The Value of Supply Security: the Costs of Power Outages to Austrian Households, Firms and the Public Sector

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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 calculated for simulated power cuts lasting 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. The costs due to power cuts are computed separately for all sectors of the economy and for households.

The average Value of Lost Load (VoLL) for a power cut lasting one hour on a workday morning in summer was calculated to be € 17.1 per kWh electricity not supplied.

1 Introduction

In the past decades, Europe has enjoyed an unprecedented degree of electricity supply security.[1] Still, this snapshot should not disguise the urgent need for action to sustain this level of energy supply security in the future. Security preserving measures are becoming increasingly important, mainly because electricity production and distribution are currently undergoing significant restructuring. This transformation is taking place at three levels:

Firstly, challenges arise due to changes of legislative components (e.g market deregulation and unbundling imposed by EU directive 2003/54/EG, see European Commission, 2003)[2].
Secondly, the significant growth of electricity generation from renewable energy sources implies an increased volatility of supplies and puts stress on traditional transmission systems (see Borggrefe and Nuessler, 2009, Boxberger, 2005, or BDEW, 2011, for details).
Thirdly, the current and anticipated growth of electricity consumption in developed countries such as Austria [3] implies the need for capacity enhancements and innovative solutions.

Together, these developments represent significant challenges to the infrastructure and thus potentially threaten the currently high level of energy supply security[4]. Energy economics can help finding ways to approach these challenges. Significant research (see Eto et al., 2001) has been done to assess the reasons responsible for imperfect infrastructure investment incentives. One key finding is, that it cannot be taken for granted a priori that the market will autonomously provide the macroeconomically optimal level of energy supply security.

In the authors' opinion the factors leading to a potential market failure (i.e. inadequate investments in energy supply security measures) can be grouped into three categories. Firstly, neither consumers, nor grid operators have precise knowledge of the effects of supply security enhancing measures. Due to the current near-perfect level of energy supply security, consumers send hardly any signals about their valuation of energy supply security's

[1]According to CEER (2008), who periodically publish reliability indices, the average duration of unplanned power cuts per market participant ranges from 15 (Germany, 2004) to 315 minutes (Norway, 2004) p.a.

[2]For a discussion on regulation and supply security see Jamasb and Pollitt (2005) or Ter-Martirosyan (2003).

[3]From 1970 to 2008, the Austrian electricity consumption increased by about 2.9 % annually.Renewable energy sources accounted for 68.2 % of electricity production in 2009 (Statistik Austria, 2009a, Consentec et al., 2008).

[4]In line with most studies, Reichl et al. (2008) concluded for Austria 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 to focus on long-term electricity supply security.

importance to suppliers, who thus misinterpret the benefits of supply security improvements and postpone infrastructure investments[5]. Secondly, in the case of grid-bound electricity supply – with most grids representing a natural monopoly – customers have for physical reasons no option of choosing an operator with a more adequate level of supply security for them. And thirdly, the short- and medium-term resilience of the grids in spite of security-preserving investments not being made creates incentives to even further postpone necessary investments.

One central prerequisite for developing an efficient regulatory system is quantifying the value of energy supply security. As supply security constitutes a non-market good, which can only be purchased in combination with the physical product (electricity), its value cannot be determined directly (see Kariuki and Allan, 1996a). That is why usually the failure of electricity supply, and in particular the cost of power cuts to non-households along with the willingness to pay (WTP) of households to avoid power outages, 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). Additionally, the EU Directive 2008/114/EG requires EU member states to assess the economic aftereffects of power supply failing, starting in January 2011. With the model presented in this paper (APOSTEL – *Austrian Power Outage Simulation Tool of Economic Losses*), it is possible for the first time to collect data on the value of energy supply security on the basis of blackout costs of firms, institutions public entities as well as on the basis of households' willingness to pay to avoid power cuts from one to 48 hours in Austria.

This paper proceeds as follows: Chapter 2 describes the different outage cost categories and introduces the methods utilized in this paper to evaluate losses due to power cuts. Chapter 3 contains the main results from households and non-households. Additionally, a case study is presented, which evaluates a possible power cut in Austria. In chapter 4 the data other studies provide on economic losses from power outages, on willingness to pay to avoid blackouts and on various approaches aiming at putting a value on energy supply security are compared with the results of this study. Chapter 5 summarizes and adds a conclusion on the need for further research.

[5]Households being less prepared in the presence of high energy supply security is dubbed the double paradox, which was researched in detail by Luiijf (2000) and De Hoo et al (1994) for the Netherlands.

2 Methodology

In this chapter we elaborate on different outage cost categories, on the methodical aspects of modeling economic losses in the event of a power outage and on the willingness to pay to avoid such power outages. As a starting point, the different categories of losses due to power outages are identified. Following Munasinghe and Sanghvi (1988) the economic aftereffects of power outages can be divided into three categories.

Direct costs represent the part of the total economic losses, which is a direct result of the failure, e.g. repair costs for defective electrical infrastructure facilities. Direct economic losses are usually limited and can be quantified precisely. They are subordinate to indirect economic losses, which tend to be very important from an economic perspective.

Indirect costs arise in direct connection with the failure. Yet they belong to that part of the total losses resulting from the absence of electricity supply in the aftermath of a failure. Examples are the cost of production outages, the expenditures for idle staff and opportunity costs to non-households (i.e. foregone value added). Indirect costs make up a significant proportion of the total costs (see Centolella et al., 2006, or Wacker and Billinton, 1989).

A third cost category are resulting long-term macroeconomic impacts such as economically relevant changes in the behavior of market participants as a result of a perceived long-term change in the level of energy supply security. Examples include the influence of the level of energy supply security on the choice of a place as a business location, the potential rise of production costs due to the increased need for backup-systems, or customer churn (i.e. by means of contractual penalties) due to unreliability regarding delivery deadlines.

The literature provides three main approaches to assess energy supply security in monetary terms, namely *proxy methods*, *market-based valuation methods*, and *contingent valuation methods* (see for instance Woo and Pupp; 1992). In this paper the losses within the segment of non-households are represented (in accordance with De Nooij et al., 2007) by a proxy method which maps the lost value added (see Chapter 2.1), while contingent valuation methods (willingness to pay analysis to avoid power outages) is used to value losses within the household segment (see chapter 2.2).

2.1 Methodology for assessing non-households' economic losses

A thorough discussion on the assessment of outage costs for non-households can be found in Kariuki and Allan (1996b). As non-households experience exclusively monetary losses in the event of power cuts, market-based loss valuation methods often follow an accounting approach (e.g. De Nooij et al. 2007, who recommend top-down methods). This approach requires that all (key) activities of non-household are checked with regard to their dependence on electricity and the impact of possible restrictions on the value adding process. Thus, the overall dependence on electricity of the non-household in question can be inferred from the aggregated monetary losses due to certain activities being impossible in the case of a power outage. 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 costs of idle staff capacity during the power outage have to be added in another calculation step. The same applies to the value of inputs being lost in the case of a power outage.

Additionally to a top-down approach using a web-based analysis tool, the outage costs assessment model, developed in this study, used survey inputs of the non-household segment. The top-down approach described in the previous paragraph required the participating non-households to asses their individual dependence on a secure electricity supply. In order to answer the questions each non-household had do gather these very detailed dependency data. Due to this complexity, and depending on the size and the structure of the non-household, the participation in this questionnaire took up to an entire person-day. This demanding approach is a disincentive to participate, but allows for more detailed analyses and reduces the possibility of strategic behaviour compared to questionnaires who directly ask for the expected damage from power cuts in monetary units. The participating firms, institutions and public entities were recruited in cooperation with the Austrian Chamber of Commerce and the Austrian Federal Chancellery[6]. 201 non-households representing 267 entities participated in the survey. 35 % of the participating non-households employed 1-10 people. 21 % had 11-50 employees, 23 % were medium sized (51-250 employees) and 21 % employed more than 250 people. Even though the largest federal

[6] To ensure unbiased company selection, a presentation of this survey together with an invitation to participate was sent to more than 100,000 firms. Additionally various sector newsletters drew attention to this project.

states of Austria were slightly over-represented in the survey, a balanced mix of all nine Austrian provinces was achieved. The non-households came from all sectors. They represented entities with a turnover of more than € 10 billion (about 3 % of Austrian GDP).

The economic losses of individual non-households calculated on the basis of value added statistics and incorporating the survey data had to be standardized in an appropriate way, to make it possible to extrapolate from the participants to all other non-household entities, so as to be able to form complete aggregates of sectors or regions subsequently. For this extrapolation the share of total losses in relation to the average daily added value in a single establishment was derived. These shares were then adapted to all establishments within the same economic sector proportional to the electricity consumption of the respective sector and the time-specific and regional characteristics of the power cut under investigation.

To assess the value added as input for the damage function, the personnel and input factor costs of sector-typical non-households were deducted from annual turnover[7]. In order to derive the daily value added from the available annual data, we made use of the reasonable dependence between productive activity and electricity consumption. For instance, a warehouse's approximate daily value added is considerably higher on workdays than on public holidays. However 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). When assessing the importance of energy supply security allocating value added proportionately to a load profile within a sector is a reasonable disaggregation method. The use of other approaches (given the same annual value added) would assign sectors without labor on non-working days (and thus without physical or accounting added value on non-working days) zero losses from a power outage on public holidays. This approach was chosen to control for the strong interdependence of value adding and electricity consumption. Unfortunately, public statistics of the electricity consumption patterns of sectors or regions do not exist in the depth needed. Thus, synthetic load profiles were used (Luebke et al,, 2007).

Using this approach we were able to get precise data on the damage costs of non-households depending on the time of the year the outage occurs (summer vs. winter), the time of the day (working hours or not), the duration of the outage and other explanatory variables. The regression and estimation approach can be found in the appendix.

[7]These data are available in great detail in public statistics (see Statistik Austria, 2011)

2.2 Methodology for assessing households' economic losses

The elicitation of households' valuation of energy supply security is quite different to non-households. For a comprehensive analysis of the household sector it is necessary to factor in immaterial as well as material losses occurring in the case of an outage. Thus, a contingent valuation methods based survey aiming at acquiring the data necessary for econometrically evaluating households' willingness to pay to avoid power cuts was conducted.

This survey was designed and implemented in accordance with the recommendations of best practice methods for contingent valuation methods (Arrow et al., 1993). 894 households participated in the survey. In order to avoid influences from the survey mode two subsamples were formed. 704 households were interviewed face to face. The questionnaire was then implemented online with the aid of diagrams. A further 190 households responded online. All participants were recruited by a market research center. 430 households provided complete data sets. The characteristics of the survey and the distribution in Austria are depicted below.

Table 1: Attributes of the participants of the household survey	**This study**	**Austria***
Share of men	62.4 %	48.7 %
Share of questionnaire participants with A-levels/high school diploma	54.8 %	18.9 %
Average age of participants	40.3 years	41.6 years
Households living in a town with >10.000 inhabitants	51.0 %	44.3 %
Average net household income per month	2,202 EUR	1,842 EUR
Share of households with children under 14	23.8 %	36.7 %

** Population aged 15 and older (see Statistik Austria, 2009b)*

Apart from season, sex, level of education, degree of urbanization, previous blackout experience, point in time, household size, 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 energy supply security the questionnaire differentiated between a very limited outage, which affected only one's own residential street, and an outage, which affected one's own home province and two neighboring provinces.

3 Results and Comparison with International Research

Using the methods described in chapter 2, it was possible for the first time to develop a model which is capable of simulating the economic losses of households and non-households in conjunction. The *Austrian Power Outage Simulation Tool of Economic Losses* (APOSTEL) can be used to assess the economic impacts of different blackout scenarios *ad hoc*. The costs of simulated with APOSTEL comprise both the indirect economic losses and the direct costs resulting from power outages. The costs due to damage to or the destruction of electricity infrastructure (which are present in most power outage cases) are excluded from the assessment, since these losses depend on the cause of the outage (e.g. break in supply line, operator error or software problems), whereas APOSTEL only simulates the resulting blackout, independently of what caused it.

The Value of Lost Load (VoLL) is one of the most common figures in the literature. We carried out a sensitivity analysis of the VoLL (in € per kWh electricity not supplied due to the outage) in order to obtain comparable estimates with other studies. As table 2 shows, the VoLL depends significantly on the characteristics of the power outage. During a one our hour outage on a weekday, the VoLL was calculated to be 17.1 € (summer) and 21.2 € (winter), respectively on average for households and non-households. The VoLL declines with duration of the power outage as adaption takes place.

Table 2: VoLL for different power outages on a working day (duration, day time and season in €/kWh unsupplied)

Duration	Summer 10a.m.	Summer 10p.m.	Winter 10a.m.	Winter 10p.m.
1h	17.1	3.2	21.2	7.1
12h	4.7	3.9	5.3	4.5

3.1 Austrian Power Outage Simulation Tool of Economic Losses

In this chapter the findings from this study and the value of energy supply security elaborated by means of the recently developed *Austrian Power Outage Simulation Tool of Economic Losses* are presented. APOSTEL analyses the effects of hypothetic blackouts for all of the nine provinces of Austria and for 15 economic sectors as well as for households in a predefined region at a random day and time of the year. Seven indicators of the economic impacts of a large scale power outage on non-households and households are calculated.

Two key indicators for the analysis of the effects of power outages on non-households are the economic loss and the amount of electricity not supplied (in MWh). This latter indicator is in this case derived from the synthetic load profiles of the sectors under consideration. In addition, using results from the survey, 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 including the Value of Lost Load (VoLL in € per kWh not supplied), the average loss per hour of the entire blackout and the average loss per hour per employee are provided. This latter indicator is a novel approach to reduce some drawbacks of the VoLL, which deflates the (relative) costs with rising levels of electricity consumption. Since the losses in a sector are partly due to stoppages in upstream sectors (e.g. to interruptions to the water supply, to telecommunication, or to transport infrastructures), there is a tendency to overestimate the VoLL for sectors particularly dependent on the functioning of other sectors.

For instance the VoLL for wholesale and retail traders is invariably much higher than the VoLL for manufacturing (i.e. industry). 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 non-households in this sector. Thus, a misleading picture of these non-households' true dependence on a secure electricity supply emerges. For these reasons the new developed indicator (hourly loss per employee) is provided as well. 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 high economic losses. Thus, 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.

3.2 Households willingness to pay to avoid power outages

Using a discrete choice model and data obtained by the surveys households' willingness to pay[8] (WTP) to avoid power outages was assessed and implemented in APOSTEL. The econometric modeling of willingness to pay (WTP) yielded a mean result of € 17.3 per household to avoid a 24-hour power outage. In order to avoid a 12-hour outage a mean WTP

[8]See McFadden (1996) or Reichl (2009) for details on the Willingness-to-pay elicitation modeling approach.

of € 9.9 was detected. To avoid a 4-hour power cut households were willing to pay € 3.8 on average. WTP to avoid a 1-hour power cut was assessed to be € 1.4. Willingness to pay to avoid a power cut regardless of its duration is 33.39 % higher in winter than in summer.

Analogously to non-households, the number of households severely or very severely affected and the number of persons living in these households are listed in APOSTEL as well. As with non-households, the shortfall of electricity is derived from the synthetic load profiles, and the economic valuation of energy supply security correspond to the households' aggregated willingness to pay to avoid a certain power outage. 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. Unexpectedly, it seems to make no statistically significant difference whether advance warning of a power outage is given or not. Considering that the severest restrictions during a power outage affect water supply, communications and space heating (services 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, the variables season, size of the outage area, participants' sex, education, household income and previous experience of power cuts are highly significant. For a detailed description of the significantly influencing parameters, please refer to appendix A2.

3.3 Case study

In this chapter a case study using APOSTEL is presented. Table 3 depicts this case study which analyses the effects of a 12 hour power outage scenario starting on an arbitrary summer workday (e.g. August 16th 2011) affecting all of Austria (nine provinces). The non-household share of the total losses is large partly due to the outage date (workday, 10 a.m.).

Table 3: Summary of impacts and the economic losses of a 12-hour power outage in Austria

Sector	Section (ÖNACE 2008)	Electricity not supplied (in MWh)	Percentage share	Total losses (in 1,000 €)	Percentage share
Primary sector	A, B	2,691	2.6%	7,154	1.5%
Secondary sector	C, D, E, F	52,383	51.2%	159,829	33.5%
Tertiary sector	G,H,I,J,K,L,M,N,' O,P,Q,R,S,T,U	23,813	23.3%	282,734	59.2%
Households		23,409	22.9%	28,080*	5.9%
TOTAL		**102,296**	**100%**	**477,798**	**100%**

* *Willingness to pay (self-quantified loss) of all households in the blackout area to avoid a power outage (in 1,000 €)*

The sector specific economic assessments of the losses and effects due to an outage of this kind are presented in tables 4 and 5.

Table 4: Economic assessment of a 12-hour outage in Austria using APOSTEL

Sector Code (ÖNACE 2008)	**Sector description**	**No. of severely or very severely affected units***	**No. of persons in severely/ very severely affected units****	**Electricity not supplied (in MWh)**	**Total loss (in 1,000 €)**
A	Agriculture, hunting and forestry	179,552	474,145	1,707	5,906
B	Mining and quarrying	335	6,063	985	1,248
C	Manufacturing	25,038	605,668	34,368	114,000
D	Electricity, gas, steam and air conditioning supply	1,452	27,006	13,930	14,136
E	Water supply; sewerage; waste managment and remediation activities	1,903	16,830	3,346	2,247
F	Construction	28,476	263,269	738	29,446
G	Wholesale and retail trade; repair of motor vehicles and motorcycles	69,331	576,027	3,558	125,163
H	Transporting and storage	13,005	200,417	4,700	27,743
I	Accommodation and food service activities	41,333	237,837	901	10,981
J	Information and communication	14,300	84,119	792	12,283
K	Financial and insurance activities	6,339	117,366	2,096	20,565
L	Real estate activities	14,407	38,528	837	8,145
M	Professional, scientific and technical activities	50,709	182,833	1,397	17,921
N	Administrative and support service activities	10,955	178,985	1,067	14,291
OPQ RSTU	Public sector	N/A*****	996,469	8,464	45,642
TOTAL	**Non-Households**	**457,135**	**4,005,563****	**78,888**	**449,718**
TOTAL	**Households*****	**3,598,258**	**8,262,101****	**23,409**	**28,080**

* *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, for firms the number of employees is given.*
*** *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 5: Economic assessment of a 12-hour outage in Austria using APOSTEL

Sector Code according to ÖNACE 2008	Sector	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, hunting and forestry	3.5	492	1.0
B	Mining and quarrying	1.3	104	17.2
C	Manufacturing	3.3	9.500	15.7
D	Electricity, gas, steam and air conditioning supply	1.0	1.178	43.6
E	Water supply; sewerage; waste managment and remediation activities	0.7	187	11.1
F	Construction	39.9	2.454	9.3
G	Wholesale and retail trade; repair of motor vehicles and motorcycles	35.2	10.430	18.1
H	Transporting and storage	5.9	2.312	11.5
I	Accommodation and food service activities	12.2	915	3.8
J	Information and communication	15.5	1.024	12.2
K	Financial and insurance activities	9.8	1.714	14.6
L	Real estate activities	9.7	679	17.6
M	Professional, scientific and technical activities	12.8	1.493	8.2
N	Administrative and support service activities	13.4	1.191	6.7
OPQRSTU	Public sector	5.4	3.804	3.8
TOTAL	**Non-Households**	**5.7*** **	**37.476**	**9.4**** **
TOTAL	**Households** **	**1.2*** **	**2.340**	**0.3**** **

* *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.*

The losses of non-households in the case of a power outage depend on the characteristics of the outage (time of the day, season, duration, etc.) and represent significant damages to the economy. In the case of a 12 hour power outage on a workday, their total losses amount to almost 450 Mio. € which is about 0.16% of the Austrian GDP. Average daily value added in Austria is roughly 790 Mio €. Given a strong dependence of GDP on electricity, it is highly reasonable, that almost not productive activity is possible in the case of a blackout.

3.4 Comparison of findings with international research

In this chapter the Value of Lost Load (VoLL) is compared with different international studies. To do this, we adapted the different indicators to a comparable unit (VoLL in € per kWh), adjusted all economic figures for inflation (all values are expressed in 2010 €) and corrected for changes in exchange rates. Particularly in the USA and Canada analysing the economic effects of blackouts has a long tradition aiming at providing a rationale for investment decisions and to make supply security enhancing measures more efficient.

For instance, Caves et al. (1990) provide outage costs ranging from 6.0 €/kWh to 25.9 €/kWh for the service sector, and from 1.5 €/kWh to 26.9 €/kWh for industry in the case of sudden events. In a meta study Woo and Pupp (1992) examined the findings of various earlier investigations for the sectors households, industry and trade. They investigated a variety of survey methods, presented the VoLL, the loss per hour and the loss per outage. For industrial firms outage costs were estimated to be between 8.0 €/kWh (Doane et al., 1990) and 71.6 €/kWh (Woo and Gray, 1987). For retailers outage costs are reported to be between 10.2 €/kWh (Woo and Train, 1988) and 20.8 €/kWh (Fischer, 1986). Sullivan et al. (1996) estimate the effects of large-scale blackouts on non-households and provide a VoLL for all firms, which is on average 45.94 €/kWh, and 7.6 €/kWh for industry.

Analysing households, Doane et al. (1988) estimate the value of energy supply security for household customers in the case of a one-hour outage to be 3.0 €/kWh (on a summer afternoon), 19.9 €/kWh (when agreeing to a tariff increase), and 20,0 €/kWh (on a winter evening). The study surveys both the Willingness to pay and to accept, i.e. the minimum value that a consumer would accept as compensation for a blackout. By contrast, Sanghvi (1983) estimates direct outage costs households face to be as little as 0.2 €/kWh.

A number of surveys have also been carried out for Europe as well. Both outage costs and willingness to pay to avoid outages of various consumer groups have been reported. Bertazzi et al. (2005) used a face-to-face survey performed in 2003 to assess firms' and households' willingness to pay and to accept 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 only 11.8 €/kWh. The authors see socio-cultural motives in Italy as the main reason for the discrepancy between costs and WTP (as uninterrupted power supply is regarded as a public service obligation). They suggest taking the mean of WTP and WTA as the most accurate yardstick for the value of energy supply security.

In an extensive survey Bliem (2007) used a choice modelling approach to investigate the economic value of energy supply security to households and firms in Austria. To avoid a one-hour outage, households are willing to pay 5.6 €/kWh. According to this survey, the average direct outage cost to firms of a one-hour blackout is 216.10 €/kWh. However, firms 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 3.5 €/kWh.

Vennegeerts et al. (2008) estimate German households' willingness to pay to avoid power outages at € 3 p.a. This figure has to be interpreted carefully, though, since 86 % of respondents protested at the idea of paying anything (WTP=0 €). Thus, the median WTP is 0 €/kWh. This suggests that most consumers in this particular survey expect the electricity supplier to ensure a reliable supply at no extra charge. However, 37 % of the participants would accept monetary compensation if outages were to occur more frequently (WTA > 0).

De Nooij et al. (2007) take a top-down approach 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 avoids some of the problems of stated preferences methods (e.g. CVM). However, the outage costs per kWh calculated for households are higher than for firms, owing to the assumptions chosen. They give a VoLL for a one-hour outage of 6.9 €/kWh for firms, and 19.1 €/kWh for households.

Table 6 provides an overview of the values different studies found adequate for energy supply security. Most of these surveys are concerned with one or more subgroups of market participants. By contrast, this paper aims to go further than that, and considers the entirety of losses incurred by all consumer groups and the macroeconomic effects. While one can identify particularly vulnerable market participants without this important step, the macroeconomic dimension of blackouts is evaluated only in rare cases (De Nooij et al., 2007, or Baarsma and Hop, 2009). The model presented here 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 6: Meta-analysis 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	VoLL in 2010 €/kWh
Fischer (1986)	USA, summer, afternoon	Trade	20.8
Woo & Gray (1987)	USA, summer, afternoon	Industry	71.6
Woo & Train (1988)	USA, summer, afternoon	Trade	10.2
Caves et al. (1990)	USA (maximum value)	Firms	26.9
Doane et al. (1990)	USA, winter, evening	Industry	8.0
Sullivan et al. (1996)	USA	Firms	45.9
Sullivan et al. (1996)	USA	Industry	7.6
De Nooij et al. (2007) *	Netherlands	Non-households	6.9
Bertazzi et al. (2005)	Italy	Firms	129.9
Bliem (2007)	Austria	Firms	216.1
Reichl et al. (2007)	Austria	Firms	7.8
De Nooij et al. (2007)*	Netherlands	Non-households	19.1
This paper	Austria, winter, morning	Non-households	26.8
Doane et al. (1988)***	USA, winter, evening	Households	20.0
Doane et al. (1988)****	USA, summer, afternoon	Households	19.9
Sanghvi, (1983)	USA, summer, midday	Households	0.2
Bertazzi et al. (2005)	Italy	Households	4.1
Fickert (2004)	Austria	Households	2.2
Bliem (2007)	Austria	Households	5.6
Reichl et al. (2007)	Austria	Households	3.5
This paper	Austria, winter, morning	Households	2.5

* *De Nooij et al. specify the costs of outages incurred by non-households, comprising firms, institutions and facilities.*
** *Baarsma and Hop employ a conjoint method (stated preferences) similar to willingness-to-pay analysis.*
*** *Direct costs to households.*
**** *Willingness to accept a tariff increase, comparable with approaches based on willingness to pay to avoid blackouts.*

4 Summary

This paper discusses approaches to putting a value on the non-market good energy supply security and develops a model to estimate the economic costs of simulated blackouts with a focus on Austria. Although the level of electricity supply security is relatively high in Europe, maintaining this degree of reliability in future involves a number of challenges. Efficient infrastructure investment decisions are possible only if the value of energy supply security is determined. To obtain an objective result, a series of different customer specific surveys among households and non-households from all economic sectors covering costs and personal feelings in the case of a blackout were carried out. Using contingent valuation methods for households and a value-added production approach for non-households, the macroeconomic effects from the economic outage costs incurred were determined. A comprehensive approach to calculate the monetary value of energy supply security for the whole of Austria, using a fine-mesh classification of all economic sectors states was used. As a result, not only particularly vulnerable sectors (such as the semiconductor industry, papermaking or data-generating processes), but all sections of the economy as per NACE 2008 are included in the outage costs assessment model. The assessment of a wide range of possible blackout scenarios, lasting from one to 48 hours, covers many different conceivable outages extents is unique for Austria. This paper does not cover blackouts lasting longer than 48 hours, with their hard-to-assess social and economic impacts, and outages in the second to minute range, which nevertheless pose a serious threat to non-households[9]. However, their effects are divers and might be mitigated by companies using available technology. The aim was to put a value on long-term energy supply security using outage costs and WTP to avoid power outages as best-practise yardstick. Summarizing the effects of a simulated 12 hour outage affecting all of Austria, it can be expected, that 457,135 non-households and roughly 4.461 Mio. inhabitants are severely or very severely affected. In this case, households account for 22.9 % of the electricity shortfall and for 5.9 % of the total losses, which amount to 478 Mio €.

Further research about the value of energy supply security is needed, 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 energy supply security uniformly throughout Europe. An improvement of the non-households' data base regarding value added and the utilisation of real-time load profiles might be able to improve the current approach.

[9] See Eto and LaCommare (2008) claim that up to 66% of all damages might be due to voltage dips and power quality problems.

5 Appendix

Appendix A1: Methodology to assess non-households' outages damage costs

In order to estimate the damages non-households face in the event of a power outage, synthetic load profiles and data on value added were implemented by means of a fixed effect regression approach for the non-households under consideration.

The percentage share (calculated deterministically for 5 power outage scenarios) of the total losses in the average daily value added of the non-households 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 β_{Br} is the sector-specific fixed effect. As the non-households sample did not have sufficient data to calculate a separate fixed effect for every one of the 21 sectors in the OENACE business branch classification[10], the sectors were grouped into six subcategories (SC-1 to SC-6, see table 7 in appendix B1[11]). $GWV(CA^{sim},BR^{int})$ represents the total value added, which is lost if the simulated power outage with the characteristics CA^{sim} in the sectors examined (BR^{int}) were to happen. $tWS_{Bl,Br}$ describes the daily value added in province *Bl* and sector *Br* (available in

[10] NACE: *Nomenclature statistique des activités économiques dans la Communauté européenne*

[11] 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.

public statistics) in proportion to the corresponding sector load profile. The total input lost was modelled in a similar way.

In Table 7 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.

Table 7: Regression coefficients of non-households' economic losses.

		Daily added value	**Daily effort in advance**
β_{CA}	Intercept	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*

Appendix A2: Methodology to assess household's' willingness to pay to avoid power outages

Households' willingness to pay was assessed using a discrete choice modelling approach.

The participating households were shown 16 different diagrammatic power-cut scenarios one after another. 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 and Frühwirth-Schnatter, 2012) accounting for scale heterogeneity (Fiebig et al. 2010) and willingness to pay was 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

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

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.

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.

The coefficients and explanatory variables of the estimation of households' willingness to pay to avoid power outages using contingent valuation are depicted in table 8.

Table 8: 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.

Analogously to the non-households, the number of households severely or very severely affected and the number of persons living in these households are calculated (see the case study in table 3). 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.

Appendix B1 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.

6 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.

Baarsma, B. E. and Hop, J. P. (2009). Pricing power outages in the Netherlands. Energy, 34, 1378 – 1386.

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 Nuessler, 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, accessed on August 24 2011.

BDEW - 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 August 24 2011.

Caves, D. W.; Herriges, J. A. and Windle, R. J. (1990). Customer Demand for Service Reliability In The Electric Power Industry: A Synthesis Of The Outage Cost Literature Bulletin of Economic Research, Blackwell Publishing Ltd, 42, 79-121.

Centolella, P.; Farber-DeAnda, M.; Greening, L. A. and Kim, T. (2006). Estimates of the Value of Uninterrupted Service for The Mid-West Independent System Operator. SAIC, available at: http://www.hks.harvard.edu/hepg/Papers/2010/VOLL%20Final%20Report%20to%20MISO%20042806.pdf, accessed on April 9 2012.

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 (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.

Eto, J. H; Koomey, J.; Lehman, B.; Martin, N.; Mills, E.; Webber, C. and Worrel, E. (2001). Scoping Study on Trends in the Economic Value of Electricity Reliability to the U.S. Economy E. O. Lawrence Berkeley National Laboratory Berkeley, CA, 2001.

Eto, J. H. and LaCommare, K. H. (2008). Tracking the Reliability of the U.S. Electric Power System - An Assessment of Publicly Available Information Reported to State Public Utility Commissions Ernest Orlando Lawrence Berkeley National Laboratory, 2008.

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

Fiebig, D. G.; Keane, M. P.; Louviere, J. and Wasi, N. (2010). The Generalized Multinomial Logit Model: Accounting for Scale and Coefficient Heterogeneity. Marketing Science, Vol. 29, No. 3. Pp. 393-421.

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.

De Hoo, S..; Böttcher, H.; Steetskamp, I. and van Wijk, A. (1994). Stroomloos : kwetsbaarheid van de samenleving, gevolgen van verstoringen van de elektriciteitsvoorziening Rathenau Instituut.

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..

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.

Luiijf, H. and Klaver, M. (2000). In bits and pieces - Vulnerability of the Netherlands ICT-infrastructure and consequences for the information society INFODROME.

Lübke, N.; Holst, A.; and Tolzmann, R. (2007). Entwicklung eines synthetischen Jahreslastprofils für Haushaltsabnahme aus Elt.-Versorgungsnetzen, Universität Rostock.

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.

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. and 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. and Frühwirth-Schnatter, S. (2012). A censored random coefficients model for the detection of zero willingness to pay. Quantitative Marketing and Economics, Doi: 10.1007/s11129-011-9115-2.

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, 4, 33-5.

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 August 24 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.

Statistik Austria (2011). Leistungs- und Strukturerhebung including the appendix (Methodeninventar). Propriety statistics, methodology extensions.

Sullivan, M.; Noland Suddeth, B.; Vardell, T. and Vojdani (1996). Interruption costs, customer satisfaction and expectations for service reliability. IEEE Transactions on Power Systems. 11, 989 -995.

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, 17, 109-126.