
Households[d]	67,654	44.6	39,120	45.8	56,021	46.5	35,704	44.8	1,671,484	43.4
All economic sectors and households	151,623		85,439		120,419		79,780		3,852,214	

[a] The state codes and the sector classifications are the same as in Table 1. [b] Excluding the manufacture of coke, refined petroleum products and nuclear fuel. [c] Including the collection, purification and distribution of water. [d] For the Households, the numbers represent value of leisure. [e] Excluding manufacture of leather. [f] Only manufacture of electrical machinery and apparatus n.e.c.. [g] Excluding the collection, purification and distribution of water. [h] Including other mining and quarrying. [i] Only manufacture of medical, precision and optical instruments, watches and clocks. [j] Only publishing, printing and reproduction of recorded media. [k] The reference year for Lower-Saxony is 2006. [l] Excluding the manufacture of other transport equipment. [m] Including the manufacture of coke, refined petroleum products and nuclear fuel. [n] Including the subsectors for which the data is not given at the disaggregated level. Source: Statistical Office of Baden-Württemberg (2011), own Calculations.

Table A.2: Electricity consumption in GWh and in % of all economic sectors considered (2007)[a]

Sector	BW		BV		BE		BB		HB		HH	
Agriculture and fishing[b]	928	1.9	1,636	2.9	39	0.5	374	3.7	21	0.6	57	0.6
Manufacturing												
• Food, beverages and tobacco	1,711	3.5	2,528	4.5					431	11.8	436	4.4
• Textile and leather	524	1.1	760[f]	1.4								
• Wood and wood products	527	1.1							4	0.1		
• Pulp, paper and print	5,149	10.7	5,382	9.7					20	0.5	71[j]	0.7
• Chemical and petro-chemical	2,073	4.3	5,603	10.1					25	0.7	279	2.8
• Rubber and plastic	2,010	4.2	2,378	4.3					10	0.3	148	1.5
• Non-metallic minerals	1,354	2.8	2,535	4.5					82	2.2		
• Basis metals and fabricated metal products	5,278	10.9	3,674	6.6					1,061	29.0	2,602	26.6
• Machinery and equipment n.e.c.	3,215	6.7	2,368	4.2					43	1.2	105	1.1
• Electrical and optical equipment	2,383	4.9	1,270[g]	2.3					7[i]	0.2	142	1.4
• Transport equipment	5,386	11.1	3,819	6.9					363	9.9	347	3.5
• Manufacturing n.e.c. and recycling	380	0.8										
Manufacturing total[c]	29,991	62.1	30,317	54.4	2,098[h]	26.4	6,599[h]	65.0	2,046	55.9	4,130	42.1
Construction[b]	135	0.3	153	0.3	25	0.3	24	0.2	6	0.2	16	0.2
Services[b,d]	17,276	35.7	23,621	42.4	5,773	72.8	3,154	31.1	1,586	43.3	5,595	57.1
Total	48,331		55,727		7,935		10,151		3,659		9,798	
All considered economic sectors	48,331	73.5	55,727	72.6	7,935	65.7	10,151	75.4	3,659	74.7	9,798	71.8
Households	17,427[e]	26.5	21,003[e]	27.4	4,148	34.3	3,316	24.6	1,238[e]	25.3	3,853	28.2
All considered economic sectors and households	65,758		76,730		12,083		13,467		4,897		13,651	

Table A.2: continued

Sector	HE		MV		NI[k]		NW		RP		SL	
Agriculture and fishing[b]	456	1.8	346	8.0	1,117	3.0	1,204	1.2	566	4.0	26	0.4
Manufacturing												
• Food, beverages and tobacco	812	3.2	566	13.0	2,728	7.2	3,432	3.3	734	5.1	204	3.5
• Textile and leather	101	0.4	2		156	0.4	899	0.9	165	1.2		
• Wood and wood products	172	0.7	348	8.0	341	0.9	1,102	1.1	255	1.8	128	2.2
• Pulp, paper and print	1,052	4.1	106	2.4	2,506	6.6	5,974	5.7	1,307	9.1		
• Chemical and petrochemical	3,380	13.2	136	3.1	6,810	18.0	19,527	18.7			442	7.6
• Rubber and plastic	1,152	4.5	79	1.8	1,781	4.7	2,693	2.6	1,418	9.9	305	5.3
• Non-metallic minerals	374	1.5	81	1.9	1,118	3.0	4,165	4.0	1,092	7.6	84	1.5
• Basis metals and fabricated metal products	1,845	7.2	159	3.7	5,702	15.1	26,150	25.1	1,954	13.6	2,133	36.9
• Machinery and equipment n.e.c.	515	2.0	58	1.3	499	1.3	2,315	2.2	312	2.2	176	3.0
• Electrical and optical equipment	990	3.9	74	1.7	674	1.8	3,628	3.5	153	1.1	88	1.5
• Transport equipment	1,345	5.3	146	3.4	2,942	7.8	2,272	2.2	657	4.6	616[l]	10.7
• Manufacturing n.e.c. and recycling	122	0.5	28	0.6	192	0.5	893	0.9	117	0.8		
Manufacturing total[c]	11,860	46.5	1,783	41.0	25,449	67.3	73,050	70.0	8,164	57.0	4,176	72.2
Construction [b]	65	0.3	16	0.4	73	0.2	157	0.2	40	0.3	10	0.2
Services[b,d]	13,146	51.5	2,201	50.6	11,154	29.5	29,979	28.7	5,550	38.8	1,568	27.1
Total	25,527		4,346		37,793		104,390		14,320		5,780	
All considered economic sectors	25,527	71.4	4,346	66.9	37,793	74.1	104,390	77.4	14,320	66.5	5,780	77.1
Households	10,209	28.6	2,154	33.1	13,191	25.9	30,549	22.6	7,220	33.5	1,721[e]	22.9
All considered economic sectors and households	35,736		6,500		50,984		134,939		21,540		7,501	

Table A.2: continued

Sector	SN		ST		SH		TH		D	
Agriculture and fishing^{b}	375	2.5	351	2.9	420	5.0	287	3.3	8,400^{m}	2.2
Manufacturing										
• Food, beverages and tobacco			979	8.1	546	6.6			17,056	4.5
• Textile and leather			78	0.6						
• Wood and wood products			238	2.0						
• Pulp, paper and print			781	6.5	845	10.2			22,351	6.3
• Chemical and petro-chemical			3,870	32.1	1,139	13.7			52,470	13.8
• Rubber and plastic			525	4.4					14,082	3.7
• Non-metallic minerals			854	7.1	324	3.9			14,152	3.7
• Basis metals and fabricated metal products			911	7.6	205	2.5			56,669	14.9
• Machinery and equipment n.e.c.			161	1.3	231	2.8			10,726	2.8
• Electrical and optical equipment			159	1.3						
• Transport equipment			183	1.5	162	1.9			19,639	5.2
• Manufacturing n.e.c. and recycling			116	1.0						
Manufacturing total^{c}	9,123	62.0	8,855	73.5	3,452	41.5	5,785	66.3	234,259^{n}	61.7
Construction^{b}	51	0.3	26	0.2	24	0.3	25	0.3	850^{m}	0.2
Services^{b,d}	5,172	35.1	2,818	23.4	4,426	53.2	2,625	30.1	136,100^{m}	35.9
Total	14,721		12,050		8,321		8,722		379,609	
All considered economic sectors	14,721	73.5	12,050	77.0	8,321	60.3	8,722	69.9	379,609	73.0
Households	5,299	26.5	3,602	23.0	5,478	39.7	3,758	30.1	140,200	27.0
All considered economic sectors and households	20,020		15,652		13,799		12,480		519,809	

[a] The state codes and the sector classification are the same as in Table 1. [b] Estimated via the federal VoLL and the federal states' gross value added. [c] Excluding manufacture of coke, refined petroleum products and nuclear fuel. [d]Including collection, purification and distribution of water. [e] Estimated via the number of households in the state and the average electricity consumption per household at the federal level. [f] Excluding manufacture of leather. [g] Only manufacture of electrical machinery and apparatus n.e.c.. [h] Including other mining and quarrying. [i] Only manufacture of medical, precision and optical instruments, watches and clocks. [j] Only publishing, printing and reproduction of recorded media. [k] The reference year for Lower-Saxony is 2006. [l] Excluding manufacture of other transport equipment. [n] Including the subsectors for which the data is not given at the disaggregated level. [m] Drawn from energy statistics provided by Eurostat. Source: Energy balances of the Federal States; Energy balance of the Federal Republic of Germany (2007); Eurostat.

Table A.3: Labor market statistics on the regional level

Federal State	Population	Employed persons	Unemployed persons	Number of hours actually work per employee per year	Labor costs per hour	Net hourly income
BW	10,746.3	5,520.2	5,226.1	1,638.0	31.33	17.21
BY	12,504.6	6,540.2	5,964.4	1,647.0	30.73	16.88
BE	3,407.6	1,604.0	1,803.6	1,641.0	28.45	15.62
BB	2,541.6	1,034.5	1,507.1	1,685.0	22.54	12.38
HB	663.3	388.4	274.9	1,639.0	29.13	16.00
HH	1,761.7	1,087.9	673.8	1,639.0	33.12	18.19
HE	6,072.5	3,081.7	2,990.8	1,650.0	33.57	18.44
MV	1,686.7	727.2	959.5	1,688.0	21.70	11.92
NI	7,979.4	3,550.2	4,429.2	1,662.0	27.23	14.95
NW	18,012.0	8,272.4	9,739.6	1,651.0	30.08	16.52
RP	4,049.5	1,828.7	2,220.8	1,656.0	28.84	15.84
SL	1,040.0	507.9	532.1	1,607.0	28.64	15.73
SN	4,234.4	1,940.5	2,293.9	1,678.0	21.71	11.92
ST	2,427.6	1,008.0	1,419.6	1,669.0	22.11	12.14
SH	2,835.3	1,252.1	1,583.2	1,657.0	26.87	14.76
TH	2,300.1	1,022.1	1,278.0	1,687.0	21.20	11.64

Sources: Statistical Office of Baden-Württemberg (2011), Federal Statistical Office of Germany (2003), Eurostat (2008), own calculations.