The value of supply security: the costs of power outages to Austrian Households, Firms and the Public Sector

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Evaluation process preamble: In this paper an economic tool for assessing simulated power cuts is presented. The tool was implemented as Excel-based Visual Basic software and will be made available on the authors' website for downloading after completion of the evaluation process.

KEYWORDS: Power Outage; Value of Supply Security; Empirical Analysis

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Abstract

This paper presents a model for assessing economic losses caused by electricity cuts as an approximation of the value of supply security. Economic losses are calculated for simulated power cuts with a duration from 1 to 48 hours, taking the respective day of the week and time of day into consideration. The simulated power cuts can be defined for the 9 Austrian provinces and the costs due to power cuts are computed separately for all sectors of the economy and for households. For instance, the average Value Of Lost Load for a power cut lasting one hour on a workday morning in summer was calculated to be € 17.1.

1 Introduction

Securing an uninterrupted electricity supply is essential for any advanced economy to function economically, socially and politically. Europe has enjoyed a high degree of supply security during the last few decades. Diagram 1-1 illustrates this by depicting the average duration of unplanned power cuts per market participant, CAIDI (Customer Average Interruption Duration Index), in selected European countries for the years available (see Council of European Energy Regulators, 2005 and 2008). Still, this snapshot should not disguise the need for action to secure the power supply in the future and long term.

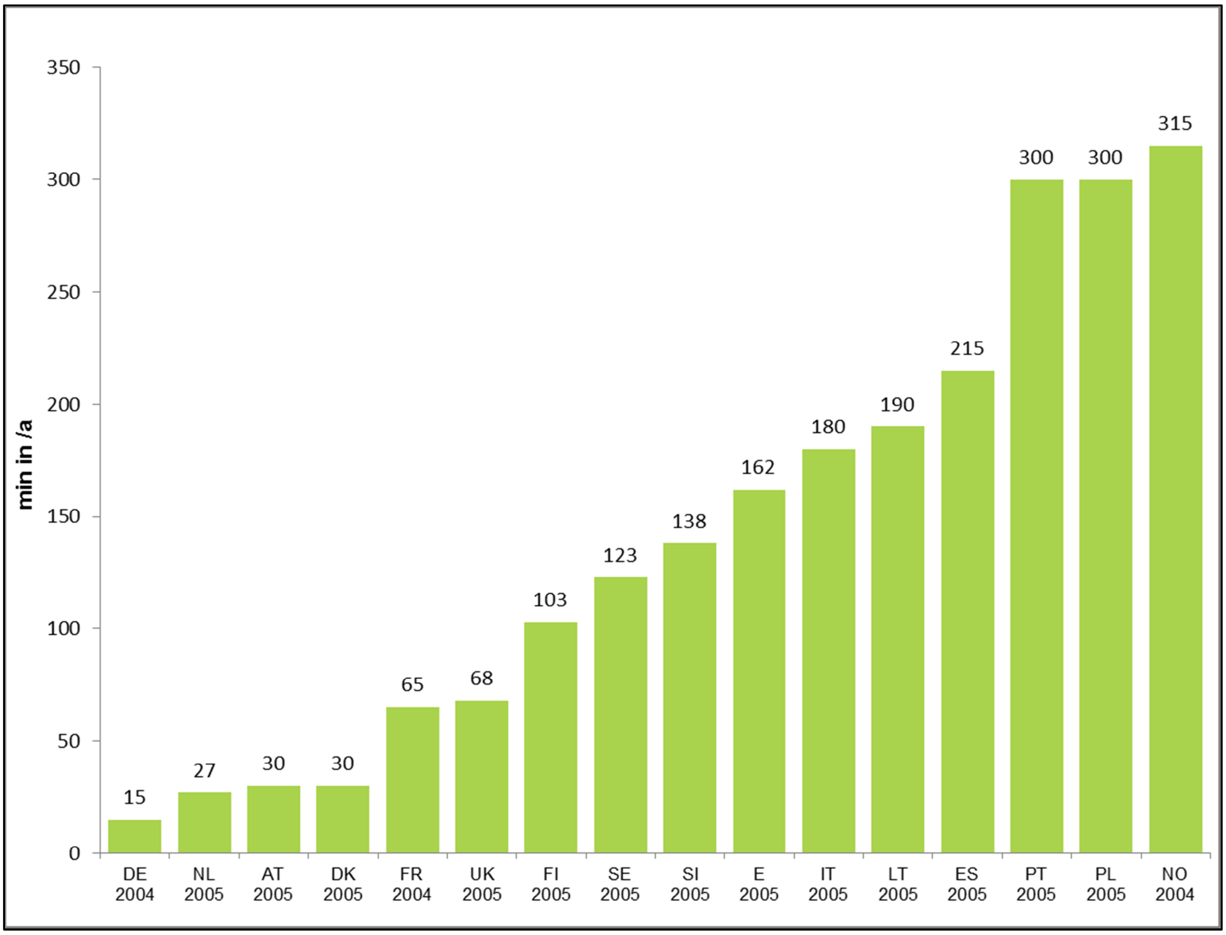


Diagram 1-1: Supply reliability in European countries; average duration of unplanned power cuts per market participant (CAIDI) p.a. More recent data based on an established uniform survey method are not available, which is why data from the 3rd and 4th Benchmarking Report of the European Commission (Council of European Energy Regulators, 2005 and 2008) have been drawn upon here.

This need for action is increasing, mainly because electricity production and distribution are currently undergoing restructuring. The transformation is taking place at three levels, of which the legislative component of market deregulation and that of unbundling have progressed the furthest. This first level[1] was to be implemented in accordance with EU directive 2003/54/EG (European Commission, 2003) by July 2007 (graded with regard to different customer groups) as well as the liberalization of the electricity market in every EU member state. While these provisions were transposed into national law in Germany in 2005, the electricity market in Austria had already been completely liberalized in 2001. This early implementation of liberalization steps in Austria made it possible to examine the effects of the legislative changes regarding supply security through empirical analysis (Reichl et al., 2008). Reichl et al. (2008) reached the conclusion that, while market deregulation does in fact lead to lower prices for electricity, the influence it has on supply security largely depends on the design of the accompanying regulatory framework. In line with international specialist literature the authors concluded that liberalization and unbundling do not automatically contribute to long-term electricity supply security, and that quality-orientated regulation is needed to create incentives which lead the grid operators (now independent) to focus on long-term electricity supply security and appropriate investments.

The second challenge of the future, alongside market liberalization, is the significant growth in input from renewable energy sources (RES) across Europe in coming years. This development is mainly due to major EU policy changes[2], and also to measures in individual countries[3]. This has far-reaching repercussions on the level of supply security, as various standards developed over time in the electricity industry have to be adapted, as they had been tailored to ways of generating electricity with little intermittency, such as fossil fuels, nuclear power and large-scale hydro-power, which still predominate today. By now the effects of expanding electricity generation with intermittent feed-in patterns on grid security (Borggrefe and Nüßler, 2009) are visible from a number of indicators. For example, the North German transmission grid operator Vattenfall Europe reported more than 197 days with "critical grid situations" in 2009 to the German Federal Grid Agency, compared with 175 days in 2008, 155 days in 2007 and only 80 days in 2006. The increasing number of critical grid

[1] Divestiture of previously vertically integrated electric utilities
[2] E.g. defining the "20/20/20 goals", see European Commission (2011)
[3] Germany's planned nuclear exit strategy, various programs to reduce greenhouse gas emissions or new legislative frameworks with incentives to promote renewable energy sources such as the "Erneuerbare-Energie-Gesetz" (Renewable Energy Law) in Germany and the Ökostromgesetz (Eco Electricity Law) in Austria should be mentioned as influencing factors.

situations can be interpreted as an indicator of the risk of power cuts, and is primarily due to the massive increase in wind farm output during this period.

The third level of change with respect to supply security involves growing electricity consumption (see for instance Consentec et al., 2008). Particularly in Austria, but also in Germany, the consumption of electricity has steadily risen in recent decades. Only since 2008 has the incipient economic crisis interrupted this trend (presumably not for long). Before that, from 1970 to 2008, the consumption of electricity in Austria had been increasing by about 2.9 % annually on average; in 2009 renewable energy sources accounted for 68.2 % of electricity production (Statistik Austria, 2009a).

Grid-related measures to secure the electricity supply usually entail considerable costs. Whereas measures to improve staff members' ability to cope with crises, and standardized and streamlined communication channels between the companies and institutions involved, can improve security at comparatively low cost, primary measures such as expanding capacities and creating extra redundancy throughout the grid are costly. Investments in the security of SCADA ("Supervisory Control And Data Acquisition") systems also involve massive costs and are of increasing importance.

Economically efficient decisions about investments to preserve or improve supply security require that supply security first be classified as a private or public good. If supply security is classified as a private good, then an efficient level is achieved when the marginal benefit for consumers (i.e. households, companies, establishments, institutions, including the public sector) equals the marginal cost of further improving supply security (cf. for instance Bliem, 2007; Jamasb and Pollitt, 2005). If supply security is regarded as a public good, then efficient providing is represented by the Samuelson rule (Samuelson, 1954). In that case the sum of marginal rates of substitution between private goods and the public good in question must equal the marginal costs of providing the public good. Extensions of this condition, as for instance in Lohse et al. (2006), also appear to be suited to the good of supply security, in particular investments to secure supply. Lohse et al. (2006) stress that certain goods do not benefit consumers directly but are centered around security considerations. That is why investments in the field of supply security (e.g. extra grid redundancy) do not benefit consumers during regular service. But these unused capacities are potentially capable of averting or reducing economic losses in the event of a failure. Extensive discussion regarding the question whether supply security is to be qualified as a private or public good is discussed in detail, and conclusions are drawn, in Engerer (2009) and Keppler (1996).

In any case, regarding electricity supply and the assessment of measures to secure this, it cannot be taken for granted a priori that the market will flawlessly and autonomously provide the macroeconomically optimal level of supply security. In the authors' opinion the factors leading to a potential market failure can be grouped into three categories:

1. Consumers and producers having insufficient information
2. Lack of adequate substitution options in the case of grid-based energy sources
3. Time dimension of investment decision regarding long-lived infrastructure facilities

So it seems justified to assume that consumers are only inadequately equipped to assess the benefit of supply security improvements. The excellent supply situation in Germany and Austria in the past has prevented people there from acquiring experience regarding the significance of widespread and long-lasting supply cuts, apart from a few, regionally very limited exceptions. In addition, neither consumers nor grid operators have precise knowledge of the effects of grid security measures. The effect of extra grid redundancy to avoid a power cut, or of increasing the capacity of existing infrastructure facilities, can be calculated only if the relevant data for every power supply line connected with the section of the grid under examination are available to the institution making the calculations. The risk can then be estimated on the basis of assumptions about the maximum load flow to be expected. Yet these grid data are among the most sensitive a grid operating company has, so they are not shared with others.

As a second factor for market failure in connection with supply security one has to acknowledge the lack of substitution options. In the area of grid-bound electricity supply customers do not have the option of choosing an operator with a more adequate level of supply security for them (at a correspondingly more adequate price). Here it is important to realize that consumers providing the electricity themselves (e.g. through an emergency power supply) does not constitute a solution on a par with a functioning grid-based supply. A considerable portion of the negative effects which ordinarily arise during power cuts are due not to local phenomena which could be mitigated by means of emergency power supplies, but to the outage of dependent infrastructure such as the water supply, transport system or communication facilities.

A third factor militating against market-driven, economically efficient grid security measures is the time dimension. The Austrian and German grid capacities are on a scale such that neglecting investment has so far not immediately resulted in extended power cuts. Schlemmermeier (2011), for instance, has held that the German grid operators' medium-term financial requirement amounts to about € 8 to 10 billion. The short-term resilience of the grids in spite of security-preserving investments not being made creates incentives to postpone investments which are necessary in the medium and long term. This seems particularly problematic as an ad-hoc response to a deteriorating quality of supply is almost impossible. For instance, it often takes more than 10 years (from the planning stage to approval and final completion) for new transmission lines to be implemented (cf. Boxberger, 2005). This makes timely action by companies as well as forward-looking and security-oriented incentivizing by regulatory authorities essential.

While eveloping the necessary measures to secure grid and supply security (as outlined above) is mainly a challenge to the engineering disciplines, it is the task of economic research to support the development of a system of incentives to counterbalance possible market failure and therefore further the implementation of these technical measures. One central prerequisite for developing an efficient regulatory system is quantifying the value of supply security. As supply security constitutes a non-market good and can be purchased only in combination with the physical product (electricity)[4], the value of supply security cannot be determined directly. That is why usually the failure of electricity supply, and in particular the cost of power cuts, is used to assess the value of supply security (see Baarsma and Hop, 2009, De Nooij et al. 2007, or Woo and Pupp, 1992, for instance).

In recent years the importance of analysing potential losses caused by power cuts has attracted more and more attention in national and especially European politics. EU Council Directive 2008/114/EG (2008) requires member states to quantify the *"economic after-*

[4] Whereby "supply security" is a prerequisite for supplying electricity.

effects[5]" of the power supply infrastructure failing, starting in January 2011. In this paper a model which meets this requirement of the directive (APOSTEL – *Austrian Power Outage Simulation of Economic Losses*), for scenario-based evaluation of the after-effects in widespread blackouts, is presented. It is thus possible for the first time to collect data on the value of supply security on the basis of blackout costs for companies, institutions and establishments, and of households' willingness to pay to avoid power cuts.

Chapter 2 introduces the methods utilized in this paper to evaluate losses due to power cuts. The chapter 0 evaluates two scenarios as examples of possible widespread power cuts in Austria. In chapter 4 international comparative studies are analysed and the data they provide on economic losses from power cuts, on willingness to pay to avoid blackouts and various approaches to putting a value on supply security as a good are compared with the results of this study. Chapter 0 contains the gist of the paper, and adds a conclusion on the need for further research.

2 Modelling the economic losses due to power cuts

In this chapter we elaborate on methodical aspects of modelling economic losses in the event of widespread blackouts and explain their significance for the interpretation of the figures for such losses. To do this, possible losses due to electricity outages need to be classified. The economic aftereffects can be divided into three categories (following Munasinghe and Sanghvi, 1988):

- Direct costs
- Indirect costs
- Resulting long-term costs of macroeconomic relevance

In the public eye direct economic losses are usually at the top of the list. Of the total economic losses they are the part which is a direct result of the failure, e.g. repair costs for defective electrical infrastructure facilities. Direct economic losses are usually limited and subordinate to indirect economic losses. These indirect costs also arise in direct connection with the failure, yet they belong to that part of the total losses resulting from the absence of

[5] *Whereby this is valued according to economic losses and/or losses in product and service quality.*

electricity supply in the aftermath of the failure. Examples are the cost of production outages or lost value added. Through multiplier effects due to the marked dependence of some industries on the flawless functioning of other industries, in particular these indirect costs mostly make up a significant proportion of the total costs (cf. Centolella et al. 2006).

On the other hand there are the long-term economic effects of blackouts. These are understood to be the economically relevant changes in the behaviour of market participants as a result of a perceived long-term change in the level of supply security. Part of this category of losses is for instance the potential influence on the choice of a place as a business location[6], the potential price rise for production facilities due to the increased need for backup-systems, or customer churn due to unreliability regarding delivery deadlines. As long-term economic effects can not be assigned to individual events long-term results are not taken into consideration for the analysis of this paper for the evaluation of a single failure event, in accordance with the literature (see chapter 1).

A number of indicators are suitable for evaluating of power cuts. In the authors' opinion aggregated observations of the after-effects of a power cut, such as the electricity shortfall or the sum of losses to all market participants, are the most important parameters for judging the macroeconomic significance of a failure incident. However, these aggregated figures are not a suitable basis for evaluating the various market participants (e.g. differentiated by sector) as regards their degree of dependence on an uninterrupted electricity supply. To make this necessary comparability nevertheless possible and thus be able to identify priority targets for state intervention, such as subsidies for appropriate insurance policies or for backup systems (e.g. emergency electricity supply facilities), it is necessary to standardize anticipated economic losses. The specialist literature often draws upon "Value of Lost Load" (VoLL); in this case the economic losses are given per kWh of electricity shortfall (see Wacker and Billinton, 1989, or Kariuki and Allen, 1996a, for instance).

[6] Examples from the field of business suggest that the specific supply security of a region can further the setting up of businesses heavily reliant on electricity. For example, in 2008, after years of searching, Kronsdorf in Upper Austria was chosen to house Google's new server station, as two particularly reliable hydro power plants and Austria's largest voltage transmission substation are nearby; thus the new location offers ideal conditions for the system-inherent uninterrupted supply of electricity which data centers need.

Then again, some authors use indicators which refer to peak load consumption (mostly specified as kW_{peak}) (see Kivikko et al., 2007, for instance). Expressing the loss this way (in €/kW_{peak}) reduces the distorting effect of VoLL, which allocates lower unit costs to consumers with high electricity consumption. On the other hand it has the disadvantage of using a less well-known reference figure (kW) as well as a tendency to allocate lower costs to consumers with a very stable consumption pattern. Less commonly used indicators, such as the unit of measurement €/kWh_{annual} relating to annual electricity consumption, or the indicator €/kWh_{peak} relating to peak load consumption behaviour/pattern, are in the authors' opinion less suitable as inputs for optimizing regulatory systems in the context of assessing supply security.

Apart from the definitions given in the preceding paragraphs, the specialist literature provides three basic paradigms for assessing supply security in monetary terms (cf. Woo and Pupp, 1992):

- Proxy methods
- Market-based valuation methods
- Contingent valuation methods

Proxy methods rely on observable variables linked indirectly to supply security. Amongst them are, for instance, expenditure on standby generating facilities, the monetarized value of lost income and production output as well as other losses to be taken into account. Proxy methods are therefore suitable in those cases where the losses anticipated can be expressed with sufficient precision by such observable variables.

Market-based valuation methods rely on actual, observable consumer decisions and, as representatives of the revealed-preference approach, can deliver very robust data. However, within natural monopolies such as grid-bound electricity supply almost no market-based consumer decisions are observable which would permit valuating supply security (as an immaterial quantity). Ultimately consumers are by definition not in a position to make decisions along market-economy lines within natural monopolies.

Contingent valuation methods permit valuing the losses incurred from the customers' (partly subjective) perspective. With this group of methods customers themselves assign a value to the loss from failure by making their willingness to pay to avoid precisely specified power cuts known (directly or indirectly). This stated-preference method is also employed for the monetary valuation of non-material losses such as stress or lost recreational benefit, which is why this method is often used to assess households' economic losses.

Each of these three valuation paradigms focusses on different causes of losses, and how suitable they are thus varies with the relevance of these causes to any particular group of consumers. While a company suffers monetary/economic losses, households suffer not only monetary losses but also a reduction in recreational benefits, additional inconvenience and mental stress, which occurs for instance if it is not known when electricity will be available again or as a result of a complete breakdown of communications. That is why Directive 2008/114/EG requires that apart from purely financial losses *"Effects on the public*[7] *" should also* be valued and outlined. This is the main reason why, while further subcategorisation of market participants can make sense, the specialist literature always differentiates between households and non-households (companies, establishments and institutions) and this differentiation is reflected by the methodology chosen. In this paper the losses within the segment of non-households are represented (in accordance with the specialist literature) by means of a method which maps the lost production value (see chapter 2.1), while a contingent valuation method is used to value losses within the household segment (see chapter 2.2).

2.1 Methodology for assessing non-households' economic losses

As non-households have to expect solely material losses in the event of power cuts, market-based loss valuation often follows an accounting approach (see for example De Nooij et al. 2007, who recommend the use of top-down methods based on a production function and lost added value). This approach requires that all (key) activities within a non-household are checked regarding their dependence on electricity being available from the grid and the impact of possible restrictions on the process of adding value. That way an inventory of activities relevant to adding value and their dependence on electricity supplied from the grid is built up. Thus the overall dependence of the entity in question can be inferred from the

[7] *Whereby they are valued according to the effects on public trust, physical suffering and disruption of daily life, including the breakdown of essential services.*

aggregated monetary losses due to certain activities being impossible. These economic losses are subsequently diminished by that portion of added value which can be recovered at a later date – at a certain cost, which has to be included in the calculation. To the lost added value calculated in this way the cost of idle staff capacity during the power cut has to be added in another calculation step, as does the value of wasted previous effort. In a final step the cost of relevant damage to production facilities or machinery is added to the costs established so far. A detailed discussion of assessing outage costs for non-households can be found in Kariuki and Allan (1996b).

For the loss assessment model in this paper the primary survey of the non-household segment was carried out with a web-based analysis tool. The questionnaire participants were recruited on a broad basis in cooperation with the Austrian Chamber of Commerce ("Wirtschaftskammer Österreich") as well as the Confederation of Austrian Industry ("Vereinigung der österreichischen Industrie"). For example, in collaboration with industry associations a presentation of this survey together with an invitation to participate was sent out to more than 100,000 companies, and various sector newsletters drew attention to this project. Following the recruitment phase in advertising media the responses received so far were checked to see how representative the questionnaire sample was, and insufficiently represented segments (especially the public sector) were detected. In these segments 500 potentially suitable institutions were identified by the authors and their CEO or the executive in charge of energy was asked in a personally addressed letter to participate and reminded of the letter in a phone call a week later.

For the level of detail in analysis described above participants need to scrutinize individual dependence on a secure electricity supply within their institution closely; to answer the questions for each firm in the analysis gathering these characteristics comprehensively is a prerequisite, so the questionnaire takes longer to complete than other less extensive questionnaires. Still, 267 business locations of 201 companies in all were persuaded to participate in the study. Of these 35 % were very small enterprises with 1 to 10 staff members. Small businesses with 11 to 50 employees represented 21 % of questionnaire participants. Medium-sized companies with 51 to 250 employees made up 23 % and large companies with more than 250 employees 21 %. 29.2 % of the companies were based in

Vienna, 20.6 % in Lower Austria and 16.6 % in Upper Austria. Even though the largest and economically most prosperous provinces of Austria were slightly over-represented, a balanced mix of all nine Austrian provinces was still achieved. The participants came from all sectors of Austrian business and the public sector, and represented entities with a total turnover of more than € 10 billion, amounting to about 3 % of Austrian GDP. With regard to experience of power cuts 33 % of the managers participating stated that they had never observed one in their own establishment. In the event of a supply cut 27 % of survey participants regarded their establishment as not at all vulnerable. On the other hand, 32 % of participants declared it to be vulnerable or very vulnerable.

Starting from this sample the economic losses of individual non-households had to be standardized in an appropriate way, to make it possible to extrapolate from the establishments participating to all other establishments, so as to be able to form complete aggregates of sectors or regions subsequently. One option would be to start from the VoLL and quantify the total loss on the basis of sectoral or regional electricity consumption. But public statistics of the electricity consumption of sectors or regions do not exist in the depth needed here. Furthermore, the VoLL (expressed in € per kWh of electricity shortfall) is by definition very dependent on the energy intensity of the value-adding process in the individual non-household. Processing the data of this study has revealed that the VoLL also varies considerably within any given industry and a few outliers can potentially lead to considerable distortions. The share of total losses in relation to the average daily added value in a single establishment proved to be more robust. To assess the annual value added, the annual personnel costs and costs of preparatory efforts were deducted from annual turnover and converted to the daily value added on the basis of the sector load profile. This means that, for example, a grocer's approximate daily value added is considerably higher on workdays than on public holidays, but even on holidays it is still higher than 0, as the relevant load profiles on those days also show values greater than 0 (e.g. for cooling and safety facilities). In the course of assessing the importance of supply security it makes sense to a allocate added value proportionately to load flow within a sector, because otherwise sectors without labour on non-working days (and thus without physical or accounting added value on non-working days) would end up with exactly zero losses from an power cut on public holidays.

The percentage share (calculated deterministically) of the total losses in the average daily value added within the establishments participating was regressed on the characteristics of the blackout *CA* analysed (date, starting time and duration) and the sector *Br* of the non-household examined. Thus for every combination of simulated blackout characteristics CA^{sim} and every sector *Br* the anticipated loss can be simulated as a proportion of the daily value added, and through aggregation of losses for a certain region and/or sector this percentage can be applied to the public economic statistics. The share $\pi(CA^{sim}, BR)$ of losses caused by a simulated power cut with the characteristics CA^{sim} in sector *Br* in the daily value added is then expressed as

$$\pi\left(CA^{sim}, BR\right) = \beta_{CA} CA^{sim} + \beta_{Br}, \tag{1}$$

from which the aggregated anticipated total losses caused by a power cut for all provinces and industries of interest is computed as

$$GWV\left(CA^{sim}, BR^{int}\right) = \sum_{Bl} Bl^{int} \sum_{Br} tWS_{Bl,Br} \pi(CA^{sim} + BR^{int}), \tag{2}$$

whereby β_{CA} are the OLS coefficients of outage characteristics and $\beta\mathrm{Br}$ is the sector-specific *fixed effect*. As the above detailed sample did not have sufficient data to calculate a separate *fixed effect* for every one of the 21 sectors in the NACE business classification[8], the sectors were grouped into 6 subcategories (SC-1 to SC-6), see the appendix[9]. $GWV(CA^{sim},BR^{int})$ represents the total value added lost through a simulated electricity outage with the characteristics CA^{sim} in the sectors examined BR^{int}. $tWS_{Bl,Br}$ describes the daily value added in province *Bl* and sector *Br* (taken from public statistics) in proportion to the corresponding sector load profile. The total preparatory effort wasted (GVV) has been modelled in a similar way. In Table 2-1 the regression coefficients are presented multiplied by 100 so that the respective coefficients can be interpreted as a percentage change. Based on this regression the economic losses caused by an outage on a workday between 7 a.m. and 7 p.m., say, are 13 % greater (in relation to the respective daily value added) than outside regular working hours.

[8] *"Nomenclature statistique des activités économiques dans la Communauté européenne"*

[9] The groups were formed based on the comparability of load profiles of individual sectors and with regard to an approximately balanced number of data sets per subcategory.

Table 2-1: Regression coefficients of non-households' economic losses.

		Daily added value	Daily effort in advance
β_{CA}	Invariable	13.178**	8.39**
		(2.384)	(2.111)
	Log outage duration	9.88**	6.71**
		(1.493)	(1.320)
	Summer	-5.49	-8.77
		(5.482)	(4.846)
	Workdays 7 a.m. to 7 p.m.	13.05**	4.47
		(3.941)	(3.486)
β_{BR}	subcategory 1	4.14	0.52
		(2.745)	(2.431)
	subcategory 2	-6.46*	-1.26
		(2.798)	(2.478)
	subcategory 3	-10.01**	-1.98
		(2.813)	(2.491)
	subcategory 4	-5.93*	-3.89
		(2.947)	(2.606)
	subcategory 5	-4.42	-2.44
		(2.942)	(2.606)
	F value	**42.8**	**15.1**
	Corrected R2	**0.256**	**0.14**

*Standard errors in brackets: **Significance < 0.01, *Significance < 0.05*

For this paper the performance and structure survey (LSE) by Statistik Austria, which is based on the NACE industrial classification ÖNACE 2008, was used as the data basis of public statistics. Along with the number of c

ompanies, employees, personnel costs, revenues and production value the LSE also already includes an added-value figure for most sectors. These data are available for each of the nine Austrian provinces and for 14 sectors of the first ÖNACE level; the remaining five sectors required (in particular the public sector) were estimated in line with the methodological inventory of Statistik Austria (2011). To counterbalance distortions caused by the approximation economic losses for the public sector were shown only cumulatively.

The two last sectors T[10] and U[11] were ignored in this analysis due to their minimal share of nationwide business output and lack of available data.

2.2 Methodology for assessing households' economic losses

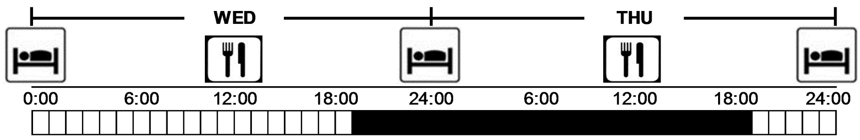
For a comprehensive analysis of the household sector it is necessary to represent immaterial losses as well as material losses. So a household survey was conducted as part of this project to evaluate willingness to pay to avoid power cuts, quite in accordance with the

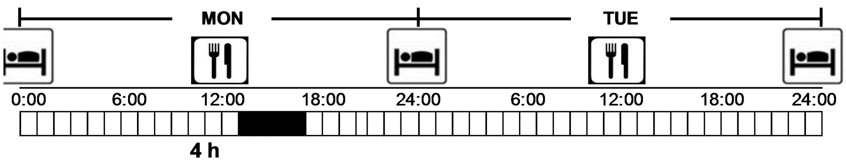
[10] *Private households with domestic staff, private households producing goods and delivering services for their own requirements without a particular focus*

[11] *Exterritorial organisations and bodies*

recommendations of "*best practice*" choice of methods for contingent valuation methods (Arrow et al., 1993).

<table>
<tr><td colspan="3">Scenario 5:

Outage area: Upper Austria, Lower Austria, Salzburg
Advance warning: Yes, 3 days in advance
Time of year: from December to February</td></tr>
<tr><td>All power cuts listed here will be avoided if you pay</td><td>Costs during the next 2 years</td><td>Willing to pay?:</td></tr>
<tr><td>Begins: 7 p.m.
Ends: 7 p.m.


Begins: 1 p.m.
Ends:5 p.m.

</td><td>17 €</td><td>☐ YES

☐ NO</td></tr>
</table>

Diagram 2-1: Scenario questions from the questionnaire on electricity supply security

All in all 894 households participated in the survey; to avoid influences from the survey mode two subsamples were formed. Part of the sample population were interviewed face to face, the remainder filled in a questionnaire online; the aim here was to insure against interviewing effects. 704 households were interviewed face to face. The questionnaire administered there was also implemented online as far as possible, with the aid of diagrams; a further 190 households responded online. All participants were recruited by a market research centre.

430 households provided complete sets of data; the majority of unanswered questions were the participants' household income or age. Conducting the face-to-face interview took 28.5 minutes on average, answering the online questionnaire an average of 27 minutes. Table 2-3 provides a descriptive analysis of the results from the household survey. For comparison the

average figures for the whole of Austria are also provided. The participants of the survey are representative of the population of Austria. The percentage of male participants, household income and the degree of urbanization were slightly higher than the national average, while age and number of children per participating household were lower. 67.5 % of participating households stated that they had already experienced a power cut lasting more than an hour, whereas only 15 % of households stated that they had experienced power cuts lasting more than 8 hours.

The participating households were shown 16 different diagrammatic power-cut scenarios one after another (see Diagram 2-1). With each scenario the households could choose whether they would prefer to pay a predefined sum of money or experience the outage depicted in the scenario. The poll participants' decisions were then econometrically assessed by means of a censored random coefficients model (Reichl, 2009) and willingness to pay inferred following McFadden (1996). Willingness to pay WTP(CA^{sim},CH) *of a* household with characteristics CH to avoid a simulated electricity outage with characteristics CA^{sim} is yielded by

$$WTP\left(CA^{sim}, CH\right) = \frac{\beta\left(CA^{sim}, CH\right)}{\alpha} \tag{3}$$

where $\beta(CA^{sim}, CH)$ describes the benefit to a household of avoiding a power cut as a function of its characteristics CH and the characteristics of the outage CA^{sim}. α describes the marginal benefit of income.

The econometric modelling of willingness to pay (WTP) to avoid power cuts yielded a mean result of € 17.3 per household for a 24-hour outage. In the event of a 12-hour outage a mean WTP of € 9.9 was detected; to avoid a 4-hour power cut households were willing to pay € 3.8 on average, and willingness to pay to avoid a 1-hour power cuts was assessed at € 1.4 on average. Table 2-2 shows the coefficients of the variables which influence this willingness to pay. The coefficients in this multiplicative model are to be interpreted as follows: willingness to pay with respect to an outage of whatever duration increases by the value of the coefficient for the corresponding variable as that variable increases. So willingness to pay to avoid a power cut regardless of its duration is for instance 33.39 % higher in winter than in summer.

Apart from season, sex, level of education, degree of urbanization, previous blackout experience, point in time, household composition, age and household income, the geographical extent of the outage and the influence of a possible advance warning before the outage began were also investigated. As regards the geographical extent of supply security the questionnaire differentiated between a very limited outage which affected only one's own street/road and an outage which affected one's own home province and two neighbouring provinces. Unexpectedly, it seems to make no statistically significant difference whether advance warning of a power cut is given or not. Considering that the severest restrictions during a power cut affect water supply, communications and space heating, areas where substitutes are rarely available even in the case of an early warning, this result seems perfectly plausible. While age does not play a statistically significant role with respect to the actual sum one is willing to pay, the variables season, size of the outage area, participants' sex, education, household income and previous experience of power cuts do.

Table 2-2: Characteristics of Austrian households' willingness to pay to avoid power cuts

Dependent variable: WTP	**Coefficient**	**Significance**
Season = winter	0.3339	**
Outage area=3 provinces	0.2675	**
Sex = male	0.2871	**
Education = at least general qualification for university entrance	-0.2368	**
Place of residence = town (population> 10,000)	0.1173	
Experience of outages = Yes (> 1 h)	-0.1303	*
Warning = Yes(planned)	-0.0109	
Point in time = working hours	0.0153	
Household with children (under 14)	0.0910	
Age (in years)	0.0021	
Household income (in 100 €)	0.0224	**

*** 5 % significance; * 10 % significance*
Model fit statistics have not yet been developed for this model

As with the results for the non-household segment, it is possible to calculate every household's expected willingness to pay to avoid this outage on the basis of the model developed in (3). From the statistical information on the demographic key data of a province it is possible to subsequently aggregate the sum of all households' willingness to pay in the chosen region.

Table 2-3: Descriptive statistics of the household survey and the distribution throughout Austria

	This study	**Austria***
Share of men	62.4 %	48.7 %
Share of questionnaire participants with A-levels/high school diploma	54.8 %	11.4 %
Average age of participants	40.3 years	41.6 years
Households living in a town with >10.000 inhabitants	51 %	44.31 %
Average net household income per month	2,202 EUR	1,842 EUR
share of households with children under 14	23.8 %	36.67 %

** Population aged 15 and older - source: Statistik Austria (2009b)*

3 Results

With the methods described in chapter 2.1 and 2.2 a model was developed to simulate the economic losses of households and non-households in conjunction. The "Austrian Power Outage Simulation Tool of Economic Losses" (APOSTEL) is capable of assessing various blackout scenarios economically ad hoc, making it possible to reach appropriate conclusions as regards the benefits from investing in measures to ensure supply security. The costs of a simulated outage assessed with APOSTEL comprise both the indirect economic losses and the direct costs resulting from damage to production facilities. The costs due to damage to or the destruction of electricity infrastructure (involved in most cases) are excluded from the APOSTEL assessment, since these losses depend on the cause of the outage (e.g. break in supply line, operator error or software problems), whereas APOSTEL just simulates the resulting blackout, independently of what caused it.

APOSTEL depicts the effects of the simulated blackout in all nine provinces of Austria and for 15 economic sectors, and also for households in the region selected for the scenario in question. To do this, seven indicators of the economic impact of the widespread blackout investigated on non-households and households are calculated. The key indicators in the case of non-households are the economic loss and especially the electricity shortfall due to the outage. This latter indicator is derived from the synthetic load profiles of the various sectors. In addition, the number of firms claiming to be severely or very severely affected by a blackout, and the number of persons employed in these firms, is listed. Further indicators used are the VoLL, the average loss per hour of the entire blackout and the average loss per hour per employee. This last indicator is not to be found in the specialist literature; however, the authors have included it as something to put against the VoLL, which is hard to interpret in many cases. The losses in a particular sector are partly due to stoppages in other sectors upstream, e.g. to interruptions to the water supply or telecommunications, or to transport problems. There is thus a tendency to overestimate the VoLL for sectors particularly dependent on the functioning of other sectors, because the electricity shortfall in the sector in question and the share of the shortfall in other economic sectors that is necessary for the functioning of the sector in question should be added together. The cases studies presented in the chapter 3 reveal how difficult it is to interpret the VoLL. The VoLL given for wholesale and retail traders is invariably much higher than that given for manufacturing (including industry). The fact is that a blackout brings the value-adding process to a virtual standstill in both these sectors; however, the electricity shortfall is much greater in the energy-intensive manufacturing sector, resulting in a lower VoLL for these firms, so a misleading picture of their true degree of dependence on a secure supply of electricity emerges.

For these reasons the loss per hour per employee is also listed; this indicator does not directly depend on the energy intensity of the sector in question, and can be used to compare one sector with another. If the absolute loss is related to the individual employee in the sector in question, a particularly high value is obtained if this sector employs relatively few people and incurs relatively high economic losses; so in most sectors this indicator counterbalances the VoLL. In the context of political debate it appears advisable to take both these indicators into account side by side.

Analogously to the non-households, the number of households severely or very severely affected and the number of persons living in these households are listed. As with the non-households, the shortfall of electricity is derived from the synthetic load profiles, and the economic losses shown correspond to the households' aggregated willingness to pay. The VoLL, the mean economic loss per hour of outage and the economic loss per hour of outage per member of household are also listed.

3.1 Case study 1 – brief outage (1 hour)

In this section an example of outage is investigated by means of the assessment model APOSTEL. Table 3-1 depicts the outage scenario.

Table 3-1: Scenario for one-hour outage in Austria investigated by means of APOSTEL

Date of start of outage	**16.08.2011**
Time of start of outage	10:00
Duration in hours	1
Provinces affected	Entire territory of Austria
Public holiday	No

In the case of the outage analysed in this scenario, the whole of Austria is affected by a blackout lasting one hour. The blackout takes place on a workday in summer. The economic assessment of the losses and effects due to an outage of this kind is presented in Table 3-2.

Table 3-2: Economic assessment of a one-hour outage in Austria by means of APOSTEL

Sector as per NACE 2008	Name	No. of severely/very severely affected units*	No. of persons in severely/very severely affected units**	Electricity not supplied (in MWh)	Total losses (in 1,000 €)
A	Agriculture	179,552	474,145	142	1,503
B	Mining	335	6,063	82	572
C	Manufacturing	25,038	605,668	2,864	36,599
D	Electricity and gas supply	1,452	27,006	1,161	4,404
E	Water supply, waste management	1,903	16,830	279	883
F	Construction	28,476	263,269	62	9,429
G	Wholesale and retail trade	69,331	576,027	297	32,298
H	Transport	13,005	200,417	392	8,563
I	Accommodation and food services	41,333	237,837	75	3,738
J	Information and communication	14,300	84,119	66	4,329
K	Finance and insurance	6,339	117,366	175	9,155
L	Real estate	14,407	38,528	70	3,545
M	Professional, scientific and technical services	50,709	182,833	116	6,322
N	Administrative and support services	10,955	178,985	89	4,734
OPQRSTU	Public sector	N/A*****	996,469	705	18,474
	Households***	647,686	1,487,178**	2,119	4,069
TOTAL		**1,104,821**	**N/A****	**8,694**	**148,617**

* *In sectors A-N the unit is the individual firm, in the case of the households the individual household.*

** *For households the number of persons in the households affected is used as a parameter, for firms the number of employees.*

*** *Households are not represented in NACE 2008; they were included in this survey, though, in order to compare how vulnerable different groups of customers are.*

**** *Persons affected in the households may also be counted as affected if employed in the sectors A to U. Aggregating without overlapping is thus not possible, which is why it was not performed.*

***** *Because of the data basis, this generic sector is treated as a residual sector.*

Table 3-3: Economic assessment of a one-hour outage in Austria by means of APOSTEL (Austrian Power Outage Simulation Tool) II

Sector as per NACE 2008	Name	Value of Lost Load (in €/kWh)	Loss per hour of outage (in 1,000 €)	Loss per person affected and hour of outage (in €*)
A	Agriculture	10.6	1,503	3.2
B	Mining	7.0	572	94.3
C	Manufacturing	12.8	36,599	60.4
D	Electricity and gas supply	3.8	4,404	163.1
E	Water supply, waste management	3.2	883	52.5
F	Construction	153.3	9,429	35.8
G	Wholesale and retail trade	108.9	32,298	56.1
H	Transport	21.9	8,563	42.7
I	Accommodation and food services	49.8	3,738	15.7
J	Information and communication	65.6	4,329	51.5
K	Finance and insurance	52.4	9,155	78.0
L	Real estate	50.9	3,545	92.0
M	Professional, scientific and technical services	54.3	6,322	34.6
N	Administrative and support services	53.2	4,734	26.4
OPQRSTU	Public sector	26.2	18,474	18.5
	Households**	1.92	4,069	2.7*
TOTAL		**17.1*****	**148,617**	**27.0******

* *The loss is expressed for employees in firms and members of households.*

** *Households are not represented in NACE 2008; they were included in this survey, though, in order to compare how vulnerable different groups of customers are.*

*** *The averaged VoLL is a weighted mean on the basis of the electricity not supplied.*

**** *The average loss per employee/household member per hour of outage is calculated by weighted mean on the basis of the number affected.*

Table 3-4 summarizes the losses to be expected if an outage of this kind occurs. The non-household share of the total losses is so large partly because the outage modelled took place when it did (at 10 a.m. on a workday).

Table 3-4: Summary of the distribution of impacts and the economic losses due to a one-hour outage in Austria

Sector	Section as per NACE 2008	Electricity not supplied (in MWh)	Percentage share	Total losses (in 1,000 €)	Percentage share
Primary sector	A, B	224	2.58%	2,075	1.40 %
Secondary sector	C, D, E, F	4,365	50.22%	51,315	34.53 %
Tertiary sector	G,H,I,J,K,L,M,N, O,P,Q,R,S,T,U	1,984	22.83%	91,158	61.34 %
Households		2,119	24.38%	4,069*	2.74 %
TOTAL		**8,692**	**100 %**	**148,617**	**100 %**

* *Willingness to pay (self-quantified loss) of all households in the blackout area so as to avoid an outage (in 1,000 Euros).*

In this outage scenario 457,135 non-households (firms, institutions and facilities) are severely or very severely affected, while 1,487,178 members of households are severely or very severely affected. In the case of this one-hour outage the households account for 24 % of the electricity shortfall and 2.74 % of the total losses, which amount to 148 million Euros.

3.2 Case study 2 – extended outage (48 hours)

The second outage analysed also affects the whole of Austria, but lasts 48 hours and occurs in winter. Table 3-5 depicts the outage scenario. The economic assessment of the losses and effects due to an outage of this kind is presented in Table 3-6 and Table 3-7.

Table 3-5: Scenario for 48-hour outage in Austria investigated by means of APOSTEL (Austrian Power Outage Simulation Tool)

Date of start of outage	26.01.2011
Time of start of outage	10:00
Duration in hours	48
Provinces affected	Entire territory of Austria
Public holiday	No, the day after the start of the outage and the day after that are both workdays.

Table 3-6: Economic assessment of a 48-hour outage in Austria by means of APOSTEL

Sector as per NACE 2008	Name	No. of severely / very severely affected units*	No. of persons in severely/very severely affected units**	Electricity not supplied (in MWh)	Total losses (in 1,000 €)
A	Agriculture	179,552	474,145	6,826	17,729
B	Mining	335	6,063	3,940	3,844
C	Manufacturing	25,038	605,668	146,954	358,452
D	Electricity and gas supply	1,452	27,006	55,722	47,010
E	Water supply, waste management	1,903	16,830	13,385	7,009
F	Construction	28,476	263,269	3,156	98,300
G	Wholesale and retail trade	69,331	576,027	15,216	430,104
H	Transport	13,005	200,417	20,097	93,132
I	Accommodation and food services	41,333	237,837	3,853	36,307
J	Information and communication	14,300	84,119	3,498	41,457
K	Finance and insurance	6,339	117,366	9,253	67,941
L	Real estate	14,407	38,528	3,693	27,259
M	Professional, scientific and technical services	50,709	182,833	6,166	64,071
N	Administrative and support services	10,955	178,985	4,709	50,100
OPQRSTU	Public sector	N/A*****	996,469	37,358	193,911
	Households***	1,943,059	4,461,534**	90,409	152,881
TOTAL		**2,400,194**	**N/A******	**424,235**	**1,689,507**

* *In sectors A-N the unit is the individual firm, in the case of the households the individual household.*

** *For households the number of persons in the households affected is used as a parameter, for firms the number of employees.*

*** *Households are not represented in NACE 2008; they were included in this survey, though, in order to compare how vulnerable different groups of customers are.*

**** *Persons affected in the households may also be counted as affected if employed in the sectors A to U. Aggregating without overlapping is thus not possible, which is why it was not performed.*

***** *Because of the data basis, this generic sector is treated as a residual sector.*

It turns out that the marginal economic loss (in relation both to an additional hour of blackout and to the shortfall of electricity) diminishes with time; however, the total economic losses are significant.

Table 3-7: Economic assessment of a 48-hour outage in Austria by means of APOSTEL (Austrian Power Outage Simulation Tool) II

Sector as per NACE 2008	Name	Value of Lost Load (in €/kWh)	Loss per hour of outage (in 1,000 €)	Loss per person affected and hour of outage (in €*)
A	Agriculture	2.6	369	0.8
B	Mining	1.0	80	13.2
C	Manufacturing	2.4	7,468	12.3
D	Electricity and gas supply	0.8	979	36.3
E	Water supply, waste management	0.5	146	8.7
F	Construction	31.1	2,048	7.8
G	Wholesale and retail trade	28.3	8,960	15.6
H	Transport	4.6	1,940	9.7
I	Accommodation and food services	9.4	756	3.2
J	Information and communication	11.9	864	10.3
K	Finance and insurance	7.3	1,415	12.1
L	Real estate	7.4	568	14.7
M	Professional, scientific and technical services	10.4	1,335	7.3
N	Administrative and support services	10.6	1,044	5.8
OPQRSTU	Public sector	5.2	4,040	4.1
	Households**	1.69*	3,185*	0.71*
TOTAL		**3.96**	**35,197**	**4.16**

* *The loss is expressed for employees in firms and members of households.*

** *Households are not represented in NACE 2008; they were included in this survey, though, in order to compare how vulnerable different groups of customers are.*

*** *The averaged VoLL is a weighted mean on the basis of the electricity not supplied.*

**** *The average loss per employee/household member per hour of outage is calculated by weighted mean on the basis of the number affected.*

Table 3-8 summarizes the distribution of impacts and the losses to be expected. The relative losses are noticeably less than in the case of a one-hour outage; this is due to marginal losses diminishing as adjustments are made.

Table 3-8: Summary of the distribution of impacts and the economic losses due to a 48-hour outage in Austria

Sector	Sector as per NACE 2008	Electricity not supplied (in MWh)	Percentage share	Total losses (in 1,000 €)	Percentage share
Primary sector	A, B	10,766	2.54 %	21,573	1.28 %
Secondary sector	C, D, E, F	219,217	51.67 %	510,771	30.23 %
Tertiary sector	G,H,I,J,K,L, M,N,O,P,Q, R,S,T,U	103,842	24.48 %	1,004,282	59.44 %
Households		90,409	21.31 %	152,881	9.05 %
TOTAL		**424,234**	**100.00 %**	**1,689,507***	**100.00 %**

* *Willingness to pay (self-quantified loss) of all households in the blackout area so as to avoid an outage (in 1,000 Euros).*

In this outage scenario 4,461,534 members of households are severely or very severely affected. In the case of this 48-hour outage the households account for 21 % of the electricity shortfall and 9.05 % of the total losses, which amount to 1.69 billion Euros.

4 Comparison of findings with international research

In this chapter the findings from using the recently developed model APOSTEL to assess the value of a reliable power supply in Austria are compared with values from the specialist literature. To do this, the authors adapted the various indicators to the VoLL, adjusted all economic losses for inflation (all values below are expressed in 2010 €) and corrected for changes in exchange rates.

Particularly in the USA, analysing the economic effects of blackouts to provide a rationale for investment decisions and to make these more efficient has a long tradition. For instance, Caves et al. (1990) carried out an extensive survey of specialist literature to assess the effects of blackouts on firms, with special attention to the industrial and service sectors. Employing the VoLL as a yardstick, they indicate outage costs ranging from 6.00 €/kWh to 25.99 €/kWh for the service sector, and from 1.52 €/kWh to 26.86 €/kWh for industry in the case of sudden events. In a metastudy Woo and Pupp (1992) examined the findings of various earlier investigations, namely those of Niagara Mohawk Power Corporation from 1987 to 1990, of Pacific Gas and Electric Company from 1985 to 1988 and of Economic Models of Israel) for the sectors households, industry and trade. They look at a variety of survey methods, use the VoLL, loss per hour and loss per outage as yardsticks and give details of duration and frequency of outages.

Analysing willingness to pay, Doane et al. (1988) estimate the VoLL for household customers in the case of a one-hour outage at 3.04 €/kWh (on a summer afternoon), at 19.93 €/kWh (when agreeing to a tariff increase), or at 20,03 €/kWh (on a winter evening). The study surveys both the WTP and the *Willingness to accept,* i.e. the minimum value that a consumer would accept as compensation for a blackout. By contrast, Sanghvi (1983) gives direct costs to household customers of as little as 0.21 €/kWh.

For industrial firms outage costs are given at between 8.03 €/kWh (Doane et al., 1990) and 71.63 €/kWh (Woo and Gray, 1987). For wholesalers and retailers outage costs are reported at between 10.20 €/kWh (Woo and Train, 1988) and 20.78 €/kWh (Fischer, 1986) (all values in 2010 Euros). In a 1996 survey from the USA, Sullivan (1996) estimates the effects of a large-scale blackout on non-households by means of the VoLL; its mean value for all firms is 45.94 €/kWh, and for industrial firms 7.62 €/kWh.

A number of surveys has also been carried out for Europe, both on outage costs and on various groups of consumers' willingness to pay. Bertazzi et al. (2005) used a face-to-face survey performed in 2003 to assess firms' and households' willingness to pay in Italy. Their analysis yielded a WTP of 4.1 €/kWh for households in the case of a one-hour outage, and a WTA of 18.7 €/kWh. By contrast, the direct costs were assessed at 27.90 €/kWh. In their study firms bear direct outage costs of 129.91 €/kWh and have a WTP of 11.78 €/kWh. The authors see socio-cultural motives in Italy, where an uninterrupted power supply is still regarded as a public service obligation, as the main reason for the discrepancy between actual costs and willingness to pay; accordingly they suggest taking the average of WTP and WTA as the most accurate yardstick for the monetary value of a reliable power supply.

In an extensive survey Bliem (2007) used a choice modelling approach to investigate the economic value of a reliable power supply to households and firms. To avoid a one-hour outage, households are willing to pay 5.61 €/kWh. According to this survey, the average direct outage cost to firms of a one-hour blackout is 216.10 €/kWh, but they are willing to pay only 13.96 €/kWh to avoid such an outage. Reichl et al. (2007) investigated the effects of blackouts on households and firms in Austria; small and medium-sized firms willingness to pay to avoid a one-hour outage is assessed at 7.8 €/kWh, that of households at 3.46 €/kWh.

Vennegeerts et al. (2008) estimate German households' willingness to pay at roughly 3 Euro per annum[12]. This figure has to be taken with a pinch of salt, though, because 86 % of respondents protested at the idea of paying anything (WTP=0 €); so the median is 0 €/kWh. This suggests that the consumers expect the electricity supplier to ensure a reliable supply at no extra charge. In many cases people regard this reliable supply as the responsibility of the electricity suppliers, even though these have meanwhile been dismembered. 37 % of consumers would accept monetary compensation if outages occur more often in future (WTA > 0).

[12] Sum necessary to ensure an uninterrupted power supply

In a top-down survey De Nooij et al. (2007) take a production function as the basis for calculating the costs of blackouts in the Netherlands. They give significantly higher figures for the costs incurred by households than most other comparative surveys, because they used Becker's (1965) time allocation model to put a value on leisure time; this approach gets round some of the problems with contingent valuation and stated preferences. However, the costs per kWh calculated for households are significantly higher than for firms, owing to the assumptions chosen; this is mainly due to leisure time being weighted more than in most other surveys. The VoLL they give for a one-hour outage is 6.94 €/kWh for firms, and 1913 €/kWh for households.

Table 4-1 provides an overview of the values quantified for supply security in the various surveys. All the surveys referred to in Table 4-1 are concerned with one or more subgroups of market participants. By contrast, this paper aims to go further than that, and consider the entirety of losses incurred by all consumer groups and the macroeconomic effects. Then again, numerous surveys assess only the vulnerability of the entities investigated in each case, even for the subgroups investigated; aggregation for all entities in the subgroup within a region is done only to a limited extent (see De Nooij et al. 2007, for example). While one can identify particularly vulnerable market participants without this important step, the macroeconomic dimension of blackouts is evaluated only in rare cases (see De Nooij et al. 2007, or Baarsma and Hop, 2009, for example). The model presented in this paper has been developed to close this gap, so as to be able to estimate the effects of an outage on all electricity consumers in one or more Austrian provinces, thus satisfying the requirements of directive 2008/114/EG.

Table 4-1: Metaanalysis of various approaches to assessing supply security; VoLL for a one-hour outage under the scenario and for the sector investigated in each survey

Survey	Scenario	Sector	€/kWh (VoLL) in 2010 €
Fischer (1986)	USA, summer, afternoon	Trade	20.78
Woo & Gray (1987)	USA, summer, afternoon	Industry	71.63
Woo & Train (1988)	USA, summer, afternoon	Trade	10.20
Caves et al. (1990)	USA (maximum value)	Firms	26.86
Doane et al. (1990)	USA, winter, evening	Industry	8.03
Sullivan (1996)	USA	Firms	45.94
Sullivan (1996)	USA	Industry	7.62
De Nooij et al. (2007) [a]	Netherlands	Non-households	6.94
Bertazzi et al. (2005)	Italy	Firms	129.91
Bliem (2007)	Austria	Firms	216.10
Reichl et al. (2007)	Austria	Firms	7.80
Baarsma and Hop (2009)[b]	Netherlands	Firms	N/A
De Nooij et al. (2007)[a]	Netherlands	Non-households	19.13
This paper	Austria, winter, morning	Non-households	26.80
Doane et al. (1988)[c]	USA, winter, evening	Households	20.03
Doane et al. (1988)[d]	USA, summer, afternoon	Households	19.93
Sanghvi, (1983)	USA, summer, midday	Households	0.21
Bertazzi et al. (2005)	Italy	Households	4.10
Fickert (2004)	Austria	Households	2.24
Bliem (2007)	Austria	Households	5.61
Reichl et al. (2007)	Austria	Households	3.46
This paper	Austria, winter, morning	Households	2.45

a) *De Nooij et al. specify the costs of outages incurred by non-households, comprising firms, institutions and facilities.*

b) *Baarsma and Hop employ a conjoint method (stated preferences) similar to willingness-to-pay analysis.*

c) *Direct costs to households.*

d) *Willingness to accept a tariff increase, comparable with approaches based on willingness to pay to avoid blackouts.*

5 Summary

This paper discusses approaches to placing a value on the immaterial good “supply security” and develops a model to estimate the economic costs of simulated blackouts in Austria. Although the supply of electricity is relatively reliable in Europe, maintaining this degree of reliability in future involves a number of challenges. Efficient decisions on investing in infrastructure are possible only if the value of the good “supply security” is determined. To obtain an objective result, the authors carried out polls covering economic costs and personal feelings in the case of a blackout, and derived the macroeconomic effects from the economic costs incurred. The polls were carried out with households, the public sector and firms.

This paper uses a comprehensive approach to calculate the monetary value of a reliable supply of electricity for the whole of Austria, with a fairly fine-mesh classification of economic sectors. As a result, not just particularly vulnerable sectors (such as the semiconductor industry, papermaking or data-generating processes), but all sections of the economy as per NACE 2008 are modelled. The wide range of possible blackout scenarios, lasting from one to 48 hours, covers many different conceivable outages for all the provinces of Austria; it is thus possible for the first time to judge subsectors of the Austrian economy province by province as regards their degree of dependence on a reliable supply of electricity. This paper does not cover blackouts lasting longer than 48 hours, with their hard-to-assess social impacts, and outages in the second to minute range, which the authors regard as all but impossible to represent objectively in economic terms.

There is a need for more research into monetarizing “supply security”, particularly at the transnational level. Given that European markets for electricity are increasingly interlinked, and that interdependence across borders is more and more marked, there seems to be a very strong case for assessing “supply security” uniformly throughout Europe.

Appendix: NACE 2008 and subcategories

NACE 2008 sectors		Subcategories
A	AGRICULTURE, FORESTRY AND FISHING	SC-6
B	MINING AND QUARRYING	SC-6
C	MANUFACTURING	SC-1
D	ELECTRICITY, GAS, STEAM AND AIR CONDITIONING SUPPLY	SC-6
E	WATER SUPPLY; SEWERAGE, WASTE MANAGEMENT AND REMEDIATION ACTIVITIES	SC-6
F	CONSTRUCTION	SC-5
G	WHOLESALE AND RETAIL TRADE; REPAIR OF MOTOR VEHICLES AND MOTORCYCLES	SC-5
H	TRANSPORTATION AND STORAGE	SC-5
I	ACCOMMODATION AND FOOD SERVICE ACTIVITIES	SC-5
J	INFORMATION AND COMMUNICATION	SC-4
K	FINANCIAL AND INSURANCE ACTIVITIES	SC-4
L	REAL ESTATE ACTIVITIES	SC-4
M	PROFESSIONAL, SCIENTIFIC AND TECHNICAL ACTIVITIES	SC-2
N	ADMINISTRATIVE AND SUPPORT SERVICE ACTIVITIES ERBRINGUNG VON SONSTIGEN WIRTSCHAFTLICHEN DIENSTLEISTUNGEN	SC-2
O	PUBLIC ADMINISTRATION AND DEFENCE; COMPULSORY SOCIAL SECURITY	SC-3
P	EDUCATION	SC-3
Q	HUMAN HEALTH AND SOCIAL WORK ACTIVITIES	SC-3
R	ARTS, ENTERTAINMENT AND RECREATION	SC-3
S	OTHER SERVICE ACTIVITIES	SC-2
T	ACTIVITIES OF HOUSEHOLDS AS EMPLOYERS, U0NDIFFERENTIATED GOODS- AND SERVICES-PRODUCING ACTIVITIES OF HOUSEHOLDS FOR OWN USE	*
U	ACTIVITIES OF EXTRATERRITORIAL ORGANISATIONS AND BODIES	*

* *These sectors are omitted from APOSTEL.*

References

Arrow, K.; Solow, R.; Portney, P. R.; Leamer, E. E.; Radner, R. und Schuman, H. (1993). *Report of the NOAA Panel on Contingent Valuation Federal Register, National Oceanic and Athmospheric Administration, 1993, 58, 4601-4614.*

Becker, G.E. (1965). A theory of the allocation of time. *The Economic Journal LXXV, 493-517 (September).*

Bertazzi, A.; Fumagalli, E. and Schiavo, L. L. (2005). The use of customer outage cost surveys in policy decision-making: The Italian experience in regulating quality of electricity supply. *Electricity Distribution, 2005. CIRED 2005.*

Bliem, M. G. (2007). Ökonomische Bewertung der Versorgungsqualität im österreichischen Stromnetz und Entwicklung eines Modells für ein Qualitäts-Anreizsystem. *Dissertation, Alpen-Adria-Universität Klagenfurt.*

Borggrefe, F. and Nüßler, N., (2009). Auswirkungen fluktuierender Windverstromung auf Strommärkte und Übertragungsnetze. *Uwf – Umweltwirtschaftsforum, 17(4), p.: 333-343.*

Boxberger, M. (2005). Nach der dena Netzstudie: Windstrom-Integration im Übertragungsnetz, available at: http://www.uni-saarland.de/fak7/fze/AKE_Archiv/AKE2005F/AKE2005F_Vortraege/AKE2005F_04Eon-Boxberger_dena-Windstudie_Konsequenzen_uf.pdf, zuletzt am 24.8.2011.

Bundesverband der Energie- und Wasserwirtschaft (2011). Abschätzung des Ausbaubedarfs in deutschen Verteilungsnetzen aufgrund von Photovoltaik- und Windeinspeisungen bis 2020, available at: http://www.bdew.de/internet.nsf/id/C8713E8E3C658D44C1257864002DDA06/$file/2011-03-30_BDEW-Gutachten%20EEG-bedingter%20Netzausbaubedarf%20VN.pdf, accessed on 24.8.2011.

Consentec et al. (2008). Analyse und Bewertung der Versorgungssicherheit in der Elektrizitätsversorgung. Abschlussbericht der Untersuchung im Auftrag des Bundesministeriums für Wirtschaft und Technologie (BMWi).

Council of European Energy Regulators (2005). 3rd Benchmarking Report on Quality of Electricity Supply.

Council of European Energy Regulators (2008). 4th Benchmarking Report on Quality of Electricity Supply.

De Nooij, M.; Koopmans, C. and Bijvoet, C. (2007). The value of supply security: The costs of power interruptions: Economic input for damage reduction and investment in networks *Energy Economics*, 29, 277 – 295.

Doane, M.J.; MCClelland, G.; Schulze, W. and Woo, C.K (1990). Industrial Outage Cost Survey, *Research Report submitted to Niagara Mohawk Power Corporation*.

Doane, M.J., Hartman, R.S. and Woo, C.K (1988). Electricity Reliability – Special Issue, *Energy Journal 9, 135.*

Engerer, H. (2009) Security Economics: Definition and Capacity, Economics of Security *Working Paper 5, Berlin: Economics of Security*.

European Commission (2003). *Directive 2003/54/EC concerning common rules for the internal market in electricity*, *Official Journal of the European Union, L 176.*

European Commission (2011). Citizens' summary, EU climate and energy package, available at: http://ec.europa.eu/climateaction/docs/climate-energy_summary_en.pdf, accessed on 29.8.2011.

Fickert, L. (2004). Zollenkopf vs. n-1 Prinzip vs. Kosten - ein Lösungsvorschlag für die optimierte Gestaltung von Netzten, *Elektrotechnik und Informationstechnik*, 10, 377-379.

Fischer, M. D. (1986). The Cost of Electrical Supply Interruptions: The Value of Service Reliability to Consumers, *Report EA-4496 Electric Power Research Institute.*

Jamasb, T. and Pollitt, M. (2005). Electricity Market Reform in the European Union: Review of Progress toward Liberalization and Integration, *Working Paper of the Center for Energy and Environmental Policy Reserach: Joint Center of the Department of Economics, Laboratory for Energy and the Environment and Sloan School of Management.*

Kariuki, K.K. and Allan, R.N. (1996a). Evaluation of Reliability Worth and Value of Lost Load. *IEE Proc.-Gener. Transm. Distrib., Vol. 143, No. 2, March 1996.*

Kariuki, K.K. and Allan, R.N. (1996b). Assessment of customer outage costs due to electric service interruptions: residential sector. *IEE Proc.-Gener. Transm. Distrib., Vol. 143, No. 2*

Keppler, J. (1996). Public Goods, Infrastructure, Externalities and Subsidies: A Conceptual Framework for the "IEA Questionnaire on Government Interventions in the Energy Sector". *Subsidies and Environment – Exploring the Linkages. Series: OECD Documents, p. 193-200.*

Kivikko, K.; Järventausta, P.; Mäkinen, A; Silvast, A.; Heine, P. und Lehtonen, M. (2007). Research and Analysis Method Comparison. Finnish Reliability Worth Study. *Proceedings 19th International Conference on Electricity Distribution Vienna, 21-24 May 2007.*

Lohse, T.; Robledo, J. R. und Schmidt, U. (2006). "Self-Insurance and Self-Protection as Public Goods". Erscheint in: *Journal of Risk and Insurance.*

McFadden, D. (1996). Computing Willingness-to-Pay in Random Utility Models. *Working Papers 011, University of California at Berkeley, Econometrics Laboratory Software Archive.*

Munasinghe, M. and Sanghvi, A. (1988). Reliability of Electricity Supply, Outage Costs and Value of Service: An Overview. *IAEA Special Issue Electricity Reliability Issue Volume 9.*

Council of the European Union (2008). COUNCIL DIRECTIVE 2008/114/EG on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection. Official Journal of the European Union L 345/75 of 23.12.2008, available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:345:0075:0082:EN:PDF, accessed on 24.8.2011.

Reichl, J.; Kollmann, A.; Schneider, F. and Tichler, R. (2007). Umsorgte Versorgungssicherheit - Eine empirische Analyse für den Strommarkt in (Ober-) Österreich, Universitätsverlag Rudolf Trauner.

Reichl, J.; Kollmann, A.; Tichler, R. und Schneider, F. (2008). The importance of incorporating reliability of supply criteria in a regulatory system of electricity distribution: An empirical analysis for Austria. *Energy Policy, 36, 3862–3871.*

Reichl, J. (2009). Estimating Individual Willingness to Pay – A Bayesian Censored Random Coefficients Model. Linz: proLibris.at.

Samuelson, P. A. (1954). "The Pure Theory of Public Expenditure". *Review of Economics and Statistics (The MIT Press) 36 (4): 387–389.*

Sanghvi, A.P. (1983). Household Welfare Loss Due to Electricity Disruptions *Energy Journal,* 1983, 4, 33-5.

Schlemmermeier, B. (2010). Deutsche Netz AG unter gesellschaftlicher Beteiligung des Bundes, *Forum Netzintegration*.

Statistik Austria (2009a). Bilanz der elektrischen Energie. Energiebilanz, available at: http://www.statistik.at/web_de/statistiken/energie_und_umwelt/energie/energiebilanzen/022711.html, accessed on 24.8.2011.

Statistik Austria (2009b). Bevölkerung im Alter von 15 und mehr Jahren nach höchster abgeschlossener Ausbildung, Geschlecht und Staatsangehörigkeit, 1971 bis 2001, Volkszählungen 1971 bis 2001. Erstellt: am 27. 01. 2009, available at: http://www.statistik.at/web_de/static/bevoelkerung_im_alter_von_15_und_mehr_jahren_nach_hoechster_abgeschlossene_035047.xls, accessed on 12.9.2011

Statistik Austria (2011). Methodeninventar, verfügbar unter: http://www.google.at/url?sa=t&source=web&cd=1&ved=0CBgQFjAA&url=http%3A%2F%2Fwww.statistik.at%2Fweb_de%2Fstatic%2Fmethodeninventar_zu_den_regionalen_gesamtrechnungen_bruttowertschoepfung_n_031683.pdf&rct=j&q=methodeninventar%20%C3%B6nace%20statistik%20austria&ei=6_NUTqWyGcqVOtXxwKgG&usg=AFQjCNG_3zMhbxsCOjNuq_M3JIQBpRegng&sig2=dm-PkPO3U8-Zkt1TMOwNhg&cad=rja, accessed on 24.8.2011

Statistisches Bundesamt Deutschland (2011). Erneuerbare Energieträger - Anteil der erneuerbaren Energieträger am Bruttostrom- und Primärenergieverbrauch ab 1991, available at: http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE/Content/Statistiken/Energie/Tabellen/Content50/ErneuerbareEnergie,templateId=renderPrint.psml, accessed on 24.8.2011.

Ter-Martirosyan, A. (2003). The Effects of Incentive Regulation on Quality of Service in Electricity Markets, *Working paper Dep. of Economics, George Washington University.*

Vennegeerts, H.; Meuser, M.; Linke, C.; Wirtz, F.; Heinrichsmeier, S. & Montebaur, A. (2008). Kundenbezogene Bewertung der Versorgungszuverlässigkeit. *VDE Kongress '08 München - Zukunftstechnologien: Innovationen - Märkte – Nachwuchs.*

Wacker, G. and Billinton, R (1989). Customer Cost of Electric Service Interruptions. *Proceedings of the IEEE*, 77, 919-939.

Woo, C.K. and Gray, B.M. (1987). An econometric analysis of industrial firms' power outage costs in northern California. *Working Paper, Pacific Gas and Electric Company*.

Woo, C.-K. and Train, K (1988). The Cost of Electric Power Interruptions to Commercial Firms. *The Energy Journal* 9, 161-172.

Woo, C.K. and Pupp, R.L (1992). Costs of Service Disruptions to Electricity Consumers. *Energy*.