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IMPROVEMENTS IN REGULATION AND INVESTMENTS IN FINNISH ELECTRICITY DISTRIBUTION BUSINESS – CUSTOMER PERSPECTIVE

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Abstract

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This study investigates how weather-proofing investments in Finnish electricity distribution networks could be done more cost-efficiently and how the Finnish regulation model for regulating distribution system operators (DSO) could be improved from the customer perspective. An impact evaluation of exploiting exceptional interruption times was carried out based on DSOs' network development plans from year 2018. The impact evaluation indicates possible cost-savings from 42 M€ to 906 M€ in weather-proofing investments, if an updated policy would be effective in the beginning of year 2020. The case-study suggests monetary implications of weather-proof readiness service could work in low power branch-line in rural areas. The case study indicates a 347 € to 651 € weather-proof readiness fee could be paid yearly to users accepting longer interruption times.

The study includes a literature review for other European countries' regulation models reviewing continuity of supply, voltage quality and commercial quality indicators. Most suitable incentives and improvements to the regulation model are presented as recommendations in this study.

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Tämä tutkielma selvittää miten sähkönjakeluverkon myrskyvarmuuden parantamiseen liittyviä investointeja voitaisiin tehdä kustannustehokkaammin ja miten suomalaisten jakeluverkkoyhtiöiden sääntelyä regulaatiomallin kautta voitaisiin parantaa asiakasnäkökulmasta. Tutkielman vaikuttavuusarviointilaskelmat pohjautuvat jakeluverkkoyhtiöiden vuoden 2018 verkon kehittämissuunnitelmien julkisten osioiden tietoihin. Vaikuttavuusarvioinnin perusteella 42 M€ - 906 M€ kustannussäästöt myrskyvarmuusinvestoinneissa olisivat saavutettavissa, jos vaadittavat muutokset lainsäädäntöön tulisivat voimaan 1.1.2020 alkaen. Case-tapauksen perusteella myrskyvalmiuspalvelua voitaisiin hyödyntää pienitehoisissa sähkönjakeluverkon haaroissa haja-asutusalueilla. Käyttäjälle voitaisiin maksaa 347 € - 651 € myrskyvalmiuspalvelumaksua käyttäjän hyväksyessä yli 36 tunnin kestäviä sähkönjakelun keskeytyksiä haja-asutusalueella.

Tutkielma sisältää kirjallisuuskatsauksen muihin eurooppalaisiin regulaatiomalleihin keskittyen toimitusvarmuuden, sähkön teknisen laadun ja kaupallisen laadun mittareihin ja kannustimiin. Johtopäätöksissä on esitetty suosituksina sopivimmat kannustimet ja parhaat käytännöt nykyisen sääntelyn kehittämiseksi.

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CEER	The Council of European Energy Regulators
DSO	Distribution System Operator
Electricity Market Act	Electricity Market Act (588/2013)
ENS	Energy Not Supplied
HV-network	High Voltage electricity distribution network
LV-network	Low Voltage electricity distribution network
MPS	The Metered Supply Point is the point at which the meter measuring a customer's consumption is located.
MV-network	Medium Voltage electricity distribution network
NPV	Net Present Value
Point of connection	A point (boundary of property) between the electrical installations of the DSO and the user
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
TSO	Transmission System Operator
WPR-fee	Weather-proof readiness fee

1. INTRODUCTION

Users of the electricity distribution network require electricity to be delivered at reasonable cost, with adequate quality of electricity supply and with an easy network subscription. Electricity networks are natural monopolies in Finland and mainly owned by municipalities or other public owned corporations. There are a few distribution system operators (later DSO), which are owned by private equity investment firms. The electricity network industry is highly regulated due to the nature of the market. Energy Authority is responsible for supervising the industry and developing regulation, which keeps the industry profits in a sustainable level for needed investments and on the other hand protects user rights with regard to reasonable pricing and quality of electricity supply. In a monopoly market DSOs receive all income from users, who have no negotiation power towards the DSO.

1.1 Background

A notable policy change happened in the electricity network industry, when the Electricity Market Act (588/2013) came in to force in 2013. Heavy winter storms left tens of thousands of households without electricity for long periods in 2011 and the government decided to set a weather-proof requirement for Finnish electricity distribution networks. The Electricity Market Act requires that all electricity distribution networks must be planned, constructed and maintained in a manner, that there are no outages longer than 6 hours in town plan zones and no longer than 36-hour outages in other areas in Finland after 31.12.2028. At the same time electricity networks are nearing the end of their technical operational life-time, because there was a rapid electricity network construction phase in the 1960's. Partanen (2018) has estimated a necessary total investment of 9,511 M€ in Finland during years 2014-2018. The weather-proofing investments for fulfilling the weather-proof requirement set in the Electricity Market Act were estimated to be 2,900 M€. Especially DSOs operating mainly in rural areas are forced to improve their distribution network for achieving the weather-proof requirement set by the law.

These investments will be financed by increasing electricity distribution fees collected from the users.

From a macroeconomic perspective the latest population forecasts in Finland are forecasting the population number to significantly decrease in rural areas in the next 20 years (MDI 2019). DSOs are reporting users terminating their network subscriptions in rural areas due to low electricity consumption. PKS Sähkönsiirto Oy, a DSO operating in rural areas in North Karelia, has 5,000 metered supply points (later MPS) without any yearly electricity consumption. On the other hand, the Finnish government has committed itself to reducing emissions and electric cars are seen as one way to reduce traffic emissions. Also, energy reserve technologies are developing rapidly. There are simultaneous signals for decreasing and increasing electricity consumption in Finland and therefore flexibility or real options in distribution network investments would be valuable. The first objective of this study is to find more optimised methods for conducting these investments in electricity distribution networks in Finland from a customer perspective.

Energy Authority as the market regulator uses a regulation model to supervise DSOs in Finland. The regulation model concentrates on controlling allowed maximum revenue and defining the rate of return. It comprises different incentives (e.g. investment, efficiency, quality of supply and innovations). The duration of the regulatory periods has been four years and in November 2015 Energy Authority confirmed its decision for the regulation model's fourth and fifth regulatory periods in 2016-2019 and 2020-2023. The weather-proof requirement came into force two years earlier and the regulation model was confirmed for eight years at that time. The regulation model will be modified at some level for the next regulatory period 2024-2027, because weather-proofing investments will improve automatically quality of supply and operational cost indicators. However, the current regulation model does not include indicators or incentives to improve technical quality of electricity or commercial quality (e.g. customer service level). The second objective of this study is to benchmark the Finnish regulation model to similar models in

Europe and suggest new or improved incentives or indicators for developing the regulation model for the next regulatory period from the customer perspective.

1.2 Research questions

The perspective of this study is a customer point of view and the scope of the study focuses on alternative methods or concepts fulfilling weather-proof requirements set by the Electricity Market Act and suggesting new or improved indicators for developing the regulation model.

The first research question is "How could electricity distribution network investments be optimised from a customer perspective?". An essential idea is to study, if co-operation between a customer and a DSO might enable a lower investment level. The goal of the study is also to identify, if legislation should be updated to allow new methods or concepts.

The second research question is "Which customer-oriented incentives of the European regulation models could be applied in Finland?". The research question narrows the scope of the study to European regulation models. The study excludes analysing parameters of the current regulation model and monetary compensation levels in the case of outages.

1.3 Structure of the study

The structure of the study can be divided into three main sections. The first section introduces and describes basic concepts, legislation and the regulation model in Finland to the reader. The second section concentrates on customer-oriented incentives in European regulation models. The third section focuses on electricity distribution investments in Finland and presents a case study for a co-operational concept achieving weather-proof readiness. The structure of the study by chapters is as follows.

Chapter 2 presents characteristics of the electricity distribution industry and explains how the term “Quality of electricity supply” is defined in this study. In addition, notable requirements of the Electricity Market Act are presented in this chapter as well as customer compensations in Finland.

Chapter 3 describes the main principal of the regulation model in a simplified way. Incentive methods of the current regulation model are briefly described.

Chapter 4 includes a literature review to customer-oriented incentives in European regulation models as well as a literature review to previous studies concerning the Finnish regulation model.

Chapter 5 focuses on the weather-proof distribution network investment level in Finland and describes investment strategies of the six largest DSOs operating in rural areas. Alternative methods for achieving weather-proof requirements are presented based on literature review.

Chapter 6 presents numerical and case-based insight to methods and concepts introduced in previous chapter. Alternative scenarios and their monetary impacts are evaluated, if DSOs applied longer exceptional time limit to MPS with low electricity consumption and remote distance in the distribution network. Possibilities of weather-proof readiness services are calculated in a case study.

Chapter 7 summarises the findings of this study and presents conclusions in form of recommendations.

2. MAIN CONCEPTS AND REGULATION IN FINLAND

Characteristics of the electricity distribution industry in Finland and notable requirements of the Electricity Market Act are presented in this chapter. Different aspects of the quality of electricity supply are presented as well.

2.1 Electricity distribution business in Finland

Electricity distribution networks are a natural monopoly, where competing networks are not feasible due to the national economy. Natural monopolies are common practise world-wide in the electricity power network business. Monopolies must be regulated and monitored for efficiency and pricing purposes. Electricity power networks can be divided into three level operations. The transmission system operator (TSO) is responsible for the national electricity transmission system (High Voltage network; 110 – 400 kV) and cross-border direct current links. The transmission system includes over 14,000 kilometres of transmission lines. (Fingrid 2019)

There are 79 local distribution system operators (DSO), which are responsible for electricity distribution networks (Low Voltage and Medium Voltage network; 0.4 – 70 kV). Between TSO and DSO are also 10 regional electricity distribution operators, which operate in regional HV-networks (110 kV). (Energy Authority 2019)

There were over 3.5 million electricity distribution network users in Finland in 2016 and there has been a stable increase during a ten-year time period. Users of electricity power networks are presented in figure 1. (Energy Authority 2018b)

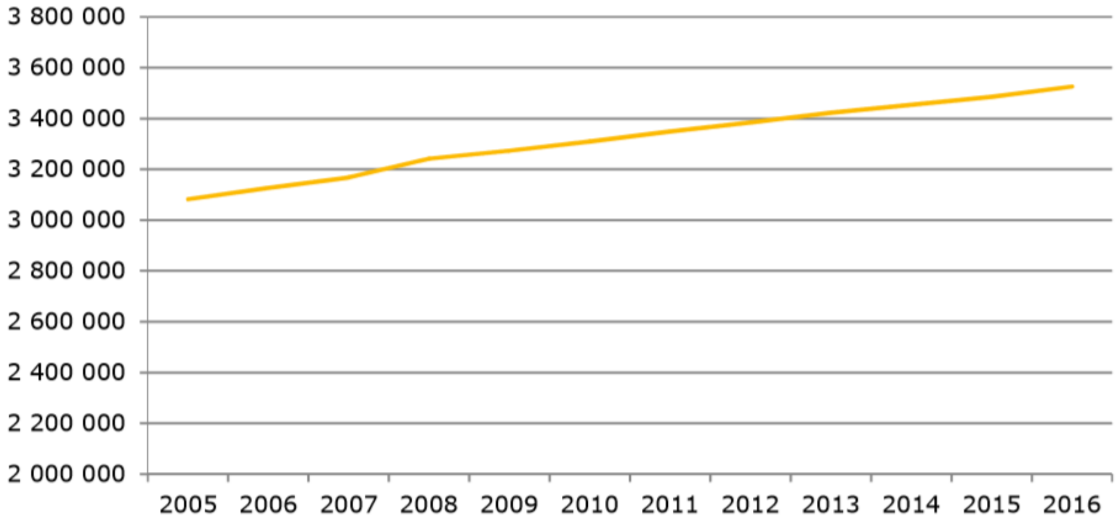

Figure 1. Users of electricity power networks 2005-2016 (Energy Authority 2018b)

Users may acquire the electricity freely from open markets, but electricity distribution fees are paid to DSOs. The electricity distribution fee pricing includes two principles called the postal stamp tariff and the point tariff. The postal stamp tariff means the electricity distribution fee covers the whole transmission chain. The point of tariff means the pricing may not depend on the user's geographical location within a distribution system operator's grid.

2.2 The role and duties of the Energy Authority

The national regulator is the Energy Authority, which monitors compliance of system operators. All system operators must have a licence to operate, which is granted by the Energy Authority, which also supervises requirements. There are 77 DSOs, 12 regional high-voltage distribution network operators and one transmission system operator in Finland.

Energy Authority Act 870/2013 introduces following issues as main duties of the Energy Authority:

- Supervising and monitoring functionality of electricity and gas markets
- Promoting energy efficiency and use of renewable energy

- Implementing executive tasks regarding policy on energy, greenhouse emissions trading and energy efficiency
- Acting as government representative in court proceedings and supervising government's interest and rights

Electricity and Gas Market Supervision Act 590/2013 sets objectives for Energy Authority as a good level of continuity of supply, competitive pricing and reasonable service level for users. Also promoting efficient, reliable and sustainable national and regional electricity markets as well as internal markets in European Union.

Electricity and Gas Market Supervision Act empowers Energy Authority to act as a national regulator in Finnish electricity markets and to give binding decisions on regulating DSOs in Finland. The main method for regulation is called regulation model, which is presented in more detail in chapter 3.

2.3 Quality of electricity supply

There are several different dimensions for the term "Quality of electricity supply" in literature. They all share the basic idea that quality of supply is a combination of availability, technical electricity quality and customer service experience. CEER (2016, 3) uses the term quality of supply and divides it into three aspects, which are continuity of supply, voltage quality and commercial quality.

Continuity of supply relates to interruptions in electricity supply. Situations, where the voltage for the user drops to zero or nearly to zero, are known as outages or blackouts. The most commonly used quality measures are number of interruptions, unavailability (interrupted minutes) and energy not supplied (ENS) per year. Network users expect a high continuity of supply at an affordable price. The fewer the interruptions and the quicker the return of electricity supply, the better the continuity from the network user's point of view. (CEER 2016, 19)

Commonly used reliability indicators for continuity of supply are the system average interruption duration index (SAIDI) and the system average interruption frequency index (SAIFI). The first one is calculated by dividing the sum of all customer interruption durations by the total number of customers served. The second one is calculated dividing the total number of customer interruptions by the total number of customers served.

The terms “availability of electricity supply” and “reliability of supply” may also be used in literature as synonyms to continuity of supply.

Voltage quality is a wide range of voltage disturbances and deviations in voltage magnitude or waveform from the optimum values. Disturbances to voltage quality may occur due to voltage variations in the grid. For example, large load changes in consumer level or in production may cause disturbances. Basically, everyone connected to the power grid could influence the quality of the voltage delivered at his/her own connection point or in other connection points throughout the power grid. Voltage quality is becoming a more important issue in the future, because the sensitivity of end-user equipment to voltage disturbances is increasing. (CEER 2016, 81)

European standard EN 50160 “Voltage Characteristics in Public Distribution Systems” lists and defines voltage quality parameters. The standard has been criticised since it was published for setting binding limits only for a few voltage quality parameters. ERGEG (2006, 4) stated already in 2006 that European regulators are concerned about the voltage quality standards indicated by EN 50160. ERGEG noted that the standard’s limits and values are too loose and do not present a good reference for voltage quality in most European distribution networks.

ERGEG (2007) acknowledges the importance of revising the EN 50160 standard, because it reflects only the lowest quality levels throughout Europe, not the average or the best level. It does not provide either incentives to promote voltage quality in networks in the long term. Also, customer needs for voltage quality have become higher and wide range limits are outdated as in the presented EN 50160.

Even though EN 50160 standard was revised in 2010, the standard's limits and values are still considered not binding enough. EN 50160 is still currently only a commonly used standard for measuring voltage quality in Europe. In Finland, the standard is referenced in the Energy Market Act as the quality level for measuring voltage quality.

Commercial quality means all forms of contacts between DSOs and customers. For example, new connections, disconnections, meter reading and verification, repairs and elimination of voltage quality problems and claims processing are different forms of interactions between a customer and a DSO. As network operators are natural monopolies, commercial quality indicators are needed to guarantee a reasonable customer service level. (CEER 2016, 111)

Different financial incentives can be placed for ensuring commercial quality. Time for connection is a typical measure, where customers may be compensated for an operator not meeting the deadline for the delivery.

2.4 Quality of electricity supply requirements by Finnish legislation

The Electricity Market Act 588/2013 introduces main principles for Finnish electricity market regulation. The objectives of the Act are securing efficient, safe and environmentally sustainable conditions for the national and regional electricity market. From the users' perspective, the objective is to guarantee a good electricity supply security, competitive electricity prices and reasonable service principles.

The Act requires a weather-proof electricity distribution network to be available for all customers in Finland in the future. Continuity of supply is the main indicator for measuring the progress. DSOs are obligated to plan and develop their network with the goal to gradually restrict weather-related interruptions to 36 hours in rural areas and to 6 hours in urban areas by the end of 2028. Each DSO must prepare a network development plan to meet these requirements and send an updated plan to the Energy Authority for a review bi-annually. DSOs may freely choose investment methods for meeting the requirements. There are two exceptions for the 36-hour requirement based on local circumstances. An exception is allowed, if a point of connection is on an island without a bridge or other permanent passage or regular ferry connection. DSOs are also allowed to make an exception, if a customer's yearly electricity consumption has been at most 2,500 kWh during the last three calendar years and required investments would be exceptionally high compared to other points of connection due to remote location.

By the end of year 2019 at least 50% of all users must be covered by the weather-proof requirement and by the end of year 2023 the coverage must be at least 75% (excluding recreational housing). Transitional provision allows DSOs to postpone building weather-proof electricity power networks till the end of year 2036 for weighty reasons.

The government's proposal for the Electricity Market Act (HE 20/2013) provides reasons and background information for chosen quality of supply levels. 75% of the total population would be covered by the 6-hour urban area requirement. Different quality of supply levels for urban areas and rural areas were chosen, because an equal requirement for maximum interruption times would lead to a too low design level in urban areas. On the other hand, it would lead to an impossibly high cost level in rural area distribution networks. The government's proposal estimates an underground cabling level of 40–75% in MV-networks and 40–90% in LV-networks is needed to achieve the 36-hour requirement in rural areas. The range in estimations occurs due to different local circumstances among DSOs in Finland. In some regions aerial cables run through forest areas, where possible storms and snow loads may cause severe interruptions. Some DSOs have already invested in underground cabling. Also, the amount of point of connections and electricity consumption per network length may vary significantly between DSOs. The government's proposal estimates that with a 50 percent underground cabling rate in

MV-networks, 70 to 80 percent of users would be covered by a weather-proof electricity power network. In that case the interruption of the rest of the users can be limited to under 36 hours by alternative methods than underground cabling. The government's proposal identifies alternative methods for improving quality of supply than underground cabling. The government expects DSOs will choose different methods e.g. constructing cables along the roads, reserve power options, backup connections. However, in practice underground cabling is always among the chosen methods.

According to the government's proposal the impact assessment ordered by the Ministry of Economic Affairs and Employment estimated the total investment requirement for fulfilling the 36-hour requirement to be 3,500 M€ during years 2014–2025. The investment requirement for MV-networks was estimated to be 2,700 M€ and for LV-networks 800 M€. The impact assessment was calculated based on the assumption that only underground cabling would be used.

The government's proposal gives reasons why local circumstances may allow exceptions for the 36-hour interruption requirement. Accessing points of connection on islands may require special transport or DSOs have no realistic possibilities to repair faults in given time limits. The proposal highlights costs might be considerably high compared to achieved benefits, if the area is sparsely populated and properties are mainly recreational housing. The total costs for other network users might increase too much. In principal, users living in these demanding circumstances concerning electricity distribution have made a voluntary decision and therefore acknowledged the same quality of supply cannot be guaranteed as for users living in normal circumstances.

Voltage quality is not directly defined in the Electricity Market Act. The 97th section of law covers possible defects in electricity distribution, other network services or electric supply. A defect occurs when the quality of electricity or procedure for delivery is not what was agreed. Delayed or incorrect billing of consumers is seen as a defect, excluding situations where the retailer can prove it had no possibility to influence or eliminate an extraneous factor causing delayed or incorrect billing. If not otherwise agreed, a defect also occurs, when the quality of electricity does not comply with standards applied in Finland. The government's proposal references EN 50160 as the current standard and indicates that higher or lower quality requirements than the standard can be agreed on, if especially needed.

In case of a defect, a user is entitled to a corresponding price reduction. A user is also entitled to claim damages to the DSO or electricity supply retailer, which are liable for indirect damages only if a defect or a damage was caused by their negligence.

Commercial quality related matters in the Act are delayed or incorrect consumer billing as mentioned above. DSOs are penalised, if they are not able to install the electricity connection within the agreed schedule. The Act obligates DSOs to share information about interruption durations and recovery schedules to users.

2.5 Continuity of supply indicators and compensations to customers

According to the Electricity Market Act (2013) DSOs are required to pay standard compensations to customers, if the supply of electricity is interrupted and the DSO is not able to prove the cause was not in its responsibility. Standard compensations are presented in table 1. Standard compensation means the DSO will automatically pay compensation to a customer without a customer applying for it.

Table 1. Standard interruption compensations to customers (Electricity Market Act 2013, § 100)

Interruption time	Standard compensation
12 h < interruption time < 24 h	10 % of yearly distribution fee
24 h ≤ interruption time < 72 h	25 % of yearly distribution fee
72 h ≤ interruption time < 120 h	50 % of yearly distribution fee
120 h ≤ interruption time < 192 h	100 % of yearly distribution fee
192 h ≤ interruption time < 288 h	150 % of yearly distribution fee
288 h ≤ interruption time	200 % of yearly distribution fee

Compensations are capped annually to 200% of the yearly distribution fee or 2,000 euros. DSOs paid 4.9 M€ standard compensations to about 36,800 customers due to interruptions in 2017 (Energy Authority 2018, 19).

2.6 Voltage quality indicators and compensations to customers

There is no voltage quality incentive scheme in Finland, but Finnish Energy has drafted general terms as “Terms of network service 2010” to be used as connection contract terms. The customer is entitled to a price reduction, if the valid voltage quality standard is not met. The price reduction shall be at least four per cent (4%) of the estimated annual network service fee paid by the user for the place of electricity use concerned. If the user is not a consumer, the above-mentioned 4% rule shall be applied to the calculation of annual price reductions up to EUR 350 per user. A price reduction shall always correspond to at least the fault. (Finnish Energy 2010)

2.7 Commercial quality indicators and compensations to customers

The DSO is also obligated to pay standard compensations, if the DSO is not able to install the electricity connection within the agreed schedule. The customer has a right to receive a standard compensation, which is 5 per cent of the connection charge during the first two weeks and after that 10 per cent per week. The maximum amount of standard compensation is 30% of the connection charge and 3,000 euros. (Electricity Market Act 2013, § 95)

3. CURRENT FINNISH REGULATION MODEL

Main objectives of Finnish regulation are ensuring reasonable pricing and high quality of network services. Finnish legislation empowers the Energy Authority to develop and maintain regulation methods in Finland. This chapter introduces the main principal of the current regulation model in a very simplified manner. The regulation model sets a maximum revenue (revenue cap), which a natural monopoly may collect yearly from customers.

3.1 Main principal of regulation model

The main idea in the Finnish regulation model (Energy Authority, 2015) is to approach the DSOs' yield from the balance sheet and the profit and loss account perspectives as shown in figure 2. The regulation model is defined to be valid during the whole four-year regulatory period, when no alterations are made to the model.

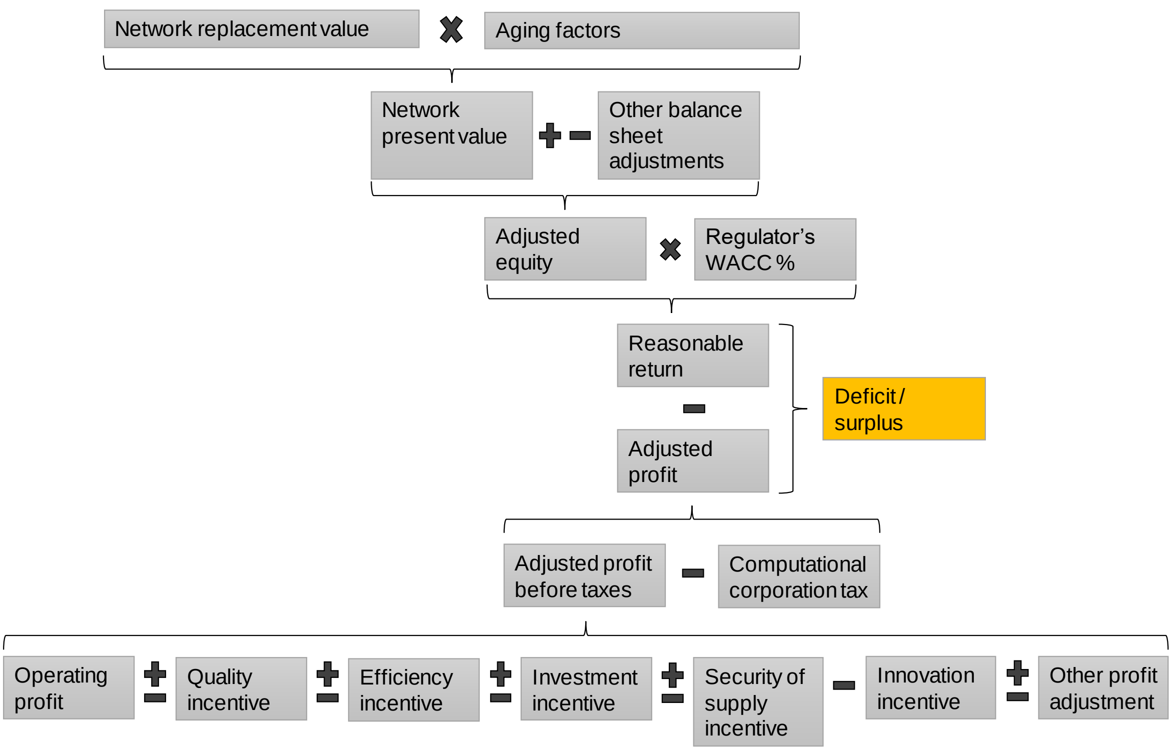

Figure 2. Simplified presentation of regulation model (Gaia Consulting 2014, 20)

The balance sheet approach includes first defining a network replacement value, which is calculated by using Energy Authority's unit prices in a network component level. DSOs may choose suitable aging factors (lifetime replacement intervals) from the given range to suit the DSOs' depreciation strategy. When other balance sheet adjustments are considered, a reasonable return is calculated by multiplying adjusted equity with WACC-percent (Weighted Average Cost of Capital) defined by the Energy Authority.

The second approach is to profit and loss account perspective, where incentives of the regulation model are added or deducted from the operating profit for defining adjusted profit before taxes. Adjusted profit is calculated by subtracting computational corporation tax from the amount.

Reasonable return and adjusted profit are compared, and a yearly surplus or deficit is defined. The total surplus or deficit of the regulatory period must be compensated or can be collected from the users during the next four-year regulatory period.

3.2 Incentive methods

The regulator has set a collection of incentive methods to regulate DSOs operating in a monopoly market. The goal of incentive methods is to form a harmonised entity, which sets boundaries for DSOs to operate in the market.

3.2.1 Investment incentive

The goal of investment incentive is to encourage DSOs to carry out investments in a cost-efficient manner and enable replacement investments. DSOs are entitled to use average unit prices, when calculating repurchase values of network components. These average unit prices for network components are given by the regulator and they are fixed for the regulation period. There is an incentive effect, if a DSO is able to make investments at a lower price level than given average unit prices. DSOs will receive a higher computational repurchase value of the investment, which is used for determining straight-line depreciations. DSOs may choose a suitable lifetime to each of the network components and straight-line depreciations are allowed as complete depreciations even after the chosen lifetime, if the component is still in use. Complete depreciations enable all needed replacement investments and possible premature replacement investments. (Energy Authority 2015, 66)

The impact of the investment incentive is taken into account calculating realised adjusted profit.

3.2.2 Efficiency incentive

The goal of the efficiency incentive is to encourage the DSO to operate in a cost-effective way. The operation of a DSO is cost-effective when the input, or costs, used in its operations are as small as possible in relation to the output of operations. In the regulation of monopoly operations, it is natural to set a general efficiency target for enterprises.

Each DSO is given a company-specific efficiency target, which includes using the efficiency frontier developed by the StoNED method (Stochastic Non-smooth Envelopment of Data).

The impact of the efficiency incentive is calculated so that the realised efficiency costs are deducted from the reference level of efficiency costs in the same year.
The impact of the efficiency incentive taken into account in the calculation of realised adjusted profit may not be higher than 20% of the DSO's reasonable return in the year in question. This applies to the efficiency bonus received from the calculation of costs and the efficiency sanction resulting from increased costs. (Energy Authority 2015, 78-95)

3.2.3 Security of supply incentive

The purpose of the security of supply incentive is to enable meeting the security of supply criteria required by law within the deadline prescribed by law as cost-effectively as possible in view of the achieved benefits. Some DSOs will have to make extremely extensive replacement investments and carry out maintenance measures in order to be able to meet the legal criteria within the specified period.

The writedowns of the security of supply incentive compensate for the demolition made in connection with replacement investments, which has been compulsory due to the security of supply criteria of the Electricity Market Act deviating from the previous network strategy, i.e. earlier than normal practice. The incentive is meant for situations where it has been necessary for the DSO, for example, to replace sections of a young network in good condition at substation outputs in order to meet the targets stipulated by law.

The impact of the security of supply incentive is calculated by adding together the write-downs of the NKA residual value resulting from early replacement investments carried out in order to improve the security of supply and the reasonable costs of maintenance and contingency measures (Energy Authority 2015, 97-102).

3.2.4 Quality incentive

The goal of the quality incentive is to encourage DSOs to develop quality of supply and achieve a higher continuity of supply level than the minimum requirement by the law.

Regulatory outage costs, i.e. the disadvantage caused by outages, are calculated on the basis of the number and duration of outages, as well as the unit prices of outages. Currently, the following information is taken into account, resulting from the medium-voltage and high-voltage distribution network:

- the number and duration of planned outages

- the number and duration of unexpected outages
- the number of high-speed autoreclosers
- the number of time-delayed autoreclosers.

Outage unit prices presented in table 2. The goal is to describe the disadvantage of outages experienced by customers as accurately as possible.

Table 2. Unit prices of disadvantage caused by outage (Energy Authority 2015, 71)

Unexpected outage		**Planned outage**		**Time-delayed autorecloser**	**High-speed autorecloser**
$h_{E,unexp}$	$h_{w,unexp}$	$h_{E,plann}$	$h_{W,plann}$	h_{TAR}	h_{HAR}
€ / kWh	€ / kWh	€ / kWh	€ / kWh	€ / kWh	€ / kWh
11.0	1.1	6.8	0.5	1.1	0.55

The unit prices in the table correspond to the 2005 value of money. In the calculation of the reference level of the regulatory outage costs and realised regulatory outage costs, the unit prices are adjusted to the value of money in each year using the consumer price index.

The impact of the quality incentive is calculated so that the realised regulatory outage costs are deducted from the reference level of regulatory outage costs.
This is taken into account when calculating realised adjusted profit as shown earlier in figure 2. However, the quality incentive is capped to be at most 15% of the DSO's reasonable return in the year in question. This applies to the quality bonus for improved quality and the quality sanction resulting from a reduction in quality (Energy Authority 2015, 69-72).

3.2.5 Innovation incentive

The goal of the innovation incentive is to encourage the DSO to develop and use innovative technical and operational solutions in its network operations.

The innovation incentive allows DSOs to deduct reasonable research and development costs in the calculation of realised adjusted profit. These costs must be directly linked to the creation of new knowledge, technology, products or methods of operation in network operations for the sector. It is also required that the results of these projects are public and can be utilised for example by other DSOs. However, it is not necessary to publish confidential information concerning customers or results protected by industrial property rights. (Energy Authority 2015, 96)

The maximum innovation incentive is 1% of the DSOs' total turnover from network operations in the unbundled profit and loss accounts in the regulatory period.

4. INCENTIVES FOR IMPROVING QUALITY OF ELECTRICITY SUPPLY

This chapter presents a literature review to customer-oriented incentives in European regulation models as well as a literature review to previous studies concerning the Finnish regulation model.

4.1 Literature review for other studies concerning the Finnish regulation model

There are few academic studies focusing on quality-related incentives of the Finnish electricity distribution regulation model. Gaia Consulting Oy (2014) reviewed the function of the quality incentive in the regulation model and possible development needs for the regulatory period of 2016-2023. The quality incentive concentrates mainly on the continuity of supply issues and commercial quality is not taken into consideration. The study also pointed out, that unit prices describing disadvantage caused by outage are based on a study from year 2005. The prices have been updated by inflation during the years, but a relevant question is, if the unit prices correspond to the current use of electricity needs and habits. Gaia Consulting Oy was not able to carry out a study as comprehensive as the original study (Silvast et al. 2005) due to the tight schedule.

Disadvantage costs of outages give an approximate idea how users experience lower quality of electricity supply. Gaia Consulting Oy (2014) used an internet survey targeting consumers to examine, whether the unit prices from year 2005 are still valid in 2014. The sample size of the survey was 289 and similarities with the original study were found in the data. The deviation in prices was notable, which may be due to the difficulty of valuing monetary disadvantage caused by outage. 10% of the highest and lowest responses were eliminated from the data. Although research methods were developed and CEER has given instructions for uniform international disadvantage cost assessment, the study was carried out in a similar manner to the original study from 2005. The study indicated that consumers experienced less harm in short planned interruptions (less than one hour). The harm caused by unplanned interruptions was experienced in the same level as in the original study.

Hämäläinen (2018) studied the value of security of electricity supply in Finland. The study included a survey determining to find the Value of Lost Load (VoLL). The VoLL was the price that electricity users would be willing to pay to avoid electricity cut off during power shortage situations. Household customers were ready to pay 3,900 – 19,300 €/MWh and recreational housing customers 38,600 – 90,400 €/MWh. The study assumed that the real VoLL would be closer to the lower values and that the recreational housing customers' estimation may have been biased due to low electricity consumption levels. The sample size of the survey was 1,010 respondents. 22% of respondents living in rural areas had acquired back-up power.

4.2 Literature review for other European countries' regulation models

The literature review is divided into three parts based on indicators. Continuity of supply, voltage quality and commercial quality indicators are presented under their own sub-chapters.

4.2.1 Continuity of supply indicators

Network users expect round-the-clock electricity supply at an affordable price. Regulation models focus mainly on decreasing interruptions and typical indicators are frequency of interruptions, their duration and energy not supplied due to interruptions. A common indicator for the duration of interruptions is SAIDI (System Average Interruption Duration Index) and SAIFI (System Average Interruption Frequency Index) is used for measuring the frequency of interruptions. According to CEER (2016, 32-33) SAIDI and/or SAIFI indicators are used for measuring long interruptions in distribution networks in Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Luxembourg, Malta, The Netherlands, Norway, Poland, Portugal, Romania, Slovenia, Sweden and Switzerland.

Many countries have developed local continuity of supply indicators, which are mostly related to SAIDI and SAIFI indicators. All members of CEER draft a national report to CEER yearly, where national circumstances and development in the regulation is described. The following indicators in table 3 are picked up from each country's national report from year 2018.

Table 3. Continuity of supply indicators by countries

Country	Continuity of supply indicator
Lithuania	The percentage share of the consumers who were timely informed on a scheduled interruption (10 calendar days in advance)
Lithuania	The percentage share of the failures eliminated for consumers in a timely manner (within 5 working days)
Estonia	Acceptable duration of an interruption caused by faults (summer 12 h / winter 16 h)
Estonia	Acceptable duration of planned interruptions (summer 10 h / winter 8 h)
Estonia	Acceptable annual accumulated interruption duration by faults (70 h)
Estonia	Acceptable annual accumulated planned interruption duration (64 h)
Slovenia	Average time until the restoration of supply in case of following a failure of current limiting device (06:00-22:00)
Slovenia	Average time until the restoration of supply in case of following a failure of current limiting device (22:00-06:00)
Cyprus	Time to repair main fuse after failure

In Italy, since 2015, the regulator has promoted the improvement of the continuity of electricity transmission service via a mechanism of rewards and penalties that refers to the indicator of energy not supplied, calculated nationally. The regulator has outlined the transition from input-based regulation to regulation more focused on the output of the transmission service. For the current regulatory period 2016-2019, the regulator has provided transitional incentive-based regulation, as well as the progressive definition of new output-focused incentive-based regulation instruments. (ARERA 2018, 9)

In Great Britain, the local regulation model is called RIIO model (Revenue = Incentives + Innovation + Outputs), which includes all three elements of electricity quality supply. The current regulation model for electricity distribution is called RIIO-ED1, which is valid for an eight-year period ending year 2023. Great Britain has started drafting RIIO-ED2 for the next regulatory period and the final version will be published by the end of year 2020. (Ofgem, 2019)

British regulator Ofgem has set an Electricity Guaranteed Standards of Performance, which describes minimum service levels for DSOs. Minimum requirements are given for key service areas including supply restoration, connections, and voltage quality. If a DSO does not meet these minimum requirements, it has to make a payment to the customer. Payments concerning continuity of supply requirements are presented in table 4.

Table 4. RIIO-ED1 customer payments in Great Britain (ENA, 2018)

Service	Performance level	Guaranteed Standards payments
Supply restoration – normal conditions	Supply must be restored within 18 hours	£75 for domestic customers and £150 for business customers plus £35 for each further 12 hours.
Supply restoration – normal conditions (5,000 or more premises interrupted)	Where a large scale event occurs, that is where 5,000 or more customers' premises are interrupted, supply must be restored within 24 hours	£75 for domestic customers and £150 for business customers, plus £35 for each further 12 hours up to a cap of £300 per customer.
Supply restoration: severe weather conditions	Depending on the category of event, supply must be restored within 24, 48 or a multiple of 48 hours	£70 for domestic and business customers, plus £70 for each further 12 hours up to a cap of £700 per customer.
Supply restoration: multiple interruptions	Four or more interruptions each lasting 3 or more hours occur in any single year (1 April – 31 March).	£75 for domestic and business customers.
Supply restoration -rota disconnections	In case of rota disconnection, supply must be restored within 24 hours	£75 for domestic customers and £150 for business customers.
Notice of planned interruption to supply	Customers must be given at least 2 days notice before a planned interruption.	£30 for domestic and £60 for business customers.

The act of Electricity Regulations 2015 in Great Britain obligates a customer to make a claim for payments presented in table 4, which is a different approach compared to standard compensations used in Finland. In Great Britain, interruption compensations are divided into three groups based on conditions. The supply must be restored within 18 hours, if the interruption effects less than 5,000 customers at a time. In this case the Guaranteed Standard payment is not capped. If the interruption affects over 5,000 customers, the time limit for restoring electricity supply is 24 hours and the Guaranteed Standard payment is capped to £300 per customer. In severe weather conditions the time limit for restoring electricity supply is defined based on three categories presented in table 5 and the Guaranteed Standard payment is capped to £700 per customer.

Table 5. Categories for Severe Weather in Great Britain (ENA, 2018)

Category of severe weather	Definition
Category 1 (medium events)	Lightning events - when a distributor experiences at least 8 times the normal amount of higher voltage faults in 1 day, supplies will be restored within 24 hours.
	Non-lightning events - when a distributor experiences 8 or more but fewer than 13 times the normal amount of higher voltage faults in 1 day, supplies will be restored within 24 hours.
Category 2 (large events	Non-lightning events - when a distributor experiences at least 13 times the normal number of faults in 1 day, supplies will be restored within 48 hours.
Category 3 (very large events)	For severe weather events affecting a very large number of customers as specified in the Electricity Regulations 2015, supplies will be restored within a period as calculated using a formula based on the number of customers affected as set out in the Electricity Regulations 2015.

For a Guaranteed Standards payment for multiple interruptions, a customer is obligated to submit a claim within three months of the end of the year to which the claim applies. A customer must provide the address of the premises affected and the dates of the electricity supply failures applying for the payment. Electricity supply may need to be interrupted on a rota basis in order to share the available load due to supply shortages. A customer is eligible for a payment, if the electricity supply is not restored within 24 hours. The DSO is obligated to give a notice at least two days before a planned interruption or otherwise a customer is eligible to compensation. (ENA 2018)

4.2.2 Voltage quality indicators

Standard EN 50160 is used as the basic instrument for voltage quality assessment in Europe. Some countries have implemented stricter requirements in national legislation, or the regulator is empowered to introduce quality requirements if needed by legislation. These countries are not satisfied even with the revised 2010 version of the standard. In Great Britain, some voltage limits were narrower in earlier regulations compared to EN 50160 and they are still in force. France and Sweden have set a stricter time restriction (100%) compared to EN 50160 (95%), which means voltage quality must be achieved continuously. (CEER 2016, 85)

According to NVE (2018) the regulator in Norway has set minimum requirements for voltage frequency, supply voltage variations, rapid voltage changes, short and long-term flickering, which are stricter than the EN 50160 standard. It may set minimum requirements for other voltage disturbances (e.g. voltage dips), if needed. DSOs are required to continuously register dips, swells, rapid voltage changes and flickering and report results to the regulator. According to CEER (2016, 85) Sweden has also introduced limits for voltage dips.

In most of the European countries, DSOs are obligated to perform measurements to verify the voltage quality, if a customer complaint is filed. The cost of verifying measurement is covered by the DSO or in some countries by the customer, if a complaint is not justified. Some countries allow for the end-user to install his/her own voltage quality recorder, when results are to be used in a dispute between the end-user and the DSO. In Norway, Ireland, Italy and Slovenia, DSOs are required to inform end-users about the past or expected future voltage quality levels. (CEER 2016, 89)

CEER (2011) recommended that the national regulatory authority or the network operator keep statistics on complaints and verification results and correlate these with the results from continuous voltage quality monitoring. Different voltage quality indicators are presented in table 6.

Table 6. Voltage quality indicators by countries

Country	Voltage quality indicator
Romania	DSOs are obligated to carry out monitoring campaigns in the relevant sections of the network with dedicated power network analysers.
Slovenia	DSOs must carry out regular monitoring at the border of transmission and distribution networks at delivery points of all large users.
Slovenia	Average time for answering the voltage complaints
Slovenia	Average time required for resolving voltage quality deviations
Hungary	Voltage variation in given limits
Great Britain	Investigation of voltage complaints in a given timeframe

In Romania, according to Stanescu et al. (2017) DSOs must carry out monitoring campaigns for metering voltage quality and they are obligated to report findings and take corresponding actions by the Romanian regulator. DSOs are also obligated to pay a compensation for non-compliance with the quality of the voltage curve, if the complaint submitted by the distribution network user is substantiated (Romanian Energy Regulator Authority 2018, 14).

In Slovenia, DSOs are obligated to carry out regular monitoring at the border of transmission and distribution networks at delivery points of all large users. Occasional monitoring is carried out based on a predetermined plan. Consumer complaints about voltage quality are reviewed by monitoring, which lasts at least a week. Monitoring of voltage quality is also carried out during the connection approval process. The Slovenian regulator has set up a guaranteed standard for commercial quality and voltage quality is included with two indicators as presented in table 6. (EARS 2018, 48)

There was a voltage quality incentive scheme in Hungary in 2010, where regulation prescribes that the voltage variation should be within 230 V ± 7.5% (95% of the 10 minute r.m.s. voltage value for 1 week) and ±10% (100% of the 10 minute r.m.s. voltage value for 1 week), and further within +15% and -20% for all 1 minute r.m.s. voltage values. If the requirements are not met, the DSO is obligated to pay compensations according to the following rules: once in the first year, quarterly in the first half of the second year, and monthly from the second half of the second year, until the problem is resolved. Customers were divided into three different groups (households, LV non-households and MV non-households), which had different compensation levels. (CEER 2011, 69)

In Great Britain, DSOs are obligated to send a customer explanation within 5 working days or offer to visit premises to investigate within 7 working days after receiving a voltage quality complaint. If a DSO fails to fulfil this requirement, it must pay £30 to the customer as an automatic compensation. (ENA 2018)

In Portugal, DSOs must give a customer an explanation of the reasons for the lack of voltage quality or visit a customer's installation to identify possible causes. If the lack of quality is the customer's responsibility, then the customer will pay the cost of the verification performed by the DSO. In Sweden or in Finland, there is no indicator related to responding to customer voltage or current complaints. (CEER 2016, 122)

4.2.3 Commercial quality indicators

CEER (2016, 113-118) has surveyed 16 European countries for used commercial quality indicators. The benchmarking report focuses on residential customers with a connection to the LV network, because it saw this group as the largest group of customers and small domestic customers often need more protection than larger business customers. CEER divided commercial quality indicators into four groups as connection, customer care, technical service and metering/billing. Indicators and their definitions as well as simple statistics of the survey are presented in Appendix 1.

The results of the survey show that all 16 responding countries apply some type of indicator regarding time for response to the customer's claim for network connection and the time for connecting customers to the network. 12 countries have 10 or more commercial quality indicators in use. (CEER 2016, 116)

Table 7. Commercial quality indicators by countries

Country	Commercial quality indicator
Lithuania	the percentage share of the timely (within 20 days from the date of payment of connection fee) connected new consumers.
Lithuania	the percentage share of the timely (within 30 calendar days) investigated complaints of the consumers and network users
Poland	time taken to connect to the network
Poland	transfer time of data regarding metering and billing data
Spain	free customer information services must be made available, including free phone lines
Cyprus	timetable for the implementation of the complaint procedures
Estonia	Time to issue a connection offer (during 30 days from the reception of the application)
Great Britain	Several indicators, see tables 8 and 9.
Slovenia	Several indicators, see table 10.

CNCM (2018, 96) requires Spanish DSOs to inform customers about their rights and establish a procedure in the case of complaints. Free customer information services must be made available, including free phone lines. Additionally, the Spanish Electricity Act foresees that CNMC is able to monitor the effectiveness and application of consumer protection measures and may issue legally binding resolutions aimed at their fulfilment.

Wozny et al. (2016) lists also other possible commercial quality indicators, which the Polish regulator may consider monitoring in the future. These are e.g.

- response time for customer enquiries or complaints with regards to billing,
- response time for customer enquiries or complaints that do not regard billing,
- response time for meter malfunctions,

- efficiency of the change of seller process, and
- efficiency of the process of connecting micro generation.

In Great Britain, commercial quality indicators can be divided into new connection and customer service indicators. If a DSO does not fulfil customer service indicator performance levels as presented in table 8, the DSO is obligated to pay an automatic compensation to a customer.

Table 8. RIIO-ED1 customer payments for commercial quality in Great Britain (ENA, 2018)

Service	Performance level	Guaranteed Standards payments
Responding to failure of distributor's fuse	DSO must respond within 3 hours on a working day (at least) 7 am to 7 pm, and within 4 hours on other days between (at least) 9 am to 5 pm.	£30 for domestic and business customers.
Making and keeping appointments	DSO must offer and keep a timed appointment where requested by the customer.	£30 for domestic and business customers.
Payments owed under the standards	Payment to be made within 10 working days.	£30 for domestic and business customers.

The British regulator monitors especially the time taken by DSOs to provide connection offers and complete the connection. The British regulator has established guaranteed standards for connections that provide compensation payments to customers if the DSO fails to deliver specified connection services within minimum timescales as shown in Appendix 2. These standards cover the provision of quotations, scheduling agreed dates for works with customers and completing works on the dates agreed with customers (Ofgem 2018, 19).

In Great Britain, customer service is one of the incentives in the regulation model. The incentive aims at ensuring that customers requiring a new connection, seeking information from the network in the event of an interruption or making general enquiries, receive good customer service. The customer service incentive includes three components, i.e. a customer satisfaction survey, a complaints metric and a reward based on an assessment of each DSO's stakeholder engagement and consumer vulnerability activities. (Ofgem 2017, 34)

The European Commission (2017) defines a consumer vulnerability as "A consumer, who, as a result of socio-demographic characteristics, behavioural characteristics, personal situation, or market environment:

- Is at higher risk of experiencing negative outcomes in the market;
- Has limited ability to maximise his/her well-being;
- Has difficulty in obtaining or assimilating information;
- Is less able to buy, choose or access suitable products; or
- Is more susceptible to certain marketing practices."

Consumer vulnerability issues are typically taken care of by the social welfare system in Scandinavian countries and not compensated as part of electricity distribution fees. Therefore, the scope of this study is narrowed to focus on the first two components in Great Britain's customer service incentive. The incentive may increase or decrease allowed revenue of the DSO by 1.5 percent yearly. DSOs are obligated to carry out a customer satisfaction survey yearly. The questionnaire format is common to all DSOs and the survey is conducted by the same independent market research company to ensure consistency. The survey consists of three categories, new connection customers, customers experiencing an interruption and customers making a general enquiry. The survey asks customers about the service provided and they are asked to score the DSO out of 10. Only the answer to the final question ('overall, how satisfied were you with the service provided') is used to measure performance for the purpose of this incentive. The DSOs' targets are set by comparing different industries, including retail, banking and other utility services. The idea is that DSOs are rewarded only when they are considered good compared with other competitive industries. The customer service incentive is capped, which means a DSO's service has to be significantly better or worse than in other industries to receive the full reward or penalty amount. The incentive also takes into account unsuccessful calls from customers experiencing an interruption, although these customers are not interviewed in the survey (Ofgem 2017, 35-36).

The second component in the customer service incentive in Great Britain is called complaints metrics, which assess the quality of DSOs' complaints handling procedures. The reasoning for metering customer complaints is that in a commercial environment companies stand to lose customers and revenue by handling complaints badly. On the other hand, they would necessarily gain customers and revenue handling complaints well and therefore the incentive is penalty-only and capped. There are four key indicators assessing the quality of DSOs' complaints handling procedures, which are weighted for a metric score as shown in table 9 (Ofgem 2017, 36).

Table 9. Complaints metric indicators and weightings in Great Britain (Ofgem 2017, 36)

Indicator	Weighting
The percentage of total complaints outstanding after one day	10 %
The percentage of total complaints outstanding after 31 days	30 %
The percentage of total complaints that are repeat complaints	50 %
The number of Energy Ombudsman decisions that go against the DSO as a percentage of the total complaints	10 %

In Great Britain, the regulation model includes a specific incentive for large connection customers called "Incentive on Connections Engagement". The aim of the incentive is to drive DSOs to understand and meet the needs of a major connection customer (e.g. larger metered demand, unmetered demand, distributed generation). DSOs are obligated to draft a high-level strategy for engagement, workplan of activities and key performance outputs for the forthcoming regulatory year. The plan will be submitted to the regulator. The requirements for the submission are

- DSO has a comprehensive and robust strategy for engaging with connection stakeholders and facilitating joint discussions where appropriate
- DSO has a comprehensive workplan of activities (with associated delivery dates) to meet the requirements of its connection stakeholders
- DSO has set itself relevant outputs that it will deliver during the regulatory year (e.g. key performance indicators, targets, etc)
- DSO's proposed strategy, activities and outputs have been informed and endorsed by a broad and inclusive range of connection stakeholders. If endorsement is not possible, DSO must provide robust evidence that it has pursued reasonable endeavours to achieve this.

This plan must be submitted to the regulator. DSOs must also submit a yearly follow-up report about its performance against the original plan. The regulator will review both plans and may take actions, if the requirements for the submission are not met (Ofgem 2015).

In Slovenia, commercial quality is metered by three dimensions as connection-related services, customer service and metering/billing. The Slovenian regulator has set up guaranteed standards in legislation and DSOs are obligated to pay compensations to customers, if these standards are not met. Guaranteed standards indicate the average level of the service quality in the system or the share of the customers provided with a particular service. Slovenian commercial quality parameters also include the dimension of technical services and technical service indicators as presented earlier in tables 3 and 6. Commercial quality parameters in Slovenia in 2016 are presented in table 10.

Table 10. Commercial quality parameters in Slovenia in 2016 (EARS 2018, 47)

Commercial quality parameters 2016	**Min.**	**Max.**
Connection-related services		
Average time required for issuing the approval for connection [days]	6.86	20.00
Average time required for issuing cost estimation or proforma invoice for simple works [days]	1.90	3.55
Average time required for issuing the contract on LV system [days]	1.00	6.56
Average time required for activating the connection to the system [days]	1.50	5.80
Customer service		
Average response time to consumers' written questions, complaints or enquiries [days]	2.11	4.51
Average hold time in the call centre [s]	18.00	122.00
Call centre performance indicator [%]	84.67	90.90
Metering and billing		
Average time required for elimination of meter failure [days]	2.55	6.00
Average time for restoration of power supply following disconnection due to non-payment [h]	0.15	8.35

Slovenian commercial parameters are divided into three sub-groups with several sub-parameters. For example, typical commercial quality indicator “Time to connect” is divided into four different phases from approval to activating the connection to the system. A high number of indicators may lead to a complex incentive scheme, but on the other hand, detailed indicators help DSOs to focus on possible soft points of service quality in the customers' viewpoint. However, according to EARS (2018, 46) no compensation was paid for violating commercial standards in 2016.

5. INVESTMENTS MADE FOR WEATHER-PROOFING THE DISTRIBUTION NETWORK

The Electricity Market Act 2013 obligates DSOs to plan and develop their network for restricting weather-related interruptions to 36 hours in rural areas and 6 hours in urban areas. At the same time, the life cycle of networks is coming to end and renewal and replacement investments are needed. Each DSO may choose suitable methods and investment strategies, because regulation is neutral to different methods as long as interruption limits are met. These weather-related interruption limits are known as weather-proof requirement.

DSOs have delivered their network development plans to the Energy Authority for a review in summer 2018 and Partanen (2018) has summarised total investment costs for each regulatory period during 2014-2028 as shown in table 11.

Table 11. Continuity of supply – investment need (Partanen 2018, 34)

Investments, M€	2014-2019	2020-2023	2024-2028
110 kV cables	156	147	131
Electric stations	343	172	207
Medium voltage	1 508	1 103	826
Distribution substations	799	626	474
Low voltage	982	997	1 040
Total	**3 788**	**3 045**	**2 678**
			9 511

The estimation for additional investment needed to meet stricter interruption requirements was 3,500 M€ in 2013, when it was assumed all DSOs must fulfil weather-proof requirements by the end of year 2028. The estimation included 2,700 M€ for MV-network investments and 800 M€ for LV-network investments. The annual straight-line depreciation level was 441 M€ in the regulation model in 2014 and the estimation for investment needs for a 15-year period was 6,615 M€. Admitted extensions for seven DSOs decrease investment needs by a few hundred million euros and the current estimation for additional investment needs due to weather-proof requirements is 2,900 M€. (Partanen 2018)

Calculational additional weather-proof investments can be divided into regulatory periods by using the same methodology as in the impact evaluation of the Electricity Market Act 2013. Table 12 presents how weather-proof investments are calculationally divided into MV-networks and LV-networks during regulatory periods 2014-2028.

Table 12. Weather-proof investment estimation by regulatory periods during 2014-2028

Investments, M€	2014-2019	2020-2023	2024-2028
Investment need estimation 2018 (excluding 110 kV cables)	3 632	2 898	2 547
Straight-line depreciation level 2014	2 646	1 764	1 764
Calculational additional weather-proof investments	**986**	**1 134**	**783**
MV-network (77%)	761	875	604
LV-network (23%)	225	259	179

It should be noted that the division into MV-network and LV-network investments is purely calculational and may not reflect the actual situation. DSOs do not separate pure weather-proof investments from replacement investments in their development plans, because they are optimising their whole distribution network for fulfilling interruption requirements. It is likely that the division of weather-proof investments may be more front-end weighted towards MV-network investments during 2014-2023, because more customers are covered by interruption requirements when investing underground cabling in MV-networks. On the other hand, it is likely that weather-proof investments in LV-networks are back-end weighted as rural area investments are carried out in the last period.

Partanen (2012, 47-48) has estimated that achieving a weather-proof requirement in the given timetable requires replacing aerial cables, which still have service lifetime left. The value of this network was estimated to be 100–240 M€ with an underground cabling level of 25–75%. The increase in electricity distribution price for customers was estimated to be 0.37 cnt/kWh with a 75% underground cabling level.

A public summary of the DSOs' latest development plans (Energy Authority 2018c) was available for this study. This summary is used as source material in this chapter. 38% of MPS in rural areas fulfilled the weather-proof requirement in 2018 according to network development plans. There were 580,693 MPS in rural areas in 2018, which were not fulfilling the weather-proof requirement. Status of fulfilment in 2018 is presented in table 13.

Table 13. Weather-proof requirement fulfilment status in rural areas in 2018 (Energy Authority 2018c)

Company	MPS in rural areas	MPS fulfilling weather-proof requirement	MPS not fulfilling weather-proof requirement
Caruna Oy	194 222	124 300	69 922
Elenia Oy	177 467	74 247	103 220
PKS Sähkönsiirto Oy	51 883	9 400	42 483
Järvi-Suomen Energia Oy	65 824	5 337	60 487
Leppäkosken Sähkö Oy	11 430	2 000	9 430
Loiste Sähköverkko Oy	23 655	9 400	14 255
Savon Voima Verkko Oy	58 833	3 710	55 123
Others	359 367	133 594	225 773
Total	**942 681**	**362 988 (38%)**	**580 693 (62%)**

Savon Voima Oy, Järvi-Suomen Energia Oy, PKS Sähkönsiirto Oy, Leppäkosken Sähkö Oy, KSS Verkko Oy, Vatajankosken Sähkö Oy, Lankosken Sähkö Oy and Rantakairan Sähkö Oy have applied for longer transition periods for fulfilling weather-proof power network requirements. The energy regulator may extend the transition period to year 2032 or 2036.

5.1 Investment strategies in rural areas

The development plans of the six largest DSOs by MPS in rural areas were reviewed in terms of how their investment strategies and methods for achieving weather-proof requirements vary. The development plans are reviewed based on a summary source material provided by the Energy Authority (2018c). Caruna Oy, Elenia Oy, Järvi-Suomen Energia Oy, Loiste Sähköverkko Oy, Savon Voima Verkko Oy and PKS Sähkönsiirto Oy operate power networks, which have 60 percent of all MPS in rural areas in Finland. More detailed information about their shares is presented in table 15.

Table 14. Methods for achieving weather-proof requirements (Energy Authority 2018c)

Methods in rural area	Caruna	Elenia	JSE	Loiste	SVV	PKS
MV: Primarily underground cabling	x					
MV: Underground cabling trunk-lines		x			x	x
MV: Moving trunk-lines along the roads		x		x	x	x
MV: Aerial cabling along the roads			x	x	x	x
MV: Wide corridors for aerial cable lines in forest				x		
MV: Replacing low power and short branch lines with 1 kV cabling			x	x		
MV: Improving network control system (switches etc)		x	x	x		x
MV: Reserve power equipment		x			x	x
MV: Branch lines are not renovated before achieving target operating life		x		x		
LV: Always underground cabling	x					
LV: Mainly underground cabling		x	x		x	x
LV: AMKA-network			x	x	x	x

Caruna Oy defines a weather-proof network as a network where weather-proof structure coverage is sufficient for the whole network corresponding to available fault repair resources. MV-networks will be built primarily as underground cabling. Aerial cabling can be used when renovating existing network. LV-networks will always be built as underground cabling.

Caruna Oy’s primary method for fulfilling weather-proof requirements is reducing significantly the amount of MV- and LV-networks in forests. Other methods are converting aerial cabling to underground cabling and improving aerial cabling structures against high wind and snow load.

Elenia Oy will build MV-networks as underground cabling in rural areas. Underground cables will be laid primarily in road areas or in other infra-zone during renovation. The entire network will not be converted to underground cabling at the same time. E.g. branch lines are renovated based on ageing. LV-networks will be built mainly as underground cabling.

Elenia Oy has invested heavily in network control systems and uses also movable reserve power units during planned and unplanned interruptions.

Järvi-Suomen Energia Oy has drafted a major disturbance model based on present state analysis. The model includes all relevant factors related to continuity of supply and current fault repair resources. The model is used to calculate needed weather-proof network investment needs for each section of the network. Consumption and customer groups are considered in rural areas, when investments are planned by zones. Trunk-lines of MV-networks will be converted to underground cabling, when power is more than 500 kVA. LV-networks are primarily built as underground cabling. AMKA-network coverage will be approximately 20% in renovation projects due to rocky terrains.

Järvi-Suomen Energia Oy is planning to continue replacing low power and short branch lines with a 1 kV network. The company will improve network control systems and build backup connections in potential MV-network locations.

Loiste Sähköverkko Oy has drafted an investment strategy for rural areas where trunk-lines are moved along roads or other more suitable locations concerning weather-proof requirements. Aerial cabling is the main method and underground cabling is used where appropriate. Improving network control systems is seen as a high priority.

Loiste Sähköverkko Oy will use several different methods for fulfilling weather-proof requirements. The technical lifetime of branch-lines will be maximised where appropriate. Disinvestments are possible due to decreasing demand for electricity.

Savon Voima Verkko Oy has set planning objectives that MV-networks are typically built as aerial cabling along the roads and LV-networks as underground cabling in rural areas. Trunk-lines and other strategically important lines will be underground cabling. Aerial cabling networks will be built circular with reasonable amount of backup connections, when possible.

PKS Sähkönsiirto Oy has divided its network into three zones, each of which has its own investment strategy. The first zone includes urban areas, the second zone rural areas close to urban areas and the third zone covers the rest of the rural areas. MV-networks will be built and converted to underground cabling in the second zone. LV-networks will be built as underground cabling and low power branch-lines are converted to 1 kV cabling. MV-networks will be built as aerial cabling along roads or moved along roads during the renovation of the third zone. LV-networks will be underground cabling, but AMK-networks are used in rocky terrains.

77 DSOs have provided their network development plans to Energy Authority in 2018. All DSOs have a different network and customer structure and therefore their network development plans vary. Only the development plans of the six largest DSOs are reviewed in this study, but it is considered to cover main strategic approaches and methods for achieving weather-proof requirements. However only a summary source material of the network development plans was available in this study.

5.2 Exceptions for weather-proof requirement based on local circumstances

As mentioned earlier, DSOs may apply for an exception of the 36-hour interruption requirement based on local circumstances. Such cases are if the MPS is on an island without a bridge or other permanent passage or regular ferry connection. Also, a DSO is allowed to make an exception, if a customer's yearly electricity consumption has been at most 2,500 kWh during the last three calendar years and required investments would be exceptionally high compared to other MPS due to remote location. The government's proposal for the Electricity Market Act highlights costs might be considerably high compared to achieved benefits, if the area is sparsely populated and properties are mainly recreational housing. The total costs for other network users might increase too much.

DSOs are obligated to include their MPS development plan information, which fulfils the requirements for exceptional interruption time limit. Information presented in table 15 was collected from development plans, which were delivered to Energy Authority in 2018.

Table 15. Metered Supply Points fulfilling local circumstance requirements (Energy Authority 2018c)

Company	MPS in rural areas	MPS fulfilling local circumstances	Planned MPS under exception	Remaining possible MPS
Caruna Oy	194 222	66 000 (34%)	14 400 (7%)	51 600 (27%)
Elenia Oy	177 467	54 502 (31%)	3 372 (2%)	51 130 (29 %)
PKS Sähkönsiirto Oy	51 883	28 988 (56 %)	205 (0%)	28 783 (56 %)
Järvi-Suomen Energia Oy	65 824	26 468 (40%)	2 105 (3%)	24 363 (37%)
Leppäkosken Sähkö Oy	11 430	10 000 (87%)	2 000 (17%)	8 000 (70%)
Loiste Sähköverkko Oy	23 655	7 300 (31%)	7 300 (31%)	0 (0%)
Savon Voima Verkko Oy	58 833	3 040 (5%)	1 980 (3%)	1 060 (2%)
Others	359 367	31 839 (9%)	15 140 (4%)	16 699 (5%)
Total	**942 681**	**228 137 (24%)**	**46 502 (5%)**	**181 635 (19%)**

Caruna Oy is planning to apply an exceptional interruption time limit only to 14,400 MPS at archipelago areas. The maximum target interruption time is set to 72 hours for MV-networks and 120 hours for LV-networks in case of high wind and storm.

Elenia Oy has not set an exceptional interruption time limit concerning MPS consuming less than 2,500 kWh yearly and fulfilling the local circumstance requirement, because the company sees that yearly consumptions may change rapidly. Elenia Oy has identified 2,493 points of connection, which fulfil the local circumstance requirement concerning islands. Hailuoto is a notable island, where a ferry connection is not in use year-round. There are 925 points of connection and 1,059 MPS on the island. The maximum target interruption time is set to 36 hours from the timepoint, when it is possible to access Hailuoto by ferry. A parallel 20 kV sea cable for improving supply security was built in 2017. In general, for MPS on island locations the 36-hour maximum interruption time limit is set from the timepoint, when the location is accessible.

PKS Sähkönsiirto Oy is planning to set a maximum exceptional interruption time limit of 72 hours for MPS located on islands. The company has identified 205 MPS fulfilling this requirement.

Järvi-Suomen Energia Oy is planning to set a maximum exceptional interruption time limit of 96 hours for MPS located on islands. The interruption time will begin from the timepoint, when safety regulations allow for carrying out fault repair. In addition, all other MPS are prioritised before island locations. There are 863 islands with 2,105 MPS, where local circumstances concerning island location are met.

Loiste Sähköverkko Oy is planning to set a maximum exceptional interruption time limit of 48 hours for MPS located on islands or MPS in rural areas consuming less than 2,500 kWh per annum. The company foresees that 12 hours of additional time enable more efficient possibilities for prioritising repairing faults in high load density areas. According to Loiste Sähköverkko Oy 12 additional hours do not cause notable inconvenience for customers with low electricity consumption. Although the company is planning to apply exceptional interruption time for all identified 7,300 MPS fulfilling local circumstance requirement, it sees that it cannot not exploit the exception widely. Most of the identified MPS are in a grid topology among normal MPS, which are under the 36-hour requirement. Therefore, it is likely that the exceptional interruption time is applied only to local faults in LV-networks.

Savon Voima Verkko Oy is planning to set a maximum exceptional interruption time limit of 168 hours for MPS located on islands or MPS in rural areas consuming less than 2,500 kWh per annum. The time limit is set based on the grid structure in 2016. Savon Voima Verkko Oy will develop a strong grid structure till 2028 and the continuity of supply will improve concerning these MPS. The company will change the maximum exceptional interruption time limit in the future.

DSOs have very heterogenous network structures and therefore their responses in development plans vary. DSOs having large inland waterways or archipelago in their area have already experience with fault repairing in MPS on islands. They have given extensive reasoning for needed exceptional interruption times. Some of the DSOs have not yet paid attention to identifying MPS fulfilling local circumstance requirements. Very few have considered the possibility to apply for exceptional interruption times for MPS in rural areas having less than 2,500 kWh per annum consumption and fulfilling other local circumstance requirements.

5.3 Alternative methods for achieving weather-proof requirements

Partanen (2018) presents four supplementary methods for fulfilling weather-proof requirements. Partanen reminds us that these methods are not substitutes to current methods but may be supplementary choices especially in rural areas. Four suggested supplementary methods are:

- Smart grids
- Reserve power equipment and energy reserves
- Terminating subscriptions of existing zero-consumption users
- Weather-proof readiness by users

Smart grid technology includes the use of energy reserves and demand response during electricity supply interruption. The objective is finding alternative more inexpensive investment options in MV- and LV-networks. A micro network with smart grid technology fulfils weather-proof requirements and may function independently for hours in case of electricity supply interruption in feeding branch-line in MV-networks. (Partanen 2018, 55-56)

Energy reserves are seen as a potential supplementary method, when they are placed in key nodes in the distribution network structure. Currently DSOs are not allowed to own energy reserves and acquiring energy reserves as a service is not beneficial in the current regulation model. (Partanen 2018, 57)

Terminating subscriptions of existing zero-consumption users is not currently possible by DSOs. DSOs are obligated to maintain continuity of supply although there is no electricity consumption in an MPS. There are DSOs in eastern parts of Finland where users are voluntarily terminating subscriptions. Partanen suggests that DSOs could have the possibility to terminate zero-consumption MPS in rural areas with distant locations. (Partanen 2018, 58)

Weather-proof readiness by users is a substitute method for weather-proof investments, where users choose suitable measures for providing weather-proof readiness and get compensated. Part of the users already have reserve power equipment in rural areas (e.g. dairy cattle or poultry farms). DSOs should acquire weather-proof readiness as a service from users, when the life-cycle costs of the service are lower than alternative investments. (Partanen 2018, 57)

6. NUMERICAL AND CASE-BASED INSIGHT

Combined effect of weather-proof requirement and replacing investments for electricity distribution networks due to ageing is increasing notably electricity distribution fees especially in rural areas in Finland. Customers have no negotiation power towards DSOs in monopoly markets. Energy savings by lowering electricity consumption is not an effective option tackling increasing electricity distribution fees, when DSOs are increasing monthly fixed fees, which do not depend on the electricity consumption. From a macroeconomic perspective the latest population forecasts in Finland are forecasting the population number to significantly decrease in rural areas in the next 20 years (MDI 2019).

Alternative flexible methods are needed to reduce future price increase from a customer perspective. This chapter presents scenarios, if DSOs used their right to apply longer interruption times for MPS fulfilling the local circumstance requirements defined in the Electricity Market Act. A case study demonstrates how weather-proof readiness service could be used as an alternative method for fulfilling the weather-proof requirement instead of traditional investments.

6.1 Impact evaluation of exploiting exceptional interruption time

DSOs have a right to apply longer exceptional interruption times for MPS fulfilling the local circumstance requirements defined in the Electricity Market Act. These MPS are called later as “Exceptions”. As presented in table 15 DSOs have identified in their development plans 228,137 Exceptions. DSOs have planned to apply exceptional interruption time for 45,602 Exceptions (later Planned Exceptions). There were 580,693 MPS in rural areas, which were not covered by the weather-proof requirement in 2018.

In this impact evaluation a calculational value for an additional Exception to fulfil the weather-proof requirement is 2,630 €. It is calculated based on the following assumptions:

- 534,191 MPS in rural areas not planned to fulfil weather-proof requirement in 2018
- Weather-proofing investments during 2020-2028 are 1,756 M€, of which 80% are dedicated to network investments in rural areas.

Rough scenarios are drafted in this chapter to demonstrate possible monetary impacts. The objective is to assess how different assumptions may affect to amount of Exceptions. The less DSOs must make weather-proofing investments as the amount of Exceptions increases. Scenarios are based on following assumptions or combinations of them:

The first assumption is DSOs are estimating possible Exceptions in rural areas too heterogeneously, because the definition of local circumstances is open to interpretations. Every DSO will evaluate independently e.g. when required investments would be exceptionally high compared to other MPS due to remote location. Therefore, harmonisation of estimation methods should be considered.

The second assumption is DSOs have estimated amount of Planned Exceptions too conservatively, because there is no exact definition for local circumstances. Current regulation model has no incentives to decrease investments, when DSO can collect investment costs from customers. This may also lead to DSOs to underestimate amount of Exceptions as they would lose return of weather-proofing investment.

The third assumption is DSOs could apply exceptional interruption time to all identified potential Exceptions. Based on their network development plans DSOs have already identified 228,137 MPS, which could be considered as Exceptions. From a customer perspective these Exceptions should be fully utilized for decreasing weather-proofing investments.

The fourth assumption is customers have willingness to provide weather-proof readiness service as an alternative to traditional investments for fulfilling weather-proof requirement in rural areas. It is assumed some of the customers in rural areas could tolerate longer interruption times than 36 hours, if they were compensated properly. Customers could choose how to protect themselves from the longer outages e.g. purchasing reserve power units or energy reserves. Recreational houses are a large customer segment in rural areas and longer outages during these houses are unoccupied do not cause notable disturbance to customers.

Scenario 1 "Harmonised estimations". DSOs independently assess MPS which fulfil requirements for Exception. Average estimation is 24% of all MPS in rural areas. It is assumed that the two largest DSOs Caruna Oy and Elenia Oy may present a more realistic approach. The assumption in scenario 1 is that 33% of all MPS in rural areas would fulfil the requirements for Exception and DSOs would plan to apply exceptional interruption times at the same level as currently (20%). This would increase the amount of Exceptions by 16,000.

Calculation formula: All MPS in rural areas (942,681) x 33% x 20% - Planned Exceptions (46,502) = 16,000 additional Exceptions

Scenario 2 "Self-assessment adjustment". DSOs may have assessed the amount of Planned Exceptions too conservatively. The assumption in scenario 2 is that the amount of Planned Exceptions could be doubled. This would increase the amount of Planned Exceptions by 46,000.

Calculation formula: Planned Exceptions (46,502) x 2 – Planned Exceptions (46,502) = ~ 46,000 additional Exceptions

Scenario 3 "Applying exceptional interruption time limit to all identified Exceptions". The assumption in scenario 3 is that DSOs could apply the exceptional interruption time limit to all identified Exceptions in their development plans. This would increase the amount of Planned Exceptions by 182,000.

Calculation formula: All identified Exceptions (228,137) – Planned Exceptions (46,502) = ~ 182,000 additional Exceptions

Scenario 4 "Applying exceptional interruption time limit to all identified Exceptions with harmonised estimations". The fourth scenario is a combination of scenarios 1 and 3. The assumption in scenario 4 is that the amount of all identified Exceptions is harmonised as in scenario 1 and DSOs would apply exceptional interruption times to all these Exceptions. This would increase the amount of Planned Exceptions by 264,000.

Calculation formula: All MPS in rural areas (942,681) x 33% – Planned Exceptions (46,502) = ~ 264,000 additional Exceptions

Scenario 5 "Scenario 4 assumptions + 30% of the rest of the users provide weather-proof readiness service". The fifth scenario includes assumptions made in scenario 4 and the assumption that 30% of the rest of the users would provide weather-proof readiness service (see more in chapter 6.2). Therefore, these MPS could be considered as Exceptions too. This would increase the amount of Planned Exceptions by 345,000.

Calculation formula: All MPS in rural areas x 33% + (MPS not fulfilling weatherproof requirement – All MPS in rural areas x 33%) x 30% – Planned Exceptions = ~ 345,000 additional Exceptions

311, 000 + (580,693 – 311,000) x 0.3 – 46,502 = ~ 345,000 MPS*
** = MPS not fulfilling weather-proof requirement in table 15.*

Potential savings in weather-proofing investments are calculated by multiplying the calculation of weather-proofing investment costs per single additional Exception (2,630 €) and additional Exception presented in the scenarios above. Potential calculational cost savings in 2020-2028 are presented in table 16.

Table 16. Potential calculational savings in weather-proofing investments in 2020-2028

Scenario	Additional Exceptions	Cost saving
1. Harmonised estimations	16 000	42 M€
2. Self-assessment adjustment	46 000	121 M€
3. Applying exceptional interruption time limit to all identified Exceptions	182 000	478 M€
4. Applying exceptional interruption time limit to all identified Exceptions with harmonised estimations	264 000	693 M€
5. Scenario 4 assumptions + 30% of the rest of the users provide weather-proof readiness service	345 000	906 M€

If an exceptional interruption time limit was set to a larger group of MPS than the Electricity Market Act already enables, the weather-proofing investments could be decreased from 42 M€ to 906 M€. It is assumed that the updated policy would be effective in the beginning of year 2020.

6.2 Case PKS Sähkönsiirtoverkko Oy – Weather-proof readiness

As mentioned earlier, weather-proof readiness as a service acquired from users might be a potential supplementary or substitute method for traditional network investments in rural areas. The service might be especially suitable to MV-network branch-lines with few users, which is reviewed in this case.

PKS Sähkönsiirto Oy is a DSO with 36,685 MPS in urban areas and 51,883 MPS in rural areas in North Karelia in 2018. The length of the MV-network is 9,794 km and the LV-network 12,278 km. PKS Sähkönsiirto Oy is owned by local municipalities and has granted an extension for fulfilling weather-proof requirements until year 2036. All information in this case study is provided by PKS Sähkönsiirto Oy, if not stated otherwise.

6.2.1 Background information

The case is a branch-line in a rural area, where the company is planning to renovate the existing network and fulfil weather-proof requirement within a 15 to 20-year time-period. The branch-line includes an 8.9 km MV-network and a 3.7 km LV-network, which are located in the forest and along roads. The network topology is shown in figure 3.

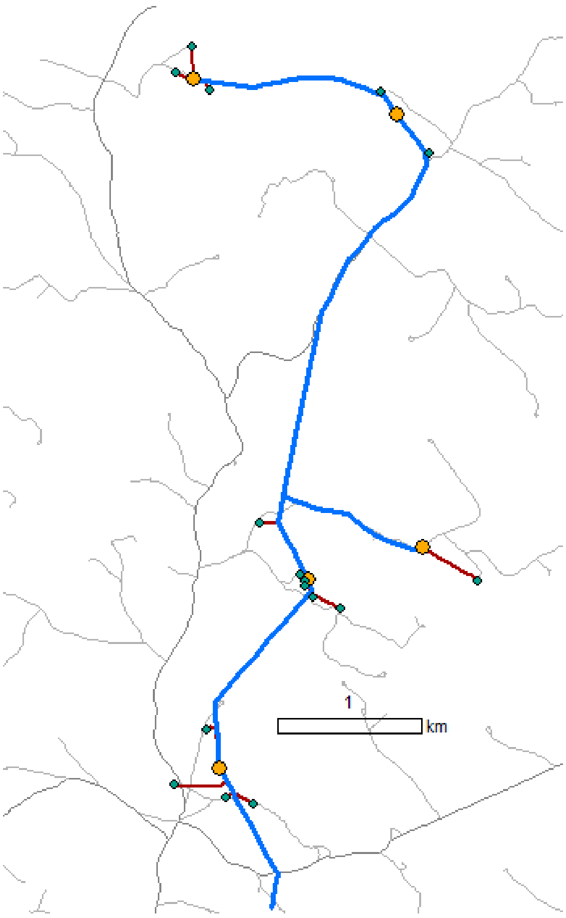

Figure 3. Network topology of the case

Points of connection are marked as green dots, distribution substations as orange dots, the MV-network as a blue line and the LV-network as a brown line in figure 3. There are 16 points of connection (users). More detailed information about the users is presented in table 17.

Table 17. Background information about users

User	Consumption MWh / year	Distribution fee € / year	User type
User 12	14.26	1 353	Single-family house
User 16	9.21	993	Single-family house
User 13	8.40	935	Single-family house
User 3	7.64	881	Single-family house
User 5	6.51	800	Single-family house / farm
User 1	5.96	761	Single-family house
User 10	5.08	698	Single-family house
User 4	4.32	644	Single-family house
User 15	2.44	510	Recreational housing
User 14	2.03	481	Recreational housing
User 11	1.72	459	Recreational housing
User 6	1.04	410	Recreational housing
User 7	0.39	364	Recreational housing
User 9	0.36	362	Recreational housing
User 8	0.08	342	Recreational housing
User 2	0	336	In maintenance

There have been 63 interruptions in the MV-network during the time-period 1.1.2014 – 11.2.2019. The total interruption time for users located at the beginning of the branch-line was 174.6 hours (2.8 h / interruption). The users at the end of the branch-line have experienced an 18.4 hours longer total interruption time. The longest interruption durations yearly concerning users at the beginning of the branch-line are presented in table 18.

Table 18. Maximum interruption durations during 2014-2018

Year	2014	2015	2016	2017	2018
Maximum duration	7 hours	7 hours	5 hours	3 hours	54 hours

The company has three alternative investment options:

1. Underground cabling along the roads
2. Aerial cabling along the roads
3. Aerial cabling to current location

Underground cabling along the roads includes a 10.7 km MV-network, a 5.4 km LV-network and five distribution substations. Aerial cabling along the roads includes an

8.3 km MV-network as aerial cabling and 2.4 km as renovating at current locations. A 5.4 km LV-network would be converted to underground cabling. Aerial cabling to current locations includes 8.9 km MV-network aerial cabling and 3.7 km LV-network aerial cabling. Five new distribution substations are needed in the two latest options too.

The company would use cost information in the investment calculations (price level 2019) as presented in table 19.

Table 19. Cost information for investment calculations

	Investment costs €	Outage costs € / year	Operational costs € / year
1. Underground cabling along the roads	800 000	1 743	1 638
2. Aerial cabling along the roads	490 000	5 117	2 651
3. Aerial cabling to current location	208 000	10 420	3 188

The third option includes notably cheaper investment costs, because only power transmission line support would be replaced. The weather-proof readiness service fee (WPR-fee) is chosen to be 50% of yearly outage costs and would be paid to users during the whole lifetime of the investment. Other calculation assumptions are:

- Discount factor 3%
- Outage costs will rise 1.5% yearly
- Operation costs will be stable
- Investment lifetime is 40 years

PKS Sähkönsiirto Oy charges 336 € / year as a fixed electricity distribution fee from case users and 71.3 €/MWh based on consumption including VAT in 2019.

6.2.2 Calculation results

Lifecycle costs of three earlier introduced investment options are calculated and the present value of options are:

- Option 1 Underground cabling along the roads 890,216 €
- Option 2 Aerial cabling along the roads 704,978 €
- Option 3 Aerial cabling to current location 594,679 €

Underground cabling is a weather-proof method and aerial cabling along the roads decreases notable risk for outages caused by weather. Both these options improve fulfilling the weather-proof requirements. Aerial cabling to current location mainly in the forest has poor performance against storms and other major weather conditions. Investment cost is very low compared to other options, but outage costs are high due to high risk of interruptions. Low investment cost may be useful, if consumption decreases in the future due to internal migration in Finland or recreational housing in remote locations becoming unattractive. There were 5,000 MPS without any electricity consumption in PKS Sähkönsiirto Oy's network in 2018. Therefore, alternative methods for traditional investment methods are needed and weather-proof readiness as a service could be one supplementary method for postponing investment decisions and enabling DSOs to fulfil weather-proof requirements set by the law.

In this case the WPR-fee payable to users was set to 50% of the computational outage cost. The present value for options 2 and 3 with WPR-fee included are:

- Option 2 Aerial cabling along the roads (+WPR) 781,830 €
- Option 3 Aerial cabling to current location (+WPR) 751,177 €

The underground cabling option is weather-proof and does not include WPR-fee. The investment option's lifecycle costs in a 40-year period are presented in figure 4.

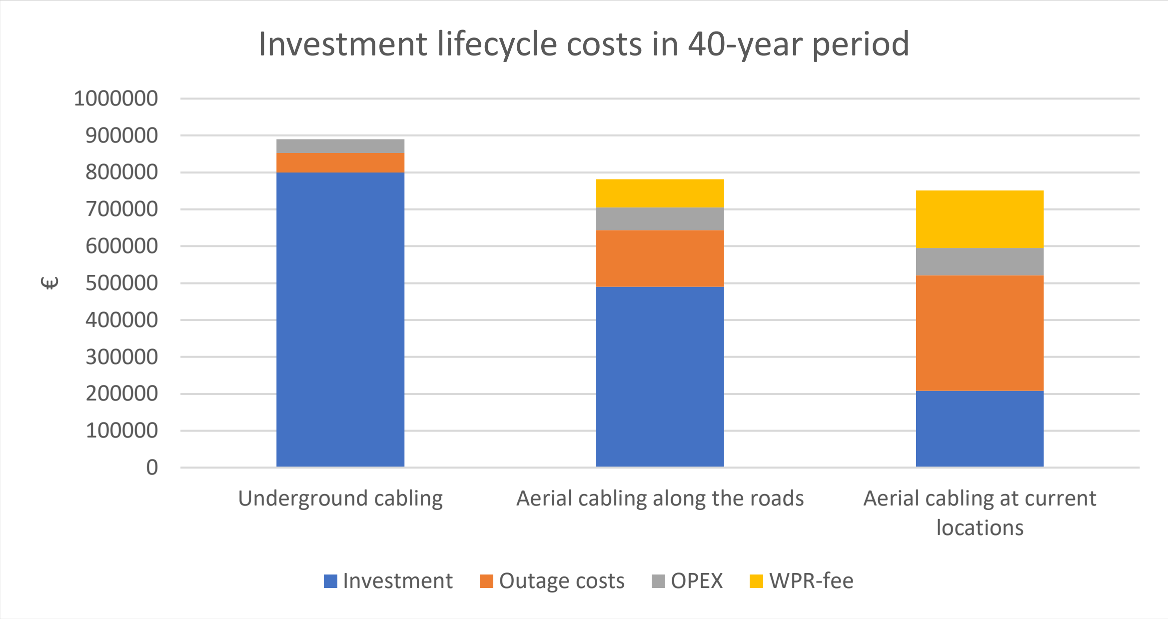

Figure 4. Investment lifecycle costs in a 40-year period including WPR-fee

As aerial cabling along the roads already reduces risks for interruptions, a WPR-fee may not be effective to use. In this case example, the investment cost to current location benefits more from a chance to use a WPR-fee for acquiring weather-proof readiness from the users. If the WPR-fee was 50% of outage costs, it would be 5,210 € in this case. Table 20 shows how it could be divided evenly among all users or if only users with higher consumption than 2,500 kWh annually would be paid. The latter division reflects a situation, where a DSO might apply for an exception of the 36-hour requirement based on local circumstances.

Table 20. WPR-fee division among users in the case

User	Consumpt. MWh / year	Distributi. fee € / year	WPR-fee € / year	WPR-fee (> 2.5 MWh)	User type
User 12	14.26	1 353	- 347	- 651	Single-family house
User 16	9.21	993	- 347	- 651	Single-family house
User 13	8.40	935	- 347	- 651	Single-family house
User 3	7.64	881	- 347	- 651	Single-family house

User 5	6.51	800	- 347	- 651	Single-family house / farm
User 1	5.96	761	- 347	- 651	Single-family house
User 10	5.08	698	- 347	- 651	Single-family house
User 4	4.32	644	- 347	- 651	Single-family house
User 15	2.44	510	- 347	-	Recr. housing
User 14	2.03	481	- 347	-	Recr. housing
User 11	1.72	459	- 347	-	Recr. housing
User 6	1.04	410	- 347	-	Recr. housing
User 7	0.39	364	- 347	-	Recr. housing
User 9	0.36	362	- 347	-	Recr. housing
User 8	0.08	342	- 347	-	Recr. housing
User 2	0	336	-	-	In maintenance

This case example shows possibilities of co-operation between DSO and users. In this case a single user would benefit yearly 347 or 651 € by accepting the current continuity of supply level instead of the weather-proof requirements set by the Electricity Market Act.

If outage costs were reduced in Finnish regulation model, when weather-proof readiness service is in use, weather-proofing investments for low power branch-lines could be decreased substantially in rural areas. Case example shows potential costs savings could be more than 10 000 €/km in lifecycle costs. There was 51 000 km MV-network aerial cabling in the forest areas in 2018 according to network development plans (Energy Authority 2018c). If weather-proof readiness service covered 20 % of current MV-network aerial cabling in the forest areas, calculational cost-savings could be over 100 M€.

7. CONCLUSIONS AND DISCUSSION

The objectives of this study were to find alternative methods or concepts fulfilling the weather-proof requirement set by the Electricity Market Act and suggesting new or improved indicators for developing the regulation model from the customer perspective. Based on a literature review most of the information and studies concerning these issues are funded or ordered by regulators or DSOs. The customer perspective is limited to users' expectations towards quality of electricity supply. An electricity distribution network is a utility providing service to the whole society and as it usually operates as a natural monopoly, a single user has no real negotiation power. The counterparty to electricity distribution network operators is the government, which has empowered an energy market regulator and a consumer ombudsman to supervise customer rights in the market. This empowerment structure may not be agile enough to understand users' needs in rapidly changing electricity markets.

7.1 Alternative methods and concepts for electricity distribution network investments

The first research question is "How could electricity distribution network investments be optimised from a customer perspective?". The main obstacle for optimised distribution network investments from a customer perspective is a lack of incentives to DSOs to optimise their investments in a natural monopoly market. Each DSO may choose suitable methods and investment strategies, because regulation is neutral to different methods as long as weather-proof requirements are met. DSOs should commercial-wise maximise their distribution networks investments, because they are able to increase electricity distribution fees collected from the users to finance investments. DSOs are entitled to reasonable return in the regulation model and the current level of WACC was 6.62% in 2018. The higher equity allows for higher turnover to be collected and in a current global financial market a low risk yield of 6.62% is very attractive.

The weather-proofing investments will concentrate on rural areas in 2020–2028. According to DSOs network development plans (Energy Authority 2018c) 38% of MPS in rural areas fulfilled weather-proof requirement in 2018. There were 580,693 MPS in rural areas in 2018, which were not fulfilling the weather-proof requirement. Network development plans indicate that DSOs have two different investment strategies. Strategy A is to use mainly underground cabling in MV- and LV-networks. Strategy B is moving trunk-lines of MV-networks along the roads and using alternative methods along underground cabling in LV-network. Figure 5 demonstrates life-cycle costs of constructing one kilometre of MV-network, when needed power capacity is 300 W.

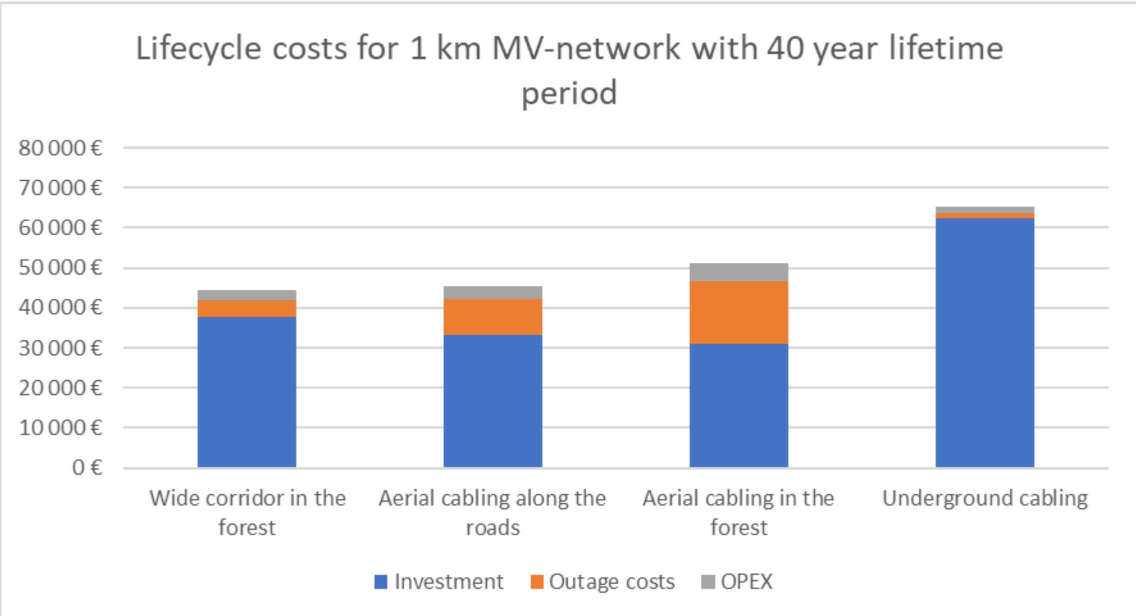

Figure 5. Lifecycle costs for 1 km MV-network (Partanen 2018, 32)

Lifecycle costs in figure 5 show a difference in investments between aerial and underground cabling. However, underground cabling fulfils best the weather-proof requirement, which can be seen in very low calculational outage costs. The current regulation model encourages DSOs to choose an investment strategy with high level underground cabling, because operational costs decrease, and continuity of supply improves. From a macroeconomic perspective the latest population forecasts in Finland are forecasting the population number to significantly decrease in rural areas in the next 20 years (MDI 2019). DSOs are reporting users terminating their network subscriptions in rural areas due to low electricity consumption. The weather-proof requirement and the decreasing population number in rural areas is an equation for DSOs to solve and an investment strategy including flexible methods for achieving weather-readiness is preferable from a customer perspective. Four recommendations were identified in this study for optimising distribution network investments.

Recommendation 1. "Weather-proof readiness service acquired from users"

Weather-proof readiness as a service acquired from the users might be a potential supplementary or substitute method for traditional network investments in rural areas. Earlier studies indicate that 22% of users living in rural areas have acquired back-up power. Case PKS Sähkönsiirtoverkko Oy proofs the method may offer attractive opportunities to users in low power MV-network branch-lines with few users. The case study indicates that 347 – 651 € could be paid yearly to each user for accepting longer interruption times in case of severe weather conditions. Weather-proof readiness as a service requires collective decision-making among users in the branch-line. There should be incentives for DSOs co-operating with users and legislation should be changed to enable this method. There are 90,000 km of private roads serving permanent residential housing in Finland in 2017 (Tieyhdistys 2017). Road maintenance associations are needed for maintaining private roads in rural areas and could be considered as one alternative to the decision making forum for weather-proof readiness service in a branch-line.

Legislator should implement this recommendation by updating current legislation and Energy Authority should include weather-proof readiness as a method into regulation.

Recommendation 2. "Utilise fully all exceptions for weather-proof requirement based on local circumstances"

DSOs may apply for an exception of the 36-hour interruption requirement based on local circumstances. Such cases include MPS on an island without a bridge or other permanent passage or regular ferry connection. DSOs are also allowed to make an exception, if a customer's yearly electricity consumption has been at most 2,500 kWh during the last three calendar years and required investments would be exceptionally high compared to other MPS due to remote location. The government's proposal for the Electricity Market Act highlights costs might be considerably high compared to achieved benefits, if the area is sparsely populated and properties are mainly recreational housing. The total costs for other network users might increase too much.

DSOs' network development plans in 2018 indicate that DSOs are not fully utilising their right to apply for longer interruption times for MPS, which fulfil local circumstance conditions. Impact evaluation scenarios indicate that the amount of these MPS could be increased from 16,000 to 345,000 MPS. A rough calculational estimation for decreasing weather-proof investments varies from 42 M€ to 693 M€, if new policy became valid in 2020. No legislation changes would be needed. If a weather-proof readiness service was available from the beginning of year 2020, calculational savings of 906 M€ could be achieved during 2020-2028.

Currently DSOs may independently define which MPS fulfil conditions of local circumstances. MPS can be classified differently across Finland, which may treat users unfairly based on the electricity distribution network they are connected to. It is recommended to draft a national definition for MPS fulfilling conditions of local circumstances.

Energy Authority should draft suggested national definition and change regulation to encourage DSOs to apply more exceptions of the 36-hour interruption requirement based on local circumstances. Legislation should be updated by legislator.

Recommendation 3. "Remove weather-proof requirement from recreational houses"

A very straight-forward method for cutting weather-proof investments in rural areas is to remove the weather-proof requirement from recreational houses. It is a political decision, but in a smaller scale recreational housing users might accept longer interruption times, if it were voluntary and compensated by lower electricity distribution fees. There is a large number of recreational houses in rural areas and by removing the weather-proof requirement and acquiring weather-proof readiness from other users in the branch, weather-proof investments could be significantly reduced. Renewable energy and energy storage solutions are quickly developing and may become attractive choices in low electricity consumption recreational houses.

Energy Market Act should be updated by legislator.

Recommendation 4. "In the regulation model network the present value of the replacement investment should be tied to the number of points of connection"
DSOs have no incentive for forecasting the number of points of connection in the future, when they are considering possible network investments. As long as there is a single user in the network branch, a DSO is allowed to write-offs in the regulation model. If the number of points of connection decreases, a lower reasonable return should be used in these investments. This practise would encourage DSOs to consider more flexible investment methods in rural areas, where a risk of a decreasing number of points of connection in the future is higher.

Energy Authority is responsible for the regulation model and this recommendation could be taken into account to the next regulatory period.

7.2 Customer-oriented incentives and development needs in the regulation model

The second research question is "Which customer-oriented incentives of the European regulation models could be applied in Finland?" A literature review of other European regulation models concentrated on continuity of supply, voltage quality and commercial quality indicators. CEER (2016, 113-118) has compared commercial quality indicators in European countries and Finland had performed poorly (3 out of 27), when the number of indicators in use were compared. The

Finnish regulator has focused mainly on continuity of supply indicators and only the time-to-connect indicator is at some level metering the customer service level in Finland. Based on the literature review and comparing the current regulation model and quality of electricity supply indicators in Finland, five recommendations were identified.

Recommendation 5. “Background information and key statistics of commercial quality should be collected for developing the regulation model and indicators”

According to the Electricity Market Act (2013, § 95), a DSO is obligated to pay standard compensation, if the electricity connection is not installed within the agreed schedule. The regulator does not obligate DSOs to provide statistics on the voltage quality or the commercial quality. It was not possible in this study to make any conclusions on how DSOs in Finland are performing against agreed timetables due to lack of information. DSOs are not required to provide statistics on customer complaints regarding poor voltage quality or other contacts (e.g. general enquiries) made by customers.

Based on the literature review response times relating to customer contacts or complaints are essential indicators metering the customer service level of DSOs in regulation models. The time for connecting customers to the network is also a very common indicator in benchmarking European countries. DSOs are obligated to provide history data about the voltage quality and future estimations to customers in Norway, Italy, Slovenia and Ireland.

There is no background information or statistics for comparing DSOs’ performance to other benchmarking countries or even considering, if new customer-oriented indicators should be added to the regulation model. Therefore, it is recommended that the regulator would obligate DSOs to provide key statistics of commercial quality and paid standard compensations concerning new electricity connections. These statistics should be used to decide, if there is a need to include new indicators to the regulation model or adjust current standard compensation levels.

Recommendation 6. "A nationwide customer satisfaction survey for background information developing the regulator model"
Poor customer service quality has no effect on a company's turnover or number of customers in a natural monopoly market. The Finnish regulation model concentrates currently on continuity of supply indicators and voltage quality and commercial quality are not adopted in the regulation model.

The current level of customer satisfaction in DSOs in Finland is unclear, because it has never been examined in a standardised survey nationwide. Each DSO may have their own customer satisfaction surveys, but a big picture about overall customer satisfaction regarding DSOs is not available.

The British regulator has included an incentive in their regulation model, which aims at ensuring that customers requiring a new connection, seeking information from the network in the event of an interruption or making general enquiries, receive good customer service. The questionnaire format is common to all DSOs and the survey is conducted by the same independent market research company, to ensure consistency. Only customers who have been in contact with DSOs are interviewed in the survey. The results of the electricity distribution network industry are benchmarked against other customer-oriented industries (e.g. banking, internet connection operators) in the regulation model. (Ofgem 2017, 35-36)

It is recommended to carry out a nationwide customer satisfaction survey for gaining better understanding of the current level of customer satisfaction. The results should be used as source material when developing the regulation model. Without any studied information about customer satisfaction it is impossible to develop a regulation model from a customer perspective.

Based on the results, a standardised nationwide customer satisfaction survey should be included as an incentive to the regulation model.

Recommendation 7. “Large connection customer and DSO dialog as incentive to the regulation model”

In Great Britain, the regulation model includes a specific incentive for large connection customers. The aim of the incentive is to drive DSOs to understand and meet the needs of major connection customers (e.g. larger metered demand, unmetered demand, distributed generation). DSOs are obligated to draft a high-level strategy for engagement, workplan of activities and key performance outputs for the forthcoming regulatory year. The plan will be submitted to the regulator. (Ofgem 2015)

It is recommended that as part of the nationwide customer satisfaction survey (recommendation 6) also large connection customers are interviewed. If the results indicate there is a need for a deeper dialog between large connection customers and DSOs, an incentive should be built into the regulation model.

Recommendation 8. “Stricter national requirements for voltage quality and standard compensations to customers”

According to CEER (2016, 85) even though EN 50160 standard was revised in 2010, the standard’s limits and values are still considered too loose. EN 50160 is still currently only commonly used for measuring voltage quality in Europe. Great-Britain, Norway and Sweden have set stricter national requirements for voltage quality.

In Finland, EN 50160 is referenced in the Energy Market Act as the quality level for measuring voltage quality. There is no voltage quality incentive scheme in Finland, but Finnish Energy (2010) has drafted general terms as “Terms of network service 2010” to be used as connection contract terms.

Two soft points can be seen in the current practise in Finland. First, it is problematic, if the lobbyist of DSOs is setting the level of compensations regarding violations of voltage quality. Secondly, Finnish legislation references the loose standard EN 50160 to be an accepted level of voltage quality in Finland. The standard allows its requirements to be deviated 5% of the time, which means voltage quality requirements may be not fulfilled for eight hours in a week. In the modern information society it could cause serious issues for customers without any decent compensation. France and Sweden have set a stricter time restriction (100%) compared to EN 50160 (95%), which means voltage quality must be achieved continuously (CEER 2016, 85).

It is recommended to set stricter national requirements for voltage quality than EN 50160 standard. If the voltage quality requirements are not met, a standard compensation to customer should be paid. Energy Authority should have an active role promoting stricter national requirements for voltage quality.

Recommendation 9. "Updating calculational outage costs and standard compensations in case of interruption"

Calculational outage costs used in the regulation model are originally defined by Silvast et al. (2005) and some updates have been made during the years. The latest review on outage costs was made by Gaia Consulting Oy (2014). Due to the tight schedule Gaia Consulting Oy was not able to carry out a comprehensive study to investigate, whether used outage costs still reflect the disadvantage experienced by a customer in case of interruption. Gaia Consulting Oy acknowledged new methods for defining outage costs have become available since the original study from 2005.

Due to weather-proof requirements Finnish electricity distribution networks are less vulnerable to severe weather conditions in 2028, when the next regulatory period begins. Customers in urban areas are likely to experience notably less interruptions than earlier and the continuity of supply will improve in rural areas, too. Currently standard compensations in case of interrupted supply of electricity are paid only when the interruption has been continuous.

It is recommended that outage costs are defined by a more comprehensive study using the latest methods available. Standard compensations should be updated to meet the new situation in 2028. Energy Authority is responsible for the regulation model and therefore this recommendation could be implemented easily.

7.3 Limitations and future research

Weather-proof requirements have been a focus of the regulator during current years and other aspects than continuity of supply have not been prioritised. Most of the information and studies concerning regulation models are funded or ordered by regulators or DSOs. Lack of information sets the following limitations to this study. Impact evaluation of exploiting exceptional interruption time was conducted at a rough level and very straight assumptions were made. The impact evaluation gives more of a ballpark estimation of possibilities than exact estimations of possible cost savings. Some of the recommendations may become obsolete, if more information about the present situation will be available.

More information and studies are needed for developing cost-efficient incentives in the Finnish electricity distribution regulation model. Following needs / research questions for future study were identified:

What kind of incentives are needed for DSOs to use weather-proof readiness as a service? It should be reviewed how the current regulation model should be modified and if DSOs could act as a service provider delivering weather-proof readiness service to its customers.

What kind of insurance-based weather-proofing solutions instead of physical solutions could be offered to customers? Energy storages, reserve power units, solar panels are traditional physical solutions achieving better continuity of supply or solutions for weather-proof readiness service. Customers might be interested to be compensated from longer interruption times by insurance-based solutions.

Does the ownership structure of DSO correlate to chosen weather-proofing investment strategy? E.g. Elenia Oy and Caruna Oy are owned by private investors. Their network development plans should be reviewed in detail and compared to DSOs owned by public sector (municipalities etc.)

Are weather-proofing investment costs for next 50 years justified compared to realised costs in last 50 years caused by severe weather conditions? Cost-efficiency of weather-proofing investments should be investigated by comparing these costs to historical realized costs.

How outage costs in the Finnish regulation model should be updated? Based on literature review several regulators in European countries have studied this theme. These different methods should be reviewed and investigate standardised methods suggested by CEER. What kind of question should be in a customer-survey for achieving less volatility in answers?

How national requirements for voltage quality should be defined? Norway, Sweden and United Kingdom have already stricter national requirements than EN 50160 standard. Which soft points these countries have identified in EN 50160 standard?

There has been little research from a customer-perspective for electricity distribution business in Finland. It has been expected customers value availability, technical electricity quality and customer service experience in electricity distribution business. Following questions should be asked from Finnish customers for achieving better understanding about their needs:

1. Do you prefer high continuity of supply level in recreational houses to lower electricity distribution fees?
2. Are you willing to provide weather-proof readiness service in rural areas for a decent compensation?
3. How satisfied you are to customer service of DSOs in Finland?

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Appendix 1 (CEER 2016, 117)

TABLE 4.3 SUMMARY OF COUNTRIES WHICH ADOPT COMMERCIAL QUALITY INDICATORS

Group	Indicator	AT	BE	CZ	EE	EL	FI	FR	GB	HR	HU	IE	IT	LT	LU	LV	MT	NL	NO	PL	PT	SE	SI	Total
I. Connection	I.1 Time for response to customer claim for network connection	X	X	X	X					X	X		X	X	X	X	X	X	X		X	X	X	16
	I.2 Time for cost estimation for simple works	X				X		X			X		X		X	X			X				X	9
	I.3 Time for connecting new customers to the network	X	X	X		X	X	X		X	X			X	X			X	X		X	X	X	15
	I.4 Time for disconnection upon customer's request		X		X	X		X								X			X					6
	I.5 Time for a switching of supplier	X	X	X	X	X	X	X		X	X			X	X				X	X		X		14
II. Customer care	II.1 Punctuality of appointments with customers	X		X				X			X										X			5
	II.2 Response time to customer complaints		X		X	X		X		X	X			X		X		X	X	X	X			12
	II.3 Response time to customer enquiries	X	X		X	X					X					X		X	X		X		X	10
	II.4 Response time to customer voltage and/or current complaints		X	X		X		X		X	X							X	X	X			X	10
	II.5 Response time to customer interruption complaints		X		X			X		X								X	X	X				7
	II.6 Response time to questions in relation with costs and payments (excluding connection)			X				X										X		X				4
	II.7 Call Centers average holding time										X													1
	II.8 Call Centers service level							X			X								X				X	4
	II.9 Waiting time in case of personal visit at client centers										X								X					2
	II.10 Percentage of customers with a waiting time below the limit in call centres																				X			1
	II.11 Percentage of customers attended within the waiting time limit in customer centres																				X			1
	II.12 Percentage of customers' requests answered within the time limit																				X			1
	II.13 Average response time to customer complaints and/or requests																				X			1
III. Technical Service	III.1 Time between the date of the answer to the VQ complaint and the elimination of the problem		X	X		X		X	X		X											X	X	8
	III.2 Time until the start of restoration of supply following failure of fuse of DSO		X	X		X			X	X	X							X			X		X	9
	III.3 Time for giving information in advance of a planned interruption	X	X	X	X				X	X	X			X		X		X					X	11
	III.4 Time until the restoration of supply in case of unplanned interruption	X	X	X	X				X	X	X			X		X		X				X		11
	IV.1 Time for meter inspection in case of meter failure		X	X	X	X			X	X	X	X		X			X		X				X	12
IV. Metering and Billing	IV.2 Time from the notice to pay until disconnection	X	X	X		X				X							X	X				X		8
	IV.3 Time for restoration of power supply following disconnection due to non-payment	X		X	X					X	X				X						X			7
	IV.4 Yearly number of meter readings by the designated company	X	X	X			X	X		X	X	X						X				X		10
	IV.5 Percentage of meter readings made within less than a certain amount of time after the last one																				X			1
Total number of indicators per country		**11**	**15**	**14**	**10**	**11**	**3**	**12**	**5**	**13**	**18**	**2**	**2**	**7**	**5**	**7**	**3**	**12**	**12**	**5**	**12**	**7**	**10**	**196**

Appendix 2 (Ofgem 2017, 78)

Guaranteed standard	period	amount
Provision of budget estimate <1MVA	10 working days	£65
Provision of budget estimate >1MVA	20 working days	£65
Provision of single phase LV quotation	5 working days	£15
Provision of small project LV quotation	15 working days	£15
Provision of other LV demand quotation	25 working days	£65
Provision of HV demand quotation	35 working days	£135
Provision of EHV demand quotation	65 working days	£200
Contact customer (post acceptance) about scheduling <5 LV service connections	7 working days	£15
Contact customer (post acceptance) about scheduling other LV demand connections	7 working days	£65
Contact customer (post acceptance) about scheduling HV demand connections	10 working days	£135
Contact customer (post acceptance) about scheduling EHV demand connections	15 working days	£200
Commence LV, HV & EHV demand works on customer's site	Timescale agreed with customer	£25
Complete service connection works		£35
Complete LV works*		£135
Complete HV works*		£200
Complete EHV works*		£270
Complete LV energisation works*		£135
Complete HV energisation works*		£200
Complete EHV energisation works*		£270
Emergency Fault Repair response	2 hours	£65
High Priority Fault Repair – Traffic Light Controlled	2 calendar days	£15
High Priority Fault Repair – non Traffic Light Controlled	10 working days	£15
Multiple unit fault repair	20 working days	£15
Single unit fault repair	25 working days	£15
Provision of a quotation – New Works order (1-100 units)	25 working days	£15
New works order – completion of works on a new site	Commence and complete in timescales agreed with the customer	£15
New works order – completion of works on adopted highways	35 working days	£15
Quotation accuracy review scheme challenge single LV single phase service connection	N/A	£335
Quotation accuracy review scheme challenge small LV projects	N/A	£670
Where a Distributor fails to make a payment under the regulations	10 working days	£65

** including phased works*