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Comparison of different models for estimating the residential sector customer interruption costs



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ABSTRACT

Estimation of economic impacts of power interruptions in residential customers segment is a challenging and tedious task. The literature presents different methods to come up with sound calculations for these customer interruption costs. This paper makes use of a detailed customer survey study that was conducted in Finland and presents a comparison of five different models: WTA, WTP, direct worth approach, price elasticity approach and a new macroeconomic model. When doing the analysis a total of 1009 customers are divided into three sub-categories regarding the distinct characteristics of power consumptions: households, vacation houses and farm house customers.

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1. Introduction

The current power system infrastructure in developed countries is quite old. Although the rate of power consumption increase is not considerably high, certain modifications and developments are needed as more renewable sources are introduced into the system. At this point the balance between further investments and acceptable level of outage events is crucial. To elaborate this point, numerous customer interruption costs analysis studies have been done for the last couple of decades.

The residential customers differ from the industrial and commercial customers in terms of power consumption characteristics. Since there is no direct economic activity linked to the continuous and high quality electricity, it is highly difficult and challenging to assess the power outage costs of the domestic consumers. Compared to the industrial and commercial customers, there has been fewer studies focusing on the residential ones. This paper aims to be a reliable source for domestic customer outage costs estimation methods.

Customer surveys are the most suitable tools to estimate the customer interruption costs (CIC) of the residential customers. The direct worth (DW) approach and the price proportional method are two main ways of conducting a customer survey. In DW approach the customers are asked to evaluate their losses in the predefined outage scenarios. On the other hand, the price proportional method includes extensively adopted Willingness to Pay (WTP) and Willingness to Accept (WTA) approaches. Ref. [1] studies the power reliability worth of residential customers by the aid of a customer survey. The paper [2] focuses on same challenge by adopting the WTP approach. A comprehensive WTP study for Swedish households is presented in [3]. Papers [4,5] follow WTP methodology for residential customers as well. The reference [6] compares the findings of DW and WTP methodologies for domestic customers. Ref. [7] includes the study of WTA/WTP findings of Flemish households. Another WTA/WTP study for German private households can be found at [8]. On the other hand, although the majority of the studies are based on customer surveys, Ref. [9] adopts a macro econometric approach to analyze the customer interruption costs of domestic customers.

This paper introduces the results of a comprehensive customer survey study conducted in Finland. It presents the comparisons of DW, WTA and WTP results. In addition, a price elasticity method and its results and the findings of a novel macroeconomic model are introduced. Instead of proposing a method that comes up with certain estimations for the residential sector outage costs, via the

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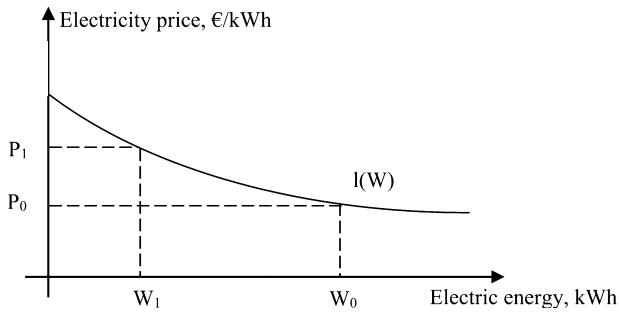


Fig. 1. The price elasticity.

novel macroeconomic model, an estimation band with maximum and minimum values is presented. The DW, WTA, WTP and price elasticity method findings are utilized for defining the boundaries to the cost estimations.

2. Interruption costs estimation methods

2.1. The direct worth approach

The DW approach includes outage scenario questions that differ in terms of the following:

- duration of the interruption,
- character of the interruption (whether the outage was reported to the customer beforehand or not),
- time of the interruption (morning, noon, evening, night),
- the season when the interruption takes place (winter, spring, summer, autumn).

The customers were asked to estimate and report their economic losses according to the above stated parameters. Then these monetary values were normalized by the average peak powers. The resulting customer damage function is designated as CIC_{DW} in €/kW.

2.2. The price proportional method

Due to geographical location Finland suffers from harsh winters. Therefore the electricity consumption peaks are seen during winters. For this reason, the highest economic impacts of possible power interruptions for the Finnish residential customers are seen during winter evenings. Under the light of this observation, the customers were asked to state a certain amount of compensation which they require to accept a scheduled 1-h outage (WTA) during winter evening time and on the other hand they were asked to report the amount of money they are willing to pay (WTP) in order to avoid the same outage. Then the monetary figures were normalized with average peak powers.

2.3. The price elasticity method

As long as the customer feels that the value of a product is greater than or equal to the price of the product, the customer receives a value added. If the price goes up, the customer customizes the amount of the product that he/she purchases. This method can also be applied when the electric energy is considered as the product. The real value of the electric power is the highest price that the customer is willing to pay. The difference between the real value of the power and the price of the power gives the value added that the customer enjoys. In case of an interruption the customer will lose some of his/her value. Fig. 1 shows the use of electricity as a function of the price of the electrical energy.

In a normal case the customer's electricity consumption is equal to W_0 where the price of the electricity is P_0 . At this point the marginal value of the product is equal to the price of the product. If the electricity price rises to P_1 , the customer reduces the use of electricity. Then the customer's electricity consumption is set to the point (W_1, P_1) . The electricity consumption is decreased by the amount of $(W_0 - W_1)$ when the price of the electricity rises by the amount of $(P_1 - P_0)$. The lost value of the undelivered energy can be calculated from Eq. (1).

$$Loss = \int_{\Delta W} (l(W) - P_0) dW \quad (1)$$

In the survey questionnaire the customers were asked to state which electrical appliances they would not use for 3 h if 5% of the annual energy cost is offered as a compensation. During calculations P_0 was taken as 0.10 €/kWh. The points W_0 , W_1 and P_1 were calculated according to the survey responses. After calculating the monetary losses, a customer damage function of CIC_{PE} in €/kW was defined via normalization by peak power.

2.4. A novel macroeconomic approach

In the paper [9] a macroeconomic approach was proposed. This model is based on the theory that one outage-hour during the leisure time corresponds to 1 h of less work during working hours and therefore the value of this lost non-working hour is equal to the wage of 1 h of work. By following the above-mentioned logic, a new macroeconomic model was derived. In this model, instead of annual energy consumption, the peak power was chosen as the normalization factor. It is calculated as follows:

$$CIC_{me} = d \frac{tw}{PP} \quad (2)$$

where, CIC_{me} is the CIC estimation via the macroeconomic approach. t is the outage duration in hours, w is the hourly wage in euros and PP is the peak power consumption in kW. d is the factor for continuous electric power dependency with $d \in [0,1]$. This factor can be calculated via the aid of a simple customer survey. The customers are asked that which electrical appliances they are willing not to use in return for a compensation. The reduction in power consumption will give an idea about the minimum requirements of a customer to carry out his/her basic needs. Then;

$$d = \frac{100\% - \% \text{ of the reduction in power consumption}}{100\%} \quad (3)$$

When inflated to 2013, the Finnish average total monthly earnings of wage and salary earners is 18.69 € per hour [10]. Furthermore, since peak power is chosen as the normalization factor in this paper, instead of energy consumption, the peak power that was reached by the customer was preferred. All CICs are presented in the unit of €/kW.

3. The customer survey

Different consumer segments have distinct power consumption characteristics and thus the economic outcomes of the power interruptions differ considerably. That is why during the survey the domestic customers were divided into three categories according to the location of the settlements. The customers who live in urban areas were named as household customers, where the ones in rural areas were named as farmhouse customers. Finally summer cottages were categorized as vacation house customers. These groups are households, holiday houses and farm houses. A total of 1009 customers were surveyed which corresponds to about 30% of response rate. The resulting customer damage functions were normalized by the peak power consumption of the customers.

Table 1
Summary of the CIC_{DW} of households customers for unexpected and planned outages.

	Unexpected outage						Planned outage	
	1 s	2 min	1 h	12 h	36 h	1 h	12 h	
Duration	1 s	2 min	1 h	12 h	36 h	1 h	12 h	
CIC_{DW} (€/kW)	0.12	0.84	7.8	65.88	196.44	3.72	48	

Table 2
Different CDFs in €/kW for household customers.

Duration	CIC_{DW}	WTA	WTP	CIC_{PE}	$CIC_{me,max}$	$CIC_{me,min}$
1 h	7.8	12.12	1.2	–	5.08	3.15
3 h	23.4 ^a	36.36 ^a	3.6 ^a	7.68	15.24	9.45

^a The values have been linearly extrapolated.

3.1. Households

The majority of the domestic power consumers in Finland are household customers. The results of the customer survey done with 744 household customers for unexpected and planned interruptions during winter time are summarized in Table 1.

The average annual energy consumption for household customers is 11,214.4 kWh and the average peak power consumption is 3.7 kW.

The distributions of the CICs via direct worth model for 1 s, 1 h and 12 h of outages during winter time are presented in Figs. 2–4, respectively:

Furthermore, $CIC_{PE} = 6.4 €/kW$ for 3 h of outage where the accepted power reduction is 38%. $WTP = 1.2 €/kW$ and $WTA = 12.12 €/kW$ for 1 h of outage.

For the macroeconomic approach, the most crucial part is to estimate the power dependency factor. It can be assumed that in modern life style 100% electric power dependency is possible for domestic customers. Clearly this figure will correspond to the maximum outage cost estimation. Nevertheless, to predict the minimum power dependency factor is a challenging task. The authors made use of the data from the questionnaire which states the willingness to reduce the power consumption in case of a certain compensation. 38% of reduction was acquired as an average from the respondents. This means 0.62 is the minimum electricity dependency that a customer is ready to experience. The customer damage functions (CDFs) of $CIC_{me,max}$ and $CIC_{me,min}$ are calculated according to the formula (2): $CIC_{me,min} = 3.15 €/kW$ for 1 h, $CIC_{me,max} = 5.08 €/kW$ for 1 h, $CIC_{me,min} = 9.45 €/kW$ for 3 h, $CIC_{me,max} = 15.24 €/kW$ for 3 h

All CIC calculations are summarized in Table 2.

Table 3
Summary of the CIC_{DW} of vacation house customers for unexpected and planned outages.

	Unexpected outage					Planned outage	
	1 s	2 min	1 h	12 h	36 h	1 h	12 h
Duration	1 s	2 min	1 h	12 h	36 h	1 h	12 h
CIC_{DW} in €/kW	0.12	0.24	29.16	90.36	206.76	10.32	95.76

Table 4
Summary of the CIC_{DW} in €/kW with respect to varying time parameters for vacation house customers.

	Winter		Summer	
	Weekday	Weekend	Weekday	Weekend
Morning (5 am–10 pm)	5.52	4.56	12.12	10.56
Noon (10 am–4 pm)	6.36	4.92	12.72	16.56
Evening (4 pm–11 pm)	7.56	5.76	13.32	12.36
Night (11 pm–5 am)	4.68	2.16	1.2	1.08

Table 5
Different CDFs in €/kW for vacation house customers.

Duration	CIC_{DW}	WTA	WTP	CIC_{PE}
1 h	29.16	18.36	2.64	0
3 h	87.48 ^a	55.08 ^a	7.8 ^a	2.88

^a The values have been linearly extrapolated.

3.2. Vacation houses

The results of the customer survey done with 102 vacation house customers for unexpected and planned interruptions during winter time is summarized in Table 3.

Where the average annual energy consumption of the customer segment is 4378.4 kWh and average peak power consumption is 2.9 kW. The outage cost calculations varying with season, time of the week and with time of the day are summarized in Table 4.

Furthermore, $CIC_{PE} = 5.64 €/kW$ for 3 h of outage where the accepted power reduction is 30.3%. $WTP = 2.64 €/kW$ and $WTA = 18.36 €/kW$ for 1 h of outage.

All CIC calculations are summarized in Table 5.

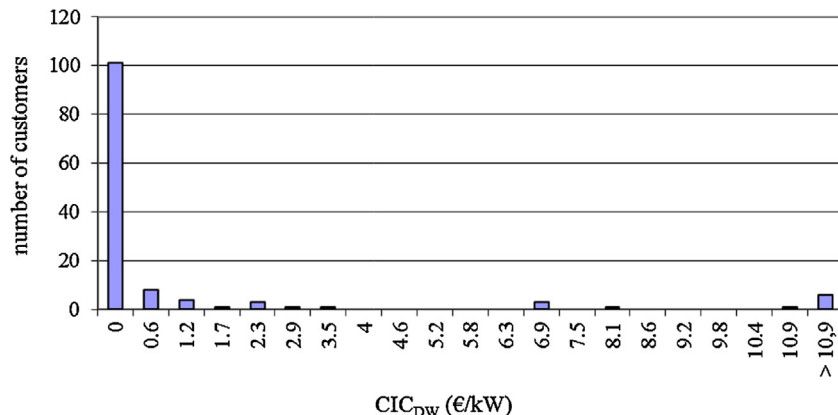


Fig. 2. CIC_{DW} distribution of household customers for 1 s.

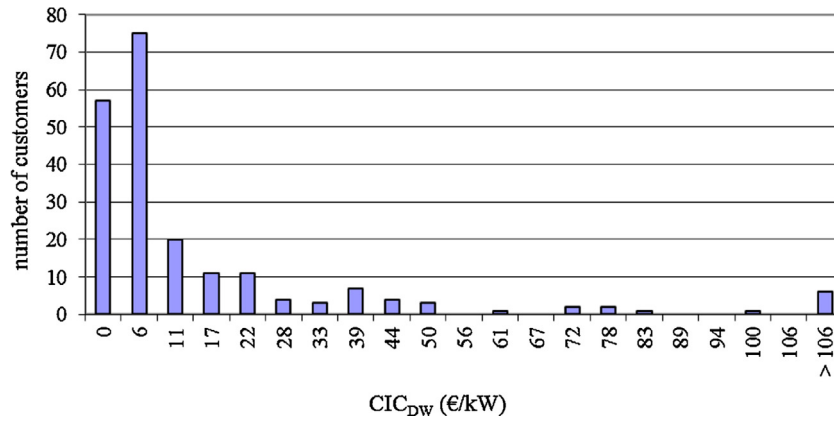


Fig. 3. CIC_{DW} distribution of household customers for 1 h.

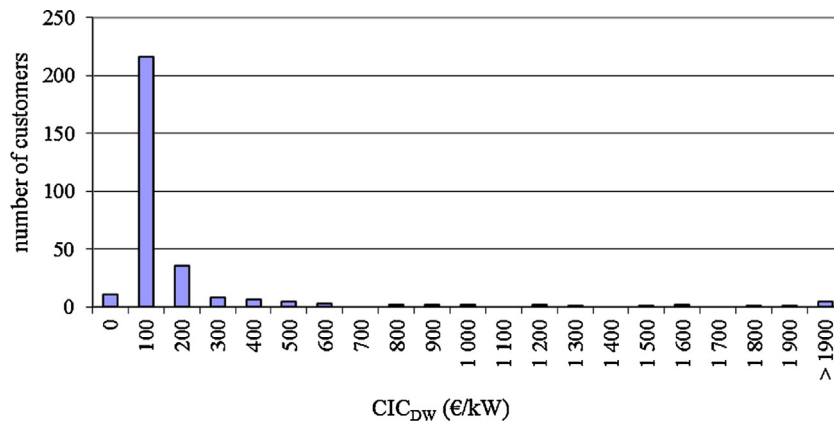


Fig. 4. CIC_{DW} distribution of household customers for 12 h.

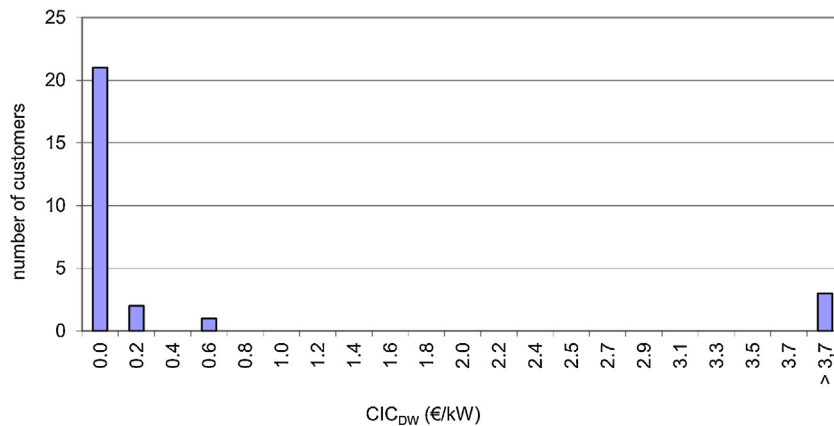


Fig. 5. CIC_{DW} distribution of farm house customers for 1 s.

3.3. Farm houses

The results of the customer survey done with 163 farm house customers for unexpected and planned interruptions during winter time is summarized in Table 6.

Where the average annual energy consumption of the customer segment is 39,563.1 kWh and average peak power consumption is 12.8 kW. The distributions of the CICs via direct worth model for 1 s, 1 h and 12 h of outages during autumn time are presented in Figs. 5–7, respectively:

A price elasticity study was not carried out for farm house customers. The WTP and WTA results were found as follows:

Table 6

The unexpected and planned CIC_{DW} in €/kW with respect to varying season and time parameters for farm house customers.

Season	Unexpected						Planned 1 h
	1 s	2 min	1 h	4 h	12 h	36 h	
Winter	0	0.72	12.48	47.04	140.88	383.4	8.88
Spring	0	0.12	7.44	14.52	71.4	199.8	2.52
Summer	0	0.24	3.6	11.64	69	186.12	2.28
Autumn	0.24	1.08	15.84	33.12	178.08	428.76	3.24

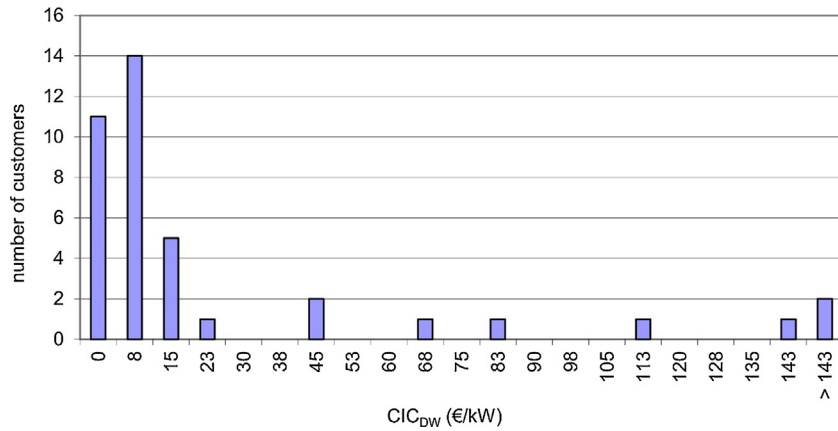


Fig. 6. CIC_{DW} distribution of farm house customers for 1 h.

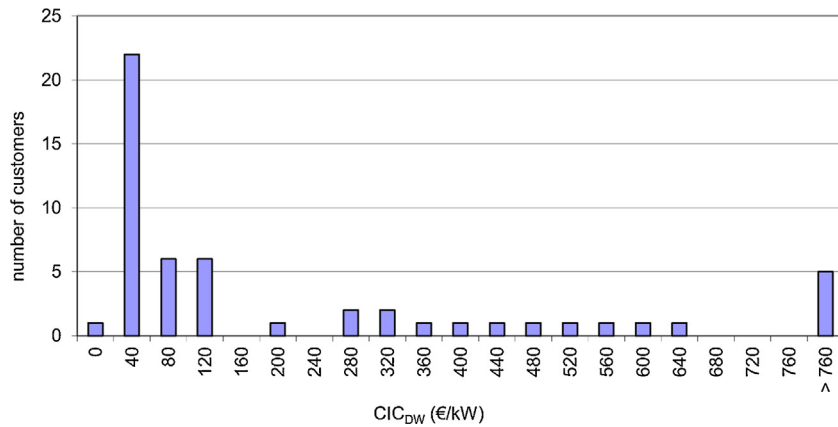


Fig. 7. CIC_{DW} distribution of farm house customers for 12 h.

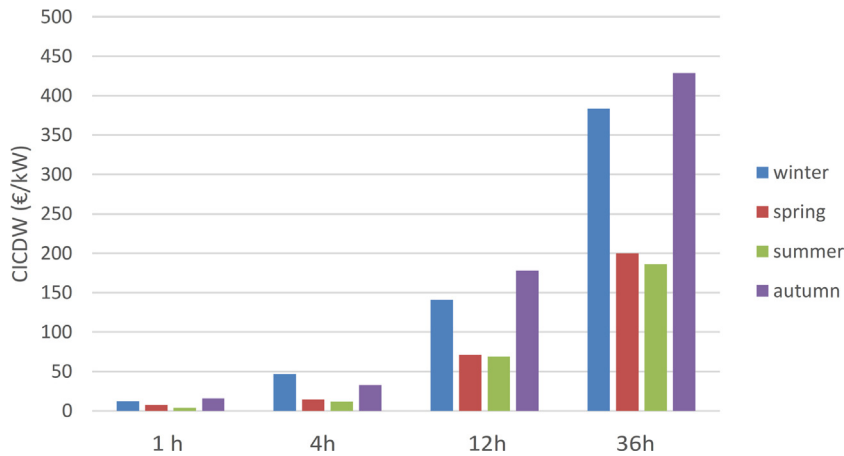


Fig. 8. The variation of CIC_{DW} of the farm house customers with respect to seasons.

Table 7
Different CDFs in €/kW for farm house customers.

Duration	CIC _{DW}	WTA	WTP
1 h	12.48	11.4	1.2
3 h	37.44 ^a	34.2 ^a	3.6 ^a

^a The values have been linearly extrapolated.

WTP = 1.2 €/kW and WTA = 11.4 €/kW for 1 h of outage.

All CIC calculations are summarized in Table 7 and the seasonally change of CIC_{DW} values is shown in Fig. 8.

As expected, the customer costs for farm house consumers fluctuate noticeably from season to season. The costs are highest during autumns while they are the lowest during summers.

4. Conclusions

In theory, it is expected that the WTA and WTP figures should be identical [11,12], the experience however show that there is a considerable gap between the customer assessments for WTA and WTP questions. However, these indices are useful in terms of providing upper and lower bounds for CIC estimations. On the other hand, the direct worth approach can be criticized by

indicating that regular domestic customers are not professionals who are fully aware of the true costs of power interruptions. This leads to the criticism about the nature of subjectivity of DW, WTA and WTP studies [13–15]. When compared to the other customer survey techniques, the price elasticity model requires much simpler survey questions (Which electrical appliances would you not use in return for a compensation of 5% annual electricity bill of the reduced amount of electrical energy?). By this way more sound estimations can easily be done. However, to reduce the subjectivity resulting from the respondents of the surveys, the authors came up with a novel macroeconomic model. The macroeconomic model is simply based on the logic that 1 h of non-working activity, or in other words lost leisure time, means 1 h of less work, and therefore the economic values are the same. This model is a straightforward, easy to apply and as objective as possible way to assess the residential customer outage costs. The only challenge with this model is to determine the electric power dependency factor. The maximum dependency could easily be claimed to be 100%. To calculate the lowest dependency factor a short and simple customer survey would be sufficient.

It should be noted that it is impossible to measure the true value of leisure activities in monetary units. This fact reduces the possibility of suggesting a highly accurate and objective methodology substantially. That is why, instead of suggesting one single model to compute precise economic impacts of the power interruptions, the authors believe that proposing multiple models in order to set boundaries to the CICs will be much healthier. The results of different CDFs in household customers are shown in Table 2. For 3 h of unexpected outage in winter time, the findings can be compared as follows:

$$WTA > CIC_{DW} > CIC_{me,max} > CIC_{me,min} > CIC_{pe} > WTP$$

On the other hand, for the scheduled outages of household customers, the CIC calculations are more promising:

$$CIC_{me,max} > CIC_{DW} > CIC_{me,min}$$

Under the light of these findings, it could be claimed that $CIC_{me,max}$ and $CIC_{me,min}$ present sound estimations for the domestic customer outage cost limits. Since by their nature the interruption costs of the residential customers are highly consumer dependent and subjective, the outage cost estimation for one domestic customer should not be a certain value, but it should be a value range of which boundaries could be set by the econometric approach presented here. To obtain customer specific and reliable results, this range should be as narrow as possible, therefore the authors claim that the use of WTA and WTP studies are inappropriate for the residential customers.

The econometric model (2) can be adopted by any region or utility easily. The outage duration t , the hourly wage w and the

peak power consumption PP are publicly declared and readily available data. The only challenge to estimate the economic costs of power interruptions remains to be calculating the continuous electric power dependency factor d . The maximum value could be assumed as 1.0. However, to find out the minimum value a limited scaled customer survey is necessary. By adopting the econometric methodology presented here, tedious customer surveys can be avoided and reliable and more objective estimations can be made in shorter time with less effort.

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