CUSTOMER INTERRUPTION COSTS IN QUALITY OF SUPPLY REGULATION: METHODS FOR COST ESTIMATION AND DATA CHALLENGES

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ABSTRACT

Several countries have introduced interruption costs in the quality of supply regulation using data from customer surveys. The regulation models differ among countries regarding how the interruption costs are calculated. For comparison of the effect of different regulation schemes, it is essential that the cost data are consistent and comparable. This paper addresses different interruption cost models and data challenges using examples from the Nordic countries.

INTRODUCTION

The network companies operate in a monopoly market. To control and give incentives to conduct a high quality of supply, the regulator in many countries has introduced quality requirements, and penalty schemes or financial incentives [1]. Such incentives are introduced to achieve a better balance between the continuity of supply and the network costs. To provide the right incentives, it is important to develop a credible regulation scheme based on reliable data on customer interruption costs.

Regulatory schemes based on customer interruption costs are implemented differently [1]. They have in common that they are using data estimated through studies such as customer surveys. For the cost estimation, various methods have been used around the world, e.g., direct worth and stated preference methods like consumer valuation [2, 3]. Even if there are recommendations and guidelines available for how to perform cost estimation studies [3], there is no agreed-upon cost estimation method. Consequently, the data are usually not comparable as the different methods reveal different cost data for the same kinds of customers.

This paper describes examples from the Nordic countries of quality of supply regulation models using customer interruption costs. The regulation models require a different level of detail regarding data about customer interruption costs. Regardless of the model, a consistent methodology for cost estimation would be of high value, enabling comparison of different quality of supply schemes and providing predictability for the network companies. Since the quality of supply regulation directly affects the network companies' income, it is essential to gain knowledge about the impacts of changing the regulation scheme itself or the input data.

The paper briefly presents the most commonly used approaches for cost estimation. Further, the challenge related to the use of different methods is discussed using data from the two latest Norwegian surveys on interruption costs, from 2002 and 2012 respectively. The cost data from 2012 are in use in the regulation from 2015, in the regulation model presented in [5]. It is illustrated that the interruption costs are considerably increased or decreased depending on customer type and time of interruption. These changes can partly be explained by changes in the cost estimation method.

INTERRUPTION COSTS IN REGULATION

Incorporation of interruption costs in the quality of supply regulation of the network companies is introduced in several European countries, see e.g., [1, 4]. The regulation models in use differ among the countries as well as to what extent interruption costs are included [1]. The models range from detailed calculation of costs for each actual interruption (as a function of time of interruption, duration and customer type) to models calculating yearly average costs based on indicators such as system average interruption duration index (SAIDI) and system average interruption frequency index (SAIFI). It also differs if notified and not notified interruptions are included, as well as short (≤ 3 minutes) and long (> 3 minutes) interruptions.

Aggregate interruption cost models

Differences in types of models can be illustrated using examples from Sweden, Finland and Norway. It should be noted here that only the principles of the models are described in the paper for comparison purposes. The details can be found in the respective regulations [6-8]. In Sweden, the interruption cost evaluation in the quality regulation was first put in place in 2004 through the Network Performance Assessment Model. The current model for calculation of interruption costs for each network company is based on the average SAIFI and SAIDI indices for long interruptions and national average cost parameters [6], as shown in principle in (1):

$$C_N = P_{av}(SAIDI \cdot c_E + SAIFI \cdot c_W) \text{ SEK/year} \qquad (1)$$

where
C_N = Annual cost of long interruptions (> 3 minutes) for network company N (for notified or not notified interr.)
P_{av} = Yearly average load in the supply area

SAIDI = Average SAIDI for the supply area
SAIFI = Average SAIFI for the supply area
c_E = Specific cost of energy not supplied (SEK/kWh)
c_W = Specific cost of power not supplied (SEK/kW)

The annual interruption cost calculated according to (1) represents in principle the total cost for a network company's supply area. Notified and not notified interruptions are both included, using different cost parameters (c_E and c_W, respectively). Short interruptions are not included. The cost parameters are based on a Swedish survey from 1994, updated to cost level 2003 and aggregated to the national level. There are plans in Sweden to further develop this scheme to incorporate customer types and average load per load point [6].

The quality incentive based regulation in Finland has been in place since 2008. In the current regulation, the number and duration of notified and not notified long interruptions and interruptions caused by high-speed and time-delayed auto-reclosers are taken into account in the calculation [7], as shown in (2):

$$C_N = P_{av}(U \cdot c_E + \lambda \cdot c_W + C^*{}_A) \text{ €/year} \quad (2)$$

where
C_N =Annual cost of interruptions for network company N
P_{av} = Yearly average load in the supply area
U = Customer's average annual duration of interruptions, weighted by annual energy consumption
λ = Customer's average annual number of interruptions, weighted by annual energy consumption
c_E = Specific cost of energy not supplied (€/kWh)
c_W = Specific cost of power not supplied (€/kW)
C^*_A = Annual cost of interruptions due to auto-reclosers (including both time-delayed and high-speed)

There are separate cost rates for notified versus not notified long interruptions. Thus, the first two elements in (2) should be calculated for both types of interruptions. There are also separate cost parameters for the two types of interruptions due to auto-reclosers included in C^*_A. The cost parameters in (2) are based on the results of a Finnish study in 2005, aggregated to the national level and updated each year by the consumer price index.

The Swedish and Finnish quality regulation models incorporating interruption costs are quite similar in the sense that the model for interruption cost assessment is an aggregate model, even though the cost parameters and reliability indicators (SAIDI, SAIFI, U, λ) are different.

Customer and interruption specific models

The Norwegian quality incentive based regulation was put into force in 2001. The calculation of the interruption costs in the current regulation is described in [5, 8]. This is based on calculation of the costs per actual interruptions per load point, taking different customer types into account, duration and time of occurrence of the interruptions, as shown in (3). Short and long interruptions as well as notified and not notified interruptions are all included.

$$C_N = \sum_{j=1}^{m}\sum_{i=1}^{nj}\sum_{k=1}^{sj} P_{ref,kj}c_{ref,kj}(\mathrm{r}_{ij})f_{Chkj}f_{Cdkj}f_{Cmkj} \quad (3)$$
NOK/year

where
C_N =Annual cost of interruptions for network company N
$P_{ref,kj}$ = Interrupted power in kW for customer sector k at load point j, at reference time
$c_{ref,kj}(r_{ij})$ = Specific cost for sector k in NOK/kW at reference time, for duration r_{ij} of interruption i at load point j
$f_{Ct,kj}$ = Correction factors for the cost (in NOK) at time t (in hour h, on weekday d and in month m) for sector k at load point j
m = number of load points in the supply area
nj = number of interruptions at load point j
sj = number of customer sectors connected to load point j

The correction factors in (3) describe the deviation in costs from the cost at the reference time (see next chapter). The factors are given in the regulations [8]. The costs of notified interruptions are calculated using a relative reduction factor, and (3) should be calculated for both notified and not-notified interruptions [8]. Comparing the Norwegian cost model against the Swedish and Finnish models, the main differences are that 1) each actual interruption in a supply area is taken into account, its duration, and which customers are affected, and 2) short interruptions are incorporated using cost functions per sector. The cost rates and relative correction factors describing the time of occurrence of the interruptions, are based on a Norwegian survey from 2012 [9] and given in the regulations [8].

The cost model in (3) is much more detailed than those in (1) and (2) as it requires cost data per customer sector as a function of the duration and individual load data per load point. The regulation models regarding interruption costs typically changes over time after collecting experiences and gaining better data about interruptions and costs [1, 3]. In order to provide a credible regulation scheme and provide predictability for the network companies, it is important that necessary studies and comparisons are performed before new regulatory steps are taken. For comparison of the effect of different regulation models such as in (1), (2) and (3), it is important that the cost data used are based on a consistent methodology. The consistency lies partly in the aggregation e.g., from single customer sector data to the national level and to the average level of interruptions, and partly in the methods used for estimating the cost data per customer sector. The latter is the topic for the next section.

ESTIMATION OF INTERRUPTION COSTS

Methods for cost estimation

Methods for estimation of costs due to electricity interruptions can be grouped into three broad categories [2, 3]:

- Indirect analytical evaluations
- Case studies of blackouts
- Customer surveys.

Among these, customer survey methods are the most common approaches to estimate costs of interruptions. The direct worth (DW) method is the dominating method for Industry and Commercial services, whereas Contingent valuation and conjoint analysis are the dominating for the Residential sector. In the direct worth methods, the customers are asked to estimate the cost of hypothetical interruption scenarios of different duration, seasons, days of the week and times of the day, etc. The costs are estimated in terms of lost production, costs for making up production, damage to equipment and raw material, etc. Contingent valuation and conjoint analysis methods measure the willingness to pay (WTP) to avoid, or willingness to accept (WTA) a compensation for, similar hypothetical interruption scenarios. Advantages and disadvantages of the different methods are discussed in [3]. Often in customer surveys, different methods are utilized for cross-check, reducing disadvantageous effects such as strategic response, etc., but also due to the suitability of the methods to cover different aspects. Another advantage is that the use of different methods gives a possible range of cost estimates.

Interruption costs vary due to both interruption characteristics and customer characteristics [2, 3]. Customer characteristics are factors such as type and size of consumer, electricity consumption, availability of reserve supply, etc. Interruption characteristics are frequency and duration of interruptions, time of occurrence (time of day, week, year), and if the interruption is notified in advance or is unexpected, etc. The customer surveys should include questions to identify at least the most important customer and interruption characteristics influencing on the cost estimate. Usually, the worst case scenarios are used as a base case (reference time) in the surveys.

Sector customer damage functions - examples

The cost estimates provided by the respondents in a survey are usually stated in absolute costs. These data are further transformed into normalized cost data that can be used to represent customers within the same sector (i.e., with similar cost characteristics but different electricity consumption level) and to provide cost data on a useable form for different applications. Applied normalization factors include interrupted power (kW), energy not supplied (kWh), annual electricity consumption (kWh) and annual peak load (kW) [3]. The normalized cost represents the customer damage function (CDF) for a single customer, as a function of interruption duration. The individual cost functions within a sector are combined into sector customer damage functions (SCDF). Figure 1 shows an example of SCDFs for the customer sectors in the Norwegian regulation from 2015.

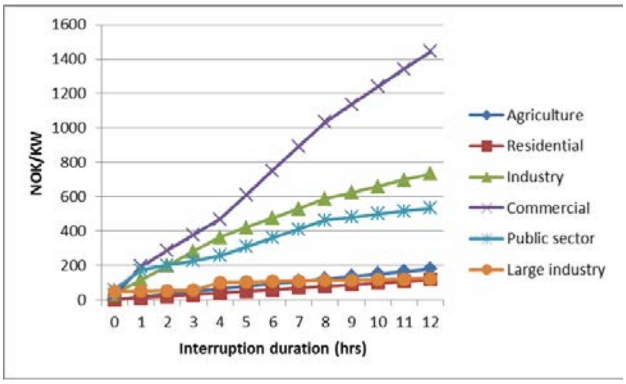

Figure 1 Sector customer damage functions in NOK/kW (cost level 2012), at the reference time "a working day in January" [8]. Cost data in use from 2015.

The SCDFs shown in Fig. 1 correspond to the specific cost for sector k ($c_{ref,kj}(r_{ij})$) in (3) above, for a given duration r_{ij}. The SCDFs can further be used as a basis to provide aggregate cost data like those used in (1) and (2), appropriately weighted to yield a composite value on the national level.

Cost studies conducted around the world, see e.g., [2, 3], provide examples of SCDFs. The variety of customer surveys shows that different methods are used for the cost estimation, involving differences in the questions used. Different methods may reveal different cost data for the same kinds of customers, as illustrated in next chapter.

COMPARISON OF DIFFERENT COST DATA

Sector customer damage functions

The challenge related to the use of different methods is discussed using data from the two latest Norwegian surveys on interruption costs, from 2002 [5] and 2012, respectively [9]. The cost data from 2012 are in use in the regulation from 2015 [8], based on the same regulation model as has been in operation since 2009 [5].

Fig. 2 shows the cost functions for the Commercial, Industry and Public sectors as used in the previous regulation and the new regulation (from 2015), respectively. Comparing the cost functions, it can be seen that the normalized costs are significantly increased in the new regulation, for all three sectors. For example, the normalized cost for a commercial customer for a 4-hour interruption is about the same as in the previous regulation, but for 8-hour interruption it is increased by 70 %, from 608 to 1034 NOK/kW. The differences can partly be explained by differences in the methods and the questions used in the survey for cost estimation, see the section below discussing differences.

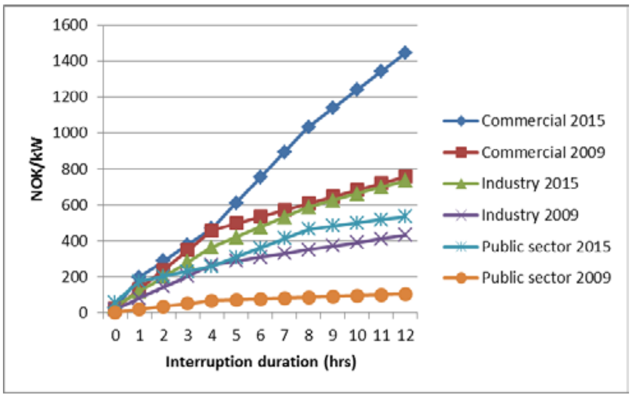

Figure 2 Comparison of SCDFs from two different surveys/regulation periods [5, 9], cost level 2012

Time variation in interruption costs

From the results of the new survey, it can also be revealed that there are larger deviations in the cost by time of interruption compared with the former survey. The decrease in the cost is for instance in the order of 70 - 80 % for the commercial and industrial sectors on Sundays and during night compared with 30 - 40 % in the former survey. This may be explained by differences in the questions in the survey. The differences are illustrated in Fig. 3 for weekly variation. The reference time used in the surveys was a working day in January at 10 am.

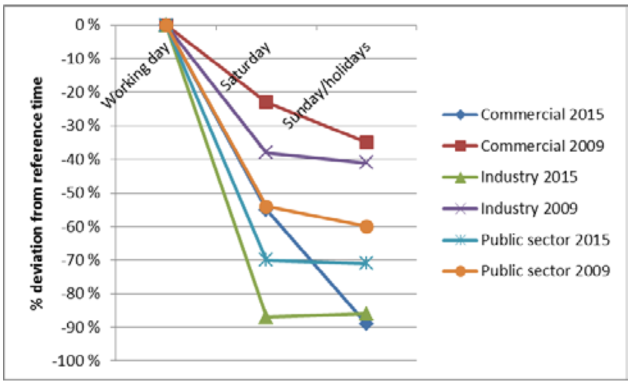

Figure 3 Comparison of relative variation in interruption cost by day of week, from two different surveys [5, 9]

In Fig. 4, an example is given of how the resulting effect of changes in the cost at reference time and the time variation influences the calculated cost for a specific interruption, for two different sectors and two different interruptions. One interruption occurs on a Saturday in July at 4 pm and lasts for 2 hours, while the other occurs on a Tuesday in May at 2 pm and lasts for 0.5 hours.

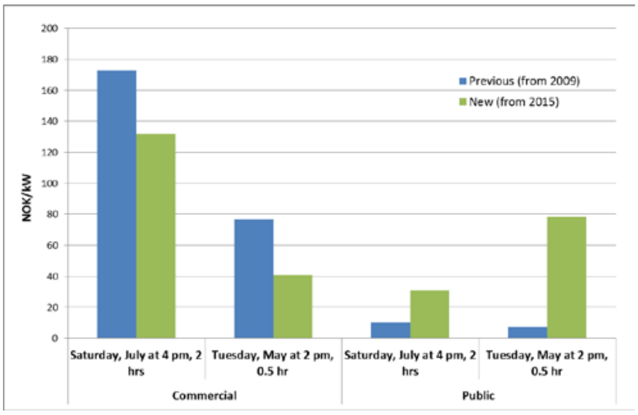

Figure 4 Comparison of costs for different interruptions

The comparison in Fig. 4 considers only the product of the normalized cost at reference time and the relative time-varying factors in (3). The figure shows that the cost might be considerably reduced at a different time of the year and day of week compared with the cost at reference time, depending on customer category and interruption scenario. It should be noted here that the cost is given in terms of NOK/kW and should be multiplied with the interrupted power at reference time according to (3) for a given customer or delivery point.

Differences in methods and data

Fig. 4 shows that the resulting cost using the new cost data is reduced for the commercial sector, while it is considerably increased for the public sector. The main reason is the new method used for estimating the cost in this sector. In the survey from 2002, the cost in public sector was calculated based on both DW and willingness to pay (WTP), while in the survey from 2012 it was based on the indirect cost estimation of lost working hours.

Table 1 gives the methods used in the two latest Norwegian surveys. In 2002, cost data were calculated using the average of the direct worth and willingness to pay-estimates, whereas the 2012-survey used only one method (mainly DW). The 2002-survey showed that DW-estimates were significantly larger than WTP-estimates, with a DW/WTP ratio in the order of 2-12, depending on customer category. This may explain the relatively large differences in the sector customer damage functions.

Table 1 Cost estimation methods in Norw. surveys [9]

Category	**2002**	**2012**
Households	(DW+WTP)/2	WTP
Industry	(DW+WTP)/2	DW
Commercial	(DW+WTP)/2	DW
Public	(DW+WTP)/2	Indirect DW*
Large industry	(DW+WTP)/2	Indirect DW*

* Lost working hours + extra costs

Another example is the differences in questions about the cost deviation from reference time. In 2002, it was asked for relative deviation per month, while in 2012 it was asked per the four seasons. For weekly and daily variation, it was asked in percentage in 2002, but in 2012 the respondents gave cost estimates in monetary terms.

Differences in methodologies and analyses made between these two surveys are related to aspects such as [9]:

- Cost estimation methodology (see Table 1)
- Type and content of questions in the survey
- Sample size and customer sectors
- Data analysis (censoring, zero values, missing data, calculation of normalized costs etc.)

As shown above, data may not be comparable as they give different information due to different cost estimation methodologies. There may also be differences in the division in customer sectors and which characteristics are covered, the choice of reference time (worst case scenario) and interruption scenarios, as well as the normalization factors and methods used for analyzing data and calculating the SCDFs. One should therefore be careful in comparing different cost estimates or customer damage functions between different studies.

It can be expected that the interruption costs will vary between countries, because of differences in factors such as sectorial composition of electricity consumption, power demand, level of dependency on electricity in the economy, by season, etc. Thus, data from one country are not necessarily transferrable to another country. A consistent methodology for cost estimation would enable comparison of the effect of different regulation schemes. References [3, 4] provide recommendations and guidelines for how to perform cost estimation studies. Following such guidelines would lead in the right direction of providing consistency. There is yet no single agreed-upon cost estimation method. Different experts tend to prefer different methods, probably since there are advantages and disadvantages related to all methods [3].

Differences in normalized cost estimates between two studies performed with e.g., 10 years in between, may also be caused by a real change in for instance the economy or electricity dependency, as well as in the normalization factor (power end energy consumption).

CONCLUSIONS

This paper has given examples of different regulation schemes incorporating customer interruption costs. These models range from customer- and interruption specific models using cost data per customer sector as a function of interruption duration and individual load data, to aggregate models using average data of costs, loads and average number and duration of interruptions.

The interruption cost assessment models are usually based on cost data revealed from customer surveys. Various methods are used for this purpose. The most common approaches are the direct worth (DW) method, contingent valuation and conjoint analysis. There may also be differences in which customer and interruption characteristics that are covered in the surveys and in the data analysis to obtain cost data for further use. Different methods give different cost data for the same kinds of customers. Examples show that the DW estimates are much higher than WTP cost estimates. Thus, the data give different information and may not be comparable. More important is that different cost data might lead to different decisions regarding the reliability of supply.

Even though there are recommendations and guidelines available for how to perform cost estimation studies, there is no single agreed-upon cost estimation method. A consistent methodology for cost estimation and data analysis would be of high value, enabling comparison of different quality of supply regulation schemes and providing predictability for the network companies.

REFERENCES

[1] CEER, 2011, "*5th Benchmarking report on the quality of supply*", http://www.energy-regulators.eu

[2] R. Billinton et al., 2001, "*Methods to consider customer interruption costs in power system analysis*", CIGRE, SC38.06.01, Ref no. 191.

[3] M. Hofmann, H. Seljeseth, G. H. Volden, G. H. Kjølle, 2010, "*Study on estimation of costs due to electricity interruptions and voltage disturbances*", SINTEF Energy Research, TR A6978.

[4] CEER, 2010, "*Guidelines of Good Practice on Estimation of Costs due to Electricity Interruptions and Voltage Disturbances*", CEER, http://www.energy-regulators.eu

[5] G. Kjølle, K. Samdal, K. Brekke, 2009, "Incorporating Short Interruptions and Time Dependency of Interruption Costs in Continuity of Supply Reg.", *Proceedings CIRED 2009*, Prague.

[6] Swedish Energy Markets Inspectorate (EI), 2010, "*Quality evaluation of power networks by ex ante regulation*", (in Swedish), EI, http://ei.se/sv/Publikationer

[7] Energy Market Authority, 2011, "*Appendix 1 – Regulation methods for the assessment of reasonableness in pricing of electricity distribution network operations"*, www.emvi.fi

[8] NVE, *Regulations governing financial and technical reporting, income caps for network operations and transmission tariffs*, www.nve.no.

[9] Energy Norway, 2012, "*Socio-economic costs of interruptions and voltage disturbances. Implications for regulation*" (in Norwegian), Energy Norway, Publication no. 354-2012