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REGIONAL DIFFERENCES IN ECONOMIC IMPACTS OF POWER OUTAGES IN FINLAND

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Estimating the worth of continuity of electricity supply is of interest to industry, governments, regulators and the research community. There are numerous methods to calculate the Customer Interruption Costs (CICs). Each method has its advantages and disadvantages. We approach the problem from the Distribution System Operator (DSO) point of view and employ two existing analytical models. One model is used by the Finnish Energy Market Authority and the second one was proposed by some of the authors in a previous study. Our model offers a simple and straightforward methodology which can provide credible and objective estimations utilizing only publicly available analytical data. We made use of cost and reliability indices data of 78 DSOs in Finland from the 2016. In addition to cost estimations, we highlight regional differences in CIC estimations in different parts of Finland and provide a critical overview of the existing standard customer compensation scheme in Finland.

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Keywords electric power outages, security of supply, customers, interruption, cost, DSO, compensation

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Abstract—**Estimating the worth of continuity of electricity supply is of interest to industry, governments, regulators and the research community. There are numerous methods to calculate the Customer Interruption Costs (CICs). Each method has its advantages and disadvantages. We approach the problem from the Distribution System Operator (DSO) point of view and employ two existing analytical models. One model is used by the Finnish Energy Market Authority and the second one was proposed by some of the authors in a previous study. Our model offers a simple and straightforward methodology which can provide credible and objective estimations utilizing only publicly available analytical data. We made use of cost and reliability indices data of 78 DSOs in Finland from the 2016. In addition to cost estimations, we highlight regional differences in CIC estimations in different parts of Finland and provide a critical overview of the existing standard customer compensation scheme in Finland.**

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1. INTRODUCTION

THE worth of electric power reliability has been a vital question since the liberalisation and unbundling of electric power systems and markets. Before suggesting further investments in the infrastructure, the planners should know the value of marginal increase power system security and compare it with the cost of interruption events. In addition to this, increasing conscience in consumer rights push authorities for more protective policies. Thus, in some countries such as Finland, Sweden, United Kingdom, the durations of single time outage events are capped and in case of exceeding these allowable limits, the Distribution System Operators (DSOs) are obliged to pay certain compensations back to their customers. Therefore, both the authorities which devise these customer compensation plans and the DSOs which undergo operation and maintenance costs and compensations should be able to understand the true costs of the outage events. Customer Interruption Cost (CIC) estimation methods can mainly be classified as: customer surveys, indirect analytical methods and case studies. Each approach has its own advantages and drawbacks. Customer Surveys are preferred most frequently in literature (Küfeoğlu and Lehtonen, 2016). They follow Direct Worth (DW), Willingness to Pay (WTP) or Willingness to Accept (WTA) approaches. A customer survey is prepared and sent to the customers by one-to-one interviews, telephone calls, e-mails or by mail. The questionnaires include questions about different power interruption scenarios. Getting customer specific results is the most significant advantage of customer surveys, since the questionnaires can be tailored and they can target industry, service, commercial, residential and agriculture sectors. However, customer surveys demand too much time, labour and money. Moreover, dealing with the subjective responses is another concern. Researchers may end up with high amount of extreme and zero responses at analysis process (Küfeoğlu and Lehtonen, 2015). Numerous examples for customer surveys can be found in (Kjolle et al., 2008; Herman and Gaunt, 2008; Chowdhury et al., 2009; Baarsma and Hop, 2009). Indirect Analytical Methods is the second most preferred CIC estimation approach. Relying on objective data such as electricity prices, value added or turnover of a customer or sector, gross domestic product of a country

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or annual energy consumption makes indirect analytical methods more favourable if reaching objective results is aimed. They are straightforward, easy to apply, less time, money and labour demanding. However, they tend to yield broad and average results. The studies (Hoo, 2006; Chen et al., 2007; Narayan and Prasad, 2008; Cheng et al., 2013) are examples for indirect analytical methods. Thirdly, Case Studies can be used to assess CICs. These are done after major blackout events. It is regarded as the most reliable CIC estimation method since both direct and indirect economic costs incurred by the power outages are covered through case studies. Nevertheless, large scale blackout events are not seen frequently and carrying out case studies is highly costly, these methods are not common in the literature. Case studies from New York City blackout of 1977 (Corwin and Miles, 1978) and Storm Gudrun of 2005 in Sweden (Carlsson et al., 2008) can be named as successful examples for these. A more comprehensive literature review about the existing studies and a more in-depth assessment of merits and weaknesses of each methodology can be found at (Kufeoglu, 2015). More recent studies can be found based on country specific data. The report (Sullivan et al., 2015) summarizes the value of service reliability for the electricity customers in the United States. Another detailed report (London Economics, 2013) investigates the value of lost load (VoLL) for electricity customers in Great Britain. The paper (Poudineh and Jamasb, 2017) presents the worth of energy not supplied (ENS) in Scotland. The studies (Shivakumar et al., 2017) and (Abrate et al., 2016) target the costs of power interruptions at residential sector in the European Union and Italy respectively. Another paper introduces outage cost estimations for industry sector customers from South Korea (Kim and Cho, 2017). Various other generic power interruption assessment papers have been published for customers from Germany (Growitsch et al., 2015), Lebanon (Bouri and Assad, 2016) and South Africa (Minnaar et al., 2017). These studies make use of customer surveys and indirect analytical methods to make the estimations. However, they approach the problem from customer's point of view. This paper aims to approach the same CIC estimations from the DSO perspective by comparing the CIC calculations through two different analytical models; formula used by the Finnish Energy Market Authority and another macroeconomic model presented by the authors at (Küfeoğlu and Lehtonen, 2015b).

The following parts of the paper are organized as follows: Section 2 introduces the methodology of the existing two indirect analytical methods. Section 3 presents the empirical study and the results of the customer interruption cost estimations through these two methods by making use of data from 78 DSOs in Finland from the year 2016. This section also briefs the standard customer compensation scheme in Finland. Section 4 includes conclusion and discussion remarks and it points out the regional income and CIC differences in Finland. Appendix includes the detailed results of the calculations as a table.

2. METHODOLOGY

In order to calculate the customer interruption costs experienced in each DSO region, we will make use of two different methodologies. The first one is the formula which is used by the Energy Market Authority of Finland (Energiavirasto) which aims to estimate the total monetary disadvantages caused by long outages according to the formula (1) (Energy Market Authority, 2015).

$$CIC_{t,k} = \begin{pmatrix} OD_{unexp,t} * h_{E,unexp} + OF_{unexp,t} * h_{W,unexp,t} + \\ OD_{plan,t} * h_{E,plan} + OF_{plan,t} * h_{W,plan} \end{pmatrix} * \frac{W_t}{T_t} * \frac{CPI_{k-1}}{CPI_{2004}} \tag{1}$$

Where;

$CIC_{t,k}$: monetary worth of the power interruptions to the DSO's customers in year t in the value of money in year k, (euros)

$OD_{unexp,t}$: customer's average annual unexpected outage time weighted by annual energies in the year t, (hours)

$h_{E,unexp}$: value of the unexpected outages to the customer in the2005 value of money, (€/kWh)

$OF_{unexp,\ t}$: customer's average annual unexpected outage number weighted by annual energies in the year t, (numbers)

$h_{W,unexp}$: value of the unexpected outages to the customer in the 2005 value of money, (€/kW)

$OD_{plan,t}$: customer's average annual planned outage timeweighted by annual energies in the year t, (hours)

$h_{E,plan}$: value of the planned outages to the customer in the 2005value of money, (€/kWh)

$OF_{plan,t}$: customer's average annual planned outage number weighted by annual energies in the year t, (numbers)

$h_{W,plan}$: value of the planned outages to the customer in the 2005 value of money, (€/kW)

W_t: the customer's amount of energy consumption in the year t, (kWh)

T_t: the number of hours in a year (hours)

CPI: Customer Price Index

The h values are given by the Energy Market Authority and they are shown in Table 1.

Furthermore, by assuming the CPI of 2005 as 100 in Finland, CPI in 2016 was 120.7 (Statistics Finland, 2017).

Table 1

Prices in 2005 Values for Calculation of the Customer Interruption Costs (Energy Market Authority, 2015).

coefficient	$h_{E,unexp}$ (€/kWh)	$h_{W,unexp}$ (€/kW)	$h_{E,plan}$ (€/kWh)	$h_{W,plan}$ (€/kW)
value	11.0	1.1	6.8	0.5

The second methodology to assess these costs is the macroeconomic approach suggested for the residential customers only (Küfeoğlu and Lehtonen, 2015b). To see the applicability of that approach to the whole customer classes which include industry, service (commercial) and residential ones, we would like to adopt it and then compare the results with the CIC results obtained from formula (1). The theory behind the macroeconomic approach is that one outage-hour during the leisure time corresponds to one hour of less work during working hours and therefore the value of this lost non-working hour is equal to the wage of one hour of work. The details of the macroeconomic approach are as follow:

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

Where;

CIC_{me}: the interruption cost estimation via the macroeconomic approach (€/kW)

t: outage duration (hours)

w: average hourly earnings (€)

PP: peak power consumption (kW)

d: factor for continuous electric power dependency with d ∈ [0,1].

The study calculates factor d as:

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

In formula (2) peak power is used as a normalization factor. In this paper, we would like to adopt another widely accepted normalization factor, which is the annual energy consumption. By this way, we will be able to compare the results obtained from (1) with the ones from (2). We already presented the data for the annual interruption hours and energy consumption for each DSO. In 2016, the average of total hourly earnings of wage and salary earners was 19.76 € in Finland (Structure of Earnings, 2017). Moreover, (Küfeoğlu and Lehtonen, 2015b) assumes d_{max} as 1.0 and d_{min} as 0.62. d_{max} is assumed as 1.0 by implying that the theoretical limit of a customer's dependency to electric power would be 100%, which means the customer would like to use all the electrical appliances without giving consent to a power cut. d_{min} is calculated according to the customer survey conducted in Finland. Details regarding to this study could be found at (Küfeoğlu and Lehtonen, 2015b). On the other hand, we should also include the factor that there might be more than one income earner in one electricity customer. According to the Finnish statistical institution, in average there are 1.79 income earners per household in Finland (Structure of Earnings, 2017). Therefore we should modify (2) as:

$$CIC_{me} = a * d\frac{tw}{AE} \qquad (4)$$

Where,

a is the number of average income earners per household (€),

AE is the annual energy consumption (kWh).

3. EMPIRICAL STUDY AND RESULTS

According to the formula (1), CIC and to formula (4), $CIC_{me,max}$ and $CIC_{me,min}$ have been calculated. The necessary statistical data to calculate the CIC for each DSO, which include the System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI), as well as the data such as number of customers and energy supplied can be found in (Energy Market Authority, 2016). The CIC results are normalized by the annual energy supply per each DSO and then summarized in € cents/kWh in Table A in Appendix. Figure 1 is presented for better understanding the comparison of the outcomes of (1) and (2).
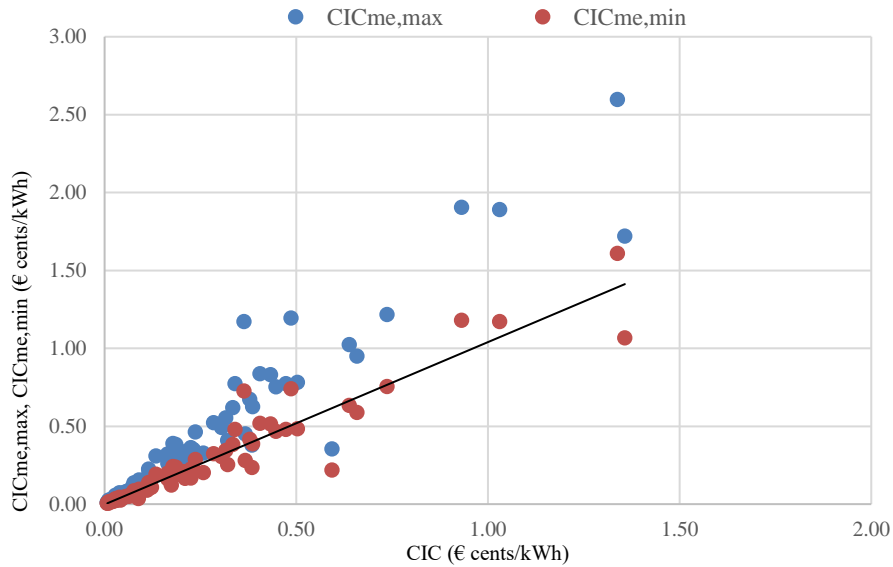

Figure 1. Comparison of CIC vs. $CIC_{me,max}$ and $CIC_{me,min}$

From Figure 1 we see that for 78 different DSOs, majority of the results of *CIC* are closer to $CIC_{me,min}$ than those of $CIC_{me,max}$. This observation tells us that instead of following (1) which requires extensive data, the novel macroeconomic approach (2) could be used to estimate the total costs of direct and indirect impacts of electric power outages. We should remind that (2) is more simple and straightforward when compared to the methodology used by the Energy Market Authority of Finland. After making this observation, we would like to mention about the customer protection scheme which aims to penalize the DSOs in case of a single outage event lasts longer that the allowable limits. If this limit is exceeded, the DSO is supposed to pay a certain percentage of the annual electricity delivery fee back to the customer. Standard Customer Compensation was accepted in Electricity Market Act in Finland in 2013 (Electricity Market Act, 2017). The details are summarized in Table 2 as:

Table 2

Standard Customer Compensation Scheme in Finland, Accepted In 2013

Standard Customer Compensation	
Outage time (h)	Compensation (%)
12-24	10
24-72	25
72-120	50
120-192	100
192-288	150
> 288	200

According to this plan, the maximum amount of compensation to be paid to a customer is to be 1,200 € per year. The purpose of this scheme is to protect electricity consumers from long lasting interruptions and motivate DSOs to provide better and higher quality services to the customers. According to the figures shared by the Energiavirasto in

2016, 7,361,479 € was paid to the customers as compensations (Energy Market Authority, 2016). Figure 2 shows the distribution of the amount of compensations per outage duration limits during this period.
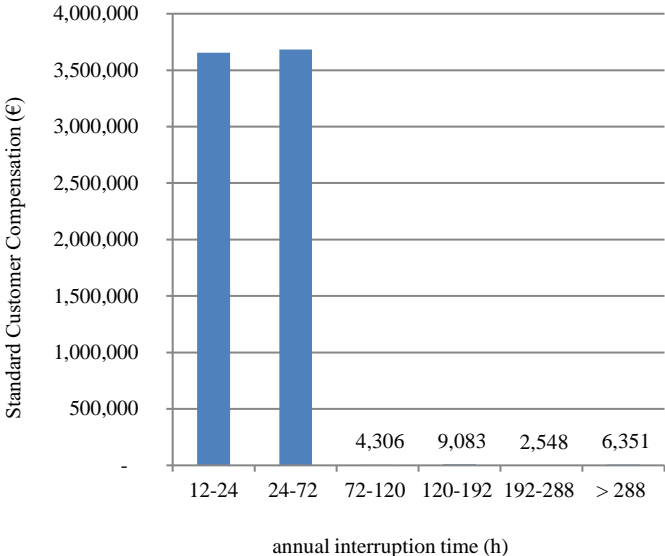

Figure 2. Standard Customer Compensations paid in 2016

As we can see, almost all of the compensation were paid due to interruption events which took between 12-24 and 24-72 hours. Each period of outage time limit corresponds to around 3.5 million euros, while the other time bands produced compensations less than 10 thousand euros. This means that single outage events that last up to 72 hours pose a threat against the wellbeing of the Finnish consumers since these events are experienced more frequently. Another crucial observation from the analysis is that quite few DSOs paid these compensations in 2016. Out of 78 DSOs, only 32 of those exceeded the allowable limits. Figure 3 shows 24 DSOs which paid standard compensations and the amount of compensation normalized by annual energy supply in 2016. The remaining 8 DSOs were neglected since their normalized figures were quite minimal.
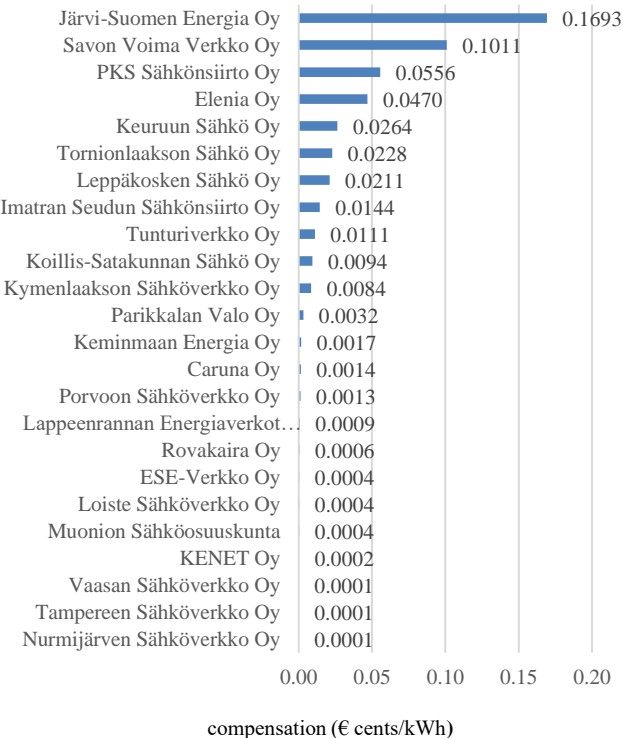

Figure 3. Standard Customer Compensations normalized by the annual energy consumption

Both (1) and (2) could be assessed the indirect analytical methods. By these methods the customer interruption costs are calculated through publicly available and objective analytical data such as number of customers, annual energy consumption, gross domestic product, average wages, SAIDI and SAIFI. Nonetheless, to be able to reach customer specific results via these methods is not possible. Extensive customer surveys targeting specific customer groups are necessary for that purpose. The macroeconomic model, CIC_{me} (2) makes use of national averages of wages, rather than regional averages that each DSO is active in. Figure 4 shows the income distribution in each Finnish region. According to the income figure from 2016, blue regions are above the national average whereas grey ones are below (Structure of Earnings, 2017).
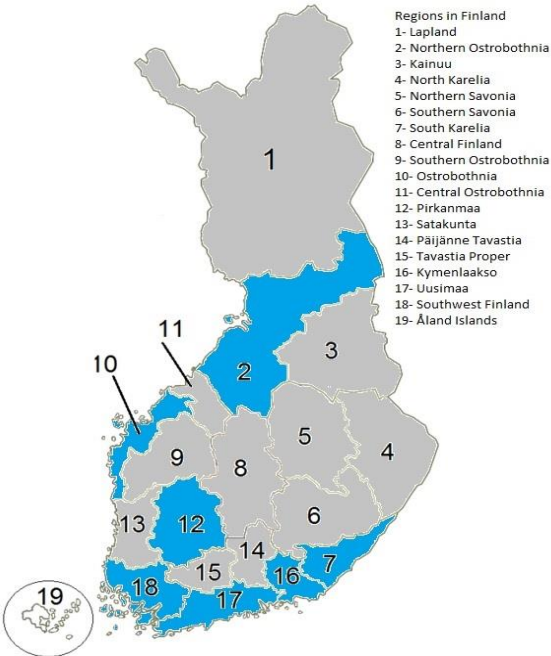

Figure 4. Regional income distribution in Finland in 2016, Blue: above national average, Grey: below national average

One may conclude that since the income level is higher in southern and western Finland, the customer interruption costs per kWh will be higher as well. In fact, this is not the case. According to our calculations, CIC is higher in northern and eastern parts of Finland and it is the lowest at the southern regions, especially in the Uusimaa region where Helsinki metropolitan area is located. Figure 5 illustrates the lowest and highest CIC regions in Finland in 2016. The share of underground cabling in the distribution network system is crucially important in power reliability. Overhead lines are more prone to external threats than the underground cables. Storms cause substantial damage to the distribution system in Nordic countries. Extreme weather events are the primary causes of power interruptions in countries like Finland and Sweden (Gündüz et al., 2017; Küfeoğlu and Lehtonen, 2014). When we check reliability figures of Finnish DSOs, we see that there are more frequent and longer lasting outages in rural regions where the distribution distances are longer (Energy Market Authority, 2016).

Figure 4 and Figure 5 tell us that there is an inverse proportion between regional level of income and regional CIC in Finland. Therefore, instead of using national average of wages at the macroeconomic model (2), it is imperative to use average wages in each DSO region.
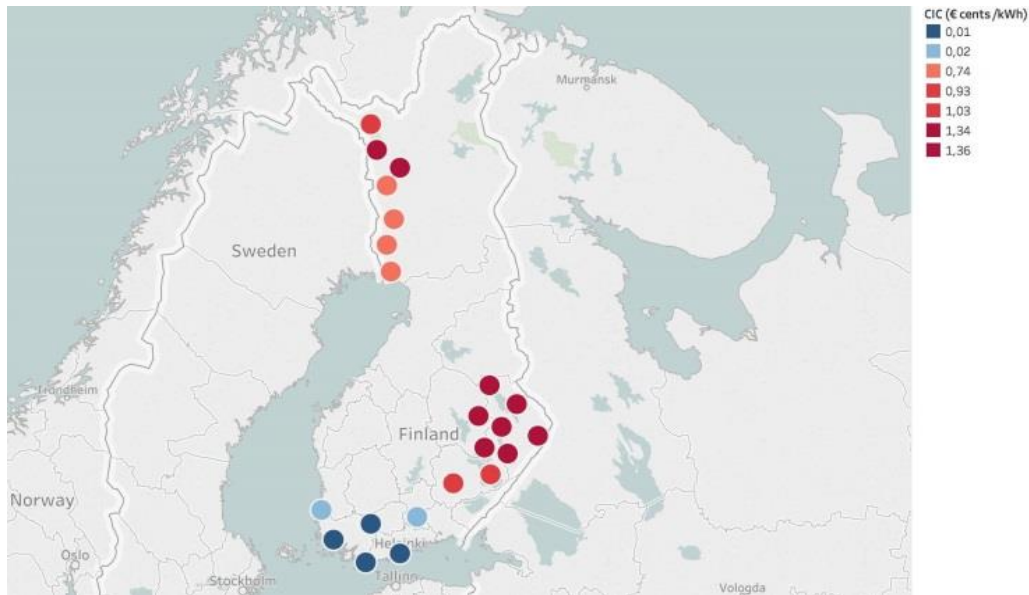
Figure 5. Regional CIC distribution in Finland (€ cents / kWh)

4. CONCLUSION

We approach the customer interruption costs estimations problem from the DSO perspective. Our study makes use of analytical data shared by 78 Finnish DSOs which provide 99% of the energy to the low voltage customers in Finland. It is quite crucial to understand the costs of power interruption for planning purposes. Furthermore, protection of customers from long lasting blackouts is another driving factor behind the need of understating the impacts of power outages and their economic worth. Being a popular area of research, there have been numerous studies targeting this problem. However, majority of these studies rely on customer surveys, which are criticized of being biased. Rather than providing a comprehensive review about the CIC phenomena, we focused on a specific case study. This paper presents two existing approaches models and the comparison of the CIC estimations reached via these models. these. As an alternative to the formula (1) used by the Finnish Energy Market Authority, the paper shows that the macroeconomic model (2) can be used by the DSOs to estimate the costs of total direct and indirect impacts of the interruption events in their region in a fast and objective manner. However, it is not possible to get customer specific results through this approach. To understand the value of customer interruptions for industry, service, commercial, residential or agriculture sector, customer surveys are necessary. CIC_{me} will yield average results. However, if regional income levels are used, more customer specific results could be reached. On the other hand, there is evidence that the standard customer compensation plan is not designed in a fair manner. From Figure 3 we see that, while some DSOs paid certain amounts of compensations back to the customers, some did not pay anything at all. This means that the allowable single time outage event time limits should be reconsidered and planned in a way that fair compensations would be paid by the DSOs in case of outage events. Another important observation is that when the CIC results at Table A and Figure 3 are checked, we see that customers are undercompensated in almost all DSO regions. This necessitates that the standard customer compensation scheme in Finland should be revised and a fairer compensation plan should be introduced.

Table A.
CIC, CIC$_{me,max}$ and *CIC$_{me,min}$* per each DSO in 2016 (€ cents / kWh)

DSO	CIC	CIC$_{me,max}$	CIC$_{me,min}$	DSO	CIC	CIC$_{me,max}$	CIC$_{me,min}$
Äänekosken Energia Oy	0.12	0.23	0.14	Leppäkosken Sähkö Oy	0.32	0.56	0.34
Alajärven Sähkö Oy	0.21	0.27	0.17	LE-Sähköverkko Oy	0.02	0.04	0.02
Caruna Espoo Oy	0.23	0.36	0.23	Loiste Sähköverkko Oy	0.18	0.39	0.24
Caruna Oy	0.31	0.49	0.31	Muonion Sähköosuuskunta	1.36	1.72	1.07
Ekenäs Energi Ab	0.01	0.01	0.01	Naantalin Energia Oy	0.01	0.01	0.01
Elenia Oy	0.47	0.77	0.48	Nivos Energia Oy	0.04	0.04	0.03
Enontekiön Sähkö Oy	1.03	1.89	1.17	Nurmijärven Sähköverkko Oy	0.11	0.16	0.10
ESE-Verkko Oy	0.03	0.06	0.04	Nykarleby Kraftverk Ab	0.18	0.30	0.19
Esse Elektro-Kraft Ab	0.64	1.02	0.64	Oulun Energia Siirto ja Jakelu Oy	0.04	0.07	0.05
Etelä-Suomen Energia Oy	0.37	0.45	0.28	Oulun Seudun Sähkö Verkko. Oy	0.12	0.20	0.12
Forssan Verkkopalvelut Oy	0.01	0.01	0.01	Outokummun Energia Oy	0.09	0.06	0.04
Haminan Energia Oy	0.03	0.04	0.03	Paneliankosken Voima Oy	0.08	0.09	0.05
Haukiputaan Sähköosuuskunta	0.08	0.12	0.07	Parikkalan Valo Oy	0.39	0.63	0.39
Helen Sähköverkko Oy	0.01	0.03	0.02	PKS Sähkönsiirto Oy	1.34	2.60	1.61
Herrfors Nät-Verkko Oy Ab	0.17	0.20	0.12	Pori Energia Sähköverkot Oy	0.09	0.10	0.06
Iin Energia Oy	0.12	0.18	0.11	Porvoon Sähköverkko Oy	0.17	0.26	0.16
Imatran Seudun Sähkönsiirto Oy	0.19	0.38	0.24	Raahen Energia Oy	0.29	0.52	0.32
Järvi-Suomen Energia Oy	0.93	1.91	1.18	Rantakairan Sähkö Oy	0.13	0.31	0.19
Jeppo Kraft Andelslag	0.59	0.36	0.22	Rauman Energia Oy	0.02	0.04	0.03
JE-Siirto Oy	0.03	0.04	0.03	Rovakaira Oy	0.38	0.38	0.24
Jylhän Sähköosuuskunta	0.23	0.35	0.22	Rovaniemen Verkko Oy	0.03	0.06	0.03
Kemin Energia Oy	0.02	0.03	0.02	Sallila Sähkönsiirto Oy	0.07	0.11	0.07
Keminmaan Energia Oy	0.45	0.75	0.47	Savon Voima Verkko Oy	0.66	0.95	0.59
KENET Oy	0.06	0.08	0.05	Seiverkot Oy	0.03	0.04	0.03
Keravan Energia Oy	0.09	0.16	0.10	Tampereen Sähköverkko Oy	0.03	0.06	0.03
Keuruun Sähkö Oy	0.38	0.67	0.42	Tenergia Oy	0.50	0.78	0.48
Koillis-Lapin Sähkö Oy	0.49	1.20	0.74	Tornion Energia Oy	0.21	0.34	0.21
Koillis-Satakunnan Sähkö Oy	0.41	0.84	0.52	Tornionlaakson Sähkö Oy	0.74	1.22	0.75
Kokemäen Sähkö Oy	0.07	0.09	0.06	Tunturiverkko Oy	0.32	0.41	0.25
Köyliön-Säkylän Sähkö Oy	0.23	0.27	0.17	Turku Energia Sähköverkot Oy	0.02	0.03	0.02
Kronoby Elverk Ab	0.09	0.14	0.09	Vaasan Sähköverkko Oy	0.08	0.12	0.08
KSS Verkko Oy	0.08	0.14	0.09	Vakka-Suomen Voima Oy	0.11	0.15	0.09
Kuopion Sähköverkko Oy	0.03	0.06	0.04	Valkeakosken Energia Oy	0.06	0.08	0.05
Kuoreveden Sähkö Oy	0.06	0.09	0.05	Vantaan Energia Sähköverkot Oy	0.02	0.03	0.02
Kymenlaakson Sähköverkko Oy	0.33	0.62	0.38	Vatajankosken Sähkö Oy	0.18	0.30	0.19
Lammaisten Energia Oy	0.05	0.07	0.05	Verkko Korpela Oy	0.26	0.33	0.20
Lankosken Sähkö Oy	0.36	1.17	0.73	Vetelin Energia Oy	0.43	0.83	0.52
Lappeenrannan Energiaverkot Oy	0.24	0.46	0.29	Vimpelin Voima Oy	0.16	0.32	0.20
Lehtimäen Sähkö Oy	0.34	0.77	0.48				

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