Lappeenranta University of Technology
School of Energy Systems
Master’s Programme in Energy Technology

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THE VALUE OF SUPPLY SECURITY FOR ELECTRICITY CONSUMERS IN FINLAND

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ABSTRACT

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The value of supply security for electricity consumers in Finland

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Keywords: electricity markets, value of lost load, security of supply, power shortage, demand response

This master's thesis was done for Finnish Energy Authority, and it estimates the value of security of electricity supply. A survey was developed and conducted to find the Value of Lost Load (VoLL). VoLL is a tool used for example in market development and it describes the cost of electricity interruptions. In this thesis, VoLL is especially the price that electricity users would be willing to pay to avoid electricity cut off during power shortage situation. VoLL for households was estimated to be 3900–19 300 €/MWh and VoLL for leisure residences was estimated to be 38 600–90 400 €/MWh. In addition, respondents were asked how much compensation they would like to have if their electricity usage was limited three times a year. Among those households with electric heating, that were assumed to be willing to participate in such arrangements, the average annual compensation was 90 €/kW.

TIIVISTELMÄ

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Tässä Energiavirastolle tehdyssä diplomityössä arvioitiin sähkön toimitusvarmuuden arvoa tehopulatilanteessa. Työssä suunniteltiin ja toteutettiin kyselytutkimus, jonka avulla selvitettiin toimittamatta jääneen sähkön arvo (VoLL - Value of Lost Load). VoLL on mm. markkinakehityksessä käytetty työkalu, joka kuvaa sähkökatkosta aiheutuvia kustannuksia. Tässä työssä sillä tarkoitetaan erityisesti hintaa, jonka sähkönkäyttäjät olisivat tehopulatilanteessa valmiita maksamaan välttääkseen sähköjen katkaisemisen. Kotitalouksien VoLL:n arvioitiin olevan välillä 3900 €/MWh ja 19 300 €/MWh. Vapaa-ajan asuntojen VoLL:n arvioitiin olevan välillä 38 600 €/MWh ja 90 400 €/MWh. Lisäksi kyselytutkimuksessa kysyttiin, kuinka paljon sähkönkäyttäjät haluaisivat korvausta, mikäli heidän kuormaansa ohjattaisiin kolme kertaa vuodessa. Niillä sähkölämmittäjillä, joiden oletettiin olevan halukkaita kuorman ohjaukseen, keskiarvo oli 90 €/kW vuodessa.

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ABBREVIATIONS

BRB	Balance Responsible Party
CE	Choice Experiment
CHP	Combined Heat and Power
CV	Contingent Valuation
COP	Coefficient of Performance
DSF	Demand Side Flexibility
DSO	Distribution System Operator
EUE	Expected Unserved Energy
FRR-M	Manual Frequency Restoration Reserve
GVA	Gross Value Added
I&C	Industrial and Commercial
LOLE	Loss of Load Expected
LV	Leisure Value
RCC	Rental Cost of Reliable Capacity
SME	Small and Medium Sized Enterprises
TSO	Transmission System Operator
PPP	Purchasing Power Partity
VoLL	Value of Lost Load
WTA	Willingness to Accept
WTP	Willingness to Pay

SYMBOLS

C_{LC}	Hourly consumption based on load curve
E_a	Annual electricity consumption
E_h	Hourly electricity consumption
ELC_{MS}	Annual household sector electricity consumption of a Member State
$ELC_{MS,t}$	Hourly household sector electricity consumption of a Member State in hour t
l	Length of a power cut

1 INTRODUCTION

1.1 Background

Electricity consumption per capita in Finland is one of the biggest in the world. Industry and construction -sector consumes roughly half of Finland's electricity and households roughly one third (Figure 1). The largest industries are forest industry, metal industry and chemical industry, which all are energy intensive industries. However, Finland has not enough own electricity production capacity to cover the demand during peak loads at winter and is highly dependent on electricity imports. Electricity is also imported when it is cheaper to buy it from other countries than to produce it in Finland. In 2016, electricity consumption was 85,1 TWh and production was 66,1 TWh, which means that 22 % of consumed electricity was imported (Finnish Energy 2017).

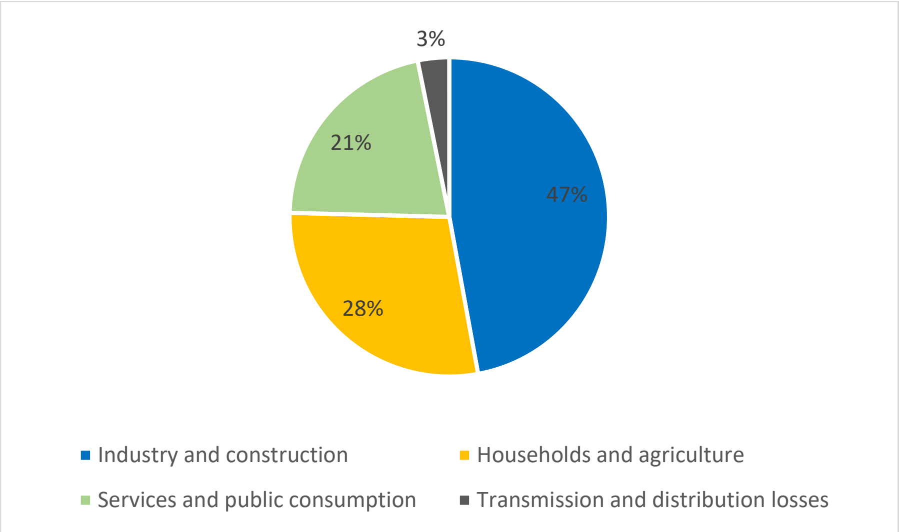


Figure 1. Electricity consumption by sector in Finland in 2016. (Tilastokeskus 2017)

1.1.1 Supply security

Energy systems, in practice, are never designed to ensure 100 % of supply security. When energy system is designed, there are usually three major objectives: supply security, economic efficiency and environmental protection. If supply security is increased, either economic efficiency or environmental protection or both may weaken. There are several things that can make the system insecure. This thesis studies the risk that production and import capacity are not enough to cover the demand during peak load. Other “sources” of insecurity are weather conditions, poor maintenance of the network, failures in primary fuel supply and faults in power plants. (Lieb-Doczy et al. 2003)

The optimum level of security of supply is, in theory, where the cost of providing extra security and the value to electricity consumer of increased security are the same. Figure 2 illustrates how consumers’ willingness to pay for extra security decreases when degree of security gets better, while cost of providing extra security increases. The closer to 100 % of supply security the system gets, the shorter interruptions will consumers experience and the less they are willing to pay for extra security. The optimal decree of security is where these curves meet. However, security of supply does not have a market and consumers’ valuations need to be obtained by indirect survey methods. (Ibid.)

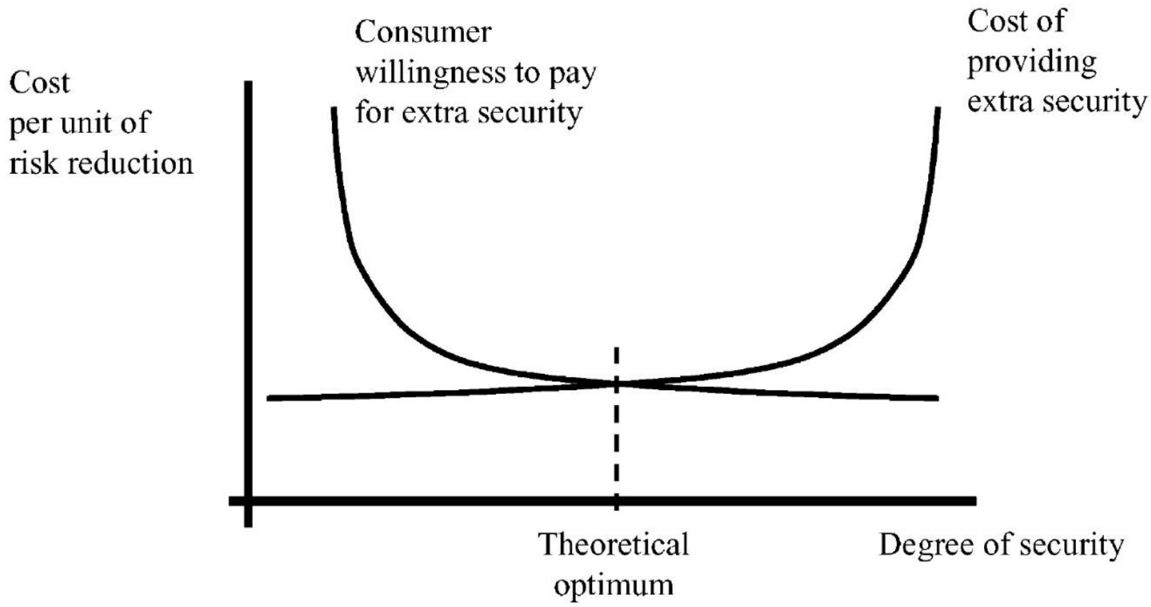


Figure 2. Theoretical optimum of degree of security (Lieb-Doczy et al. 2003, 12.)

1.1.2 Measuring supply security

Value of Lost Load (VoLL) describes the value of supply security. It is the value of electricity not supplied, and on the other hand it tells, how much consumers are willing to pay to avoid outages. VoLL can be used for many purposes in energy policy and market design (London Economics 2013). For example, VoLL can be used as a tool to find the economically best solution, when peak load capacity is designed. During a scarcity situation, electricity market price in day-ahead market may rise very high. There has been debate on whether VoLL should be used as a price cap instead of current price cap in EU (European commission 2016a). The idea of the proposal is that electricity market price should not be limited below the level that consumers are actually willing to pay to ensure and incentivize adequate electricity production capacity.

European Commission’s “Proposal for a regulation of the European Parliament and of the Council on the internal market for electricity” describes VoLL as follows: “Value of lost load means an estimation in €/MWh, of the maximum electricity price that customers are willing to pay to avoid an outage.” Article 9, which discusses about price restrictions, says: “There shall be no maximum limit of the wholesale electricity price unless it is set at the value of lost load”. The proposal seeks to improve scarcity pricing and therefore encourage more resources to participate fully in the market. The main objective of the proposal is to increase security of supply. (European Commission 2016b)

Cost of electricity distribution interruptions have been estimated in Finland couple of times. The latest comprehensive survey was conducted in 2005 and it covered all customer types, but limited to distribution system operator (DSO) customers (Silvast et al. 2005). In 2009 a survey was conducted for transmission system operator (TSO) customers (Mäkinen et al. 2009). After these studies, value of electricity distribution interruption costs have been updated based on a price index. In 2014, a small-scale survey was conducted for household customers to see, if further update for electricity interruption costs is needed (Matschoss 2014). VoLL and cost of electricity interruption have a lot in common, but no research focused specially on VoLL has been done in Finland before. Cost of electricity distribution interruption is typically expressed as €/kW, whereas VoLL is expressed as €/kWh and is thus related to electricity market price. Cost of electricity interruption includes all kind of interruptions, no matter what are their origins, whereas in this thesis VoLL is based on a power scarcity situation.

1.2 Goals and delimitations

The main goal of this thesis is to make a survey based estimation of VoLL for households and leisure residences. Another goal is to study households' willingness to participate in demand response and the compensation they would like to have for it. Also, simple, non-survey based estimation of VoLL for industry will be conducted. The steps of the survey are: literature review, choosing the survey method, planning the questionnaire, conducting the survey and analyzing the results.

1.3 Structure of the thesis

Chapter 2 discusses about security of supply. It starts with an overview of the current situation in Finland. It describes how power balance is maintained with different markets and how power shortage situation is handled in Finland. It also describes how VoLL is related to security of supply.

Chapter 3 is a literature review. It contains different methods how VoLL can be calculated. Four recent studies are introduced.

Chapter 4 discusses about survey. It begins with general issues on a survey planning. It describes the methodology of this survey and how the questionnaire was designed.

Chapter 5 contains the results of the survey. It shows how data is analyzed and what processing is done to achieve our own estimates.

Chapter 6 contains a non-survey-based estimation of VoLL for industrial sector in Finland.

2 SECURITY OF SUPPLY

2.1 Security of supply in Finland

It is estimated that Finland has 11 300 MW available electricity production capacity during a cold winter day. In addition, there is a strategic reserve system (729 MW) for peak load situations. Maximum electricity consumption in Finland is estimated to be 15 200 MW. Electricity import capacity is 5100 MW (Figure 3). Under normal circumstances, production and import capacity should be enough to cover the consumption. However, if many faults happen at the same time, security of supply may be in danger. (Energy Authority 2017, 17)

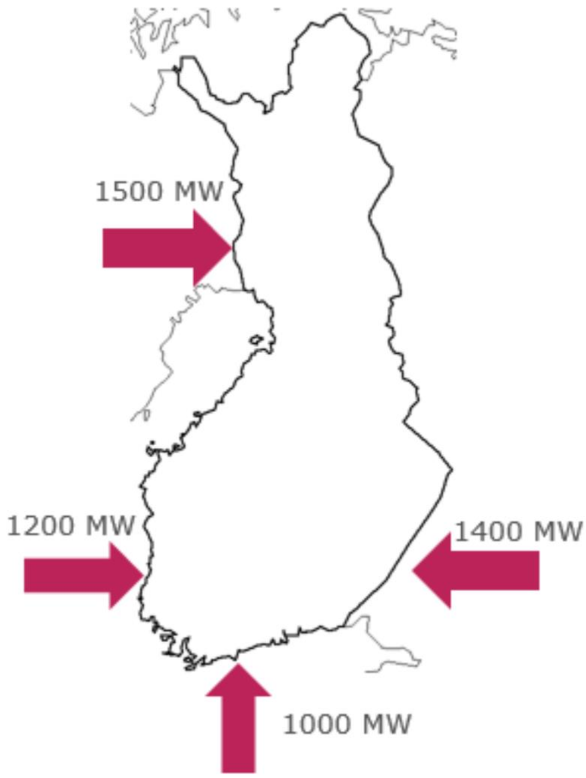


Figure 3. Import capacity to Finland from Sweden, Estonia and Russia. (Energy Authority 2017, 17)

In the future, maintaining the power balance in Finland might be more challenging. In recent years, some combined heat and power (CHP) plants have been replaced with heat-only production plants because of low electricity market price. If a CHP plant is replaced with a heat pump system, electricity production unit becomes electricity consumption unit, which naturally decreases electricity production capacity and increases consumption. Wind power production has been increasing. Wind power, as well as other fluctuating electricity production, makes the balancing even more challenging. On the other hand, two nuclear power units will start operating in the near future. Olkiluoto 3 -power plant unit (1600 MW) will be commissioned in 2019 and Fennovoima (1400 MW) is planned to be commissioned in 2024. Also, import capacity from Sweden is planned to be increased 800 MW in 2025 and possibly 300 MW by 2030. (Energy Authority, 2017)

2.2 Nordic electricity markets

Day-ahead market is the main marketplace for power trading in Nordic and Baltic countries. In 2016, 391 TWh of electricity was traded in day-ahead market in Nordic and Baltic countries, which was 95 % of their total electricity consumption. Members can be buyers or sellers or both. A buyer estimates the amount of electricity it needs for the next day hour by hour. For each hour, it places a bid based on its willingness to pay for that amount of electricity. The seller plans how much electricity it can deliver next day hour by hour and set prices for each hour. These bids form supply and demand curves for each hour as shown in Figure 4. The intersection of these curves will show the market price and the amount of electricity being exchanged. (Nord Pool)

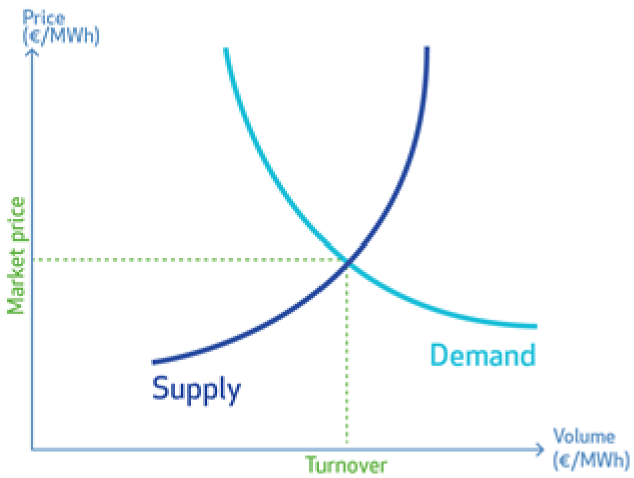


Figure 4. Supply and demand curves in day-ahead market (Nord Pool)

After the closing of the day-ahead market, buyers and sellers can trade electricity at the intraday market. Electricity can be traded 24 hours a day until one hour before delivery. The pricing is based on “first-come, first-served” -principle, and best prices are used first. Buying electricity from intraday-market can be more expensive than from day-ahead market, depending on the market situation. (Nord Pool)

The actual consumption always differs from the forecasted, which causes imbalance for electricity buyers and sellers. All electricity market parties must have an open supplier to balance its power balance. Those market parties, whose open supplier is TSO, are called balance responsible parties (BRP). A BRB makes imbalance settlement with TSO and compensates its imbalance with imbalance power. Price of imbalance power can be disadvantageous to the market party and extra cost can occur compared to well-forecasted production/consumption. Thus, it is advisable for market participants to forecast the production/consumption as accurately as possible. The nationwide power balance is maintained with frequency control reserves and through the regulating market. (Partanen et al. 2015)

2.2.1 Under supply in day-ahead market

Currently, the maximum price cap in day ahead market is 3000 €/MWh. If it seems that demand will be more than supply, purchase bids must be curtailed. When purchase bids are curtailed, the demand curve will move left. Curtailment is carried out until the demand curve intersects with supply curve at the maximum price (Figure 5). (Nord Pool)

Figure 5. Curtailment of purchase bids so that the supply curve intersects with the demand curve at the maximum price (Nord Pool)

2.2.2 Strategic reserve system

For peak load situations, there is a strategic reserve system in Finland. It consists of both electricity production plants and demand side flexibility (DSF) facilities. Power plants accepted to the system are used only when market based production cannot cover electricity consumption, and they are not allowed to be in normal market use during the strategic reserve period, which is few years at a time. DSF facilities must be ready to decrease their consumption if needed. The strategic reserve capacity for period 2017–2020 is 729 MW, 22 MW of which is DSF capacity. The accepted power plants and DSF facilities receive compensation for participating to the system. Strategic reserve capacity is activated when day-ahead market price reaches its price cap, which is currently 3000 €/MWh in Nord Pool. The capacity can be also activated at Fingrid's (Finland's TSO) request. (Energy Authority)

The strategic reserve system is based on Finnish act 117/2011 (Act on peak load capacity which secures a balance between electricity production and consumption). Production capacity and DSF facilities must be in use within 12 hours between 1st of December and 28th of February. The rest of the year the units must be ready to be launched within one month. Energy Authority makes the decision on the amount of peak load capacity and chooses the units based on their bids. Fingrid pays compensation to the units belonging to the system and charges the money from electricity users. (Finlex 2011)

Choosing the amount of strategic reserve capacity is balancing between total costs of power shortage and total costs of the strategic reserve capacity. The amount of strategic reserve capacity can be calculated based on Loss of Load Expected (LOLE), Expected Unserved Energy (EUE), Value of Lost Load (VoLL) and the price of available capacity. LOLE (h/a) indicates how many hours per year supply cannot cover demand, and it is based on probability. EUE is calculated by multiplying each possible power shortfall (MW) by its probability (h/a). VoLL (€/MWh) multiplied by EUE (MWh/a) gives the total annual cost of unsupplied electricity. The larger the strategic reserve capacity is, the lower is the expected cost of unsupplied energy. On the other hand, improved security of supply means higher costs. Figure 6 shows how the cost effective strategic reserve capacity is chosen in theory. (Pöyry 2016)

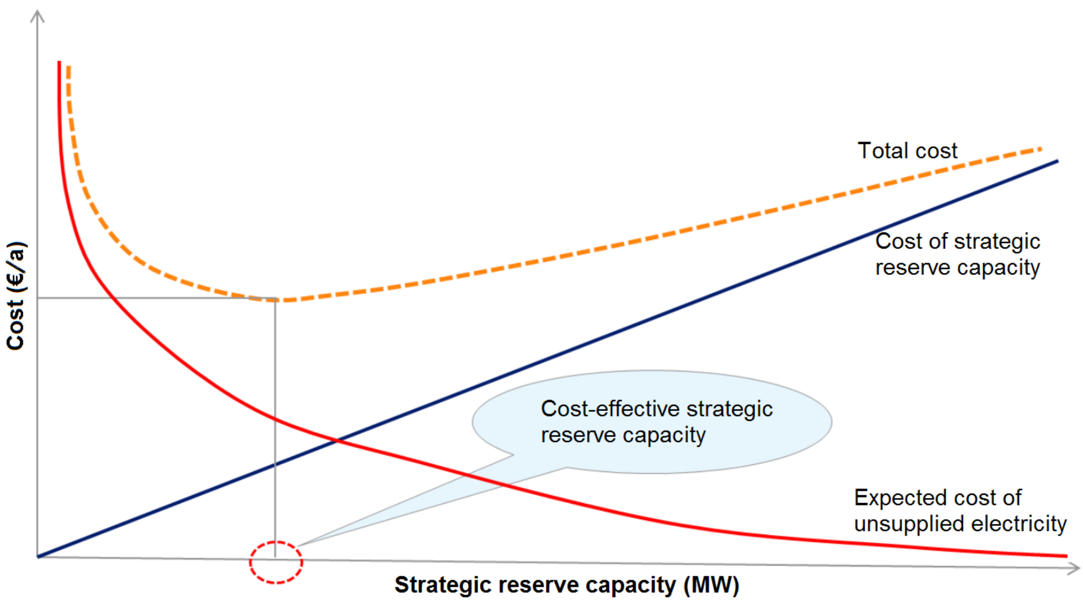


Figure 6. Cost effective strategic reserve capacity (Pöyry 2016).

2.2.3 Power shortage

If there is not enough electricity production or import capacity available to cover the electricity consumption, the result is power shortage. If it is close to happen in Finland, Finland's TSO Fingrid has a plan how to act. The procedure consists of three steps, which are shown in Table 1.

Table 1. Management of power shortage. (Fingrid 2017)

1. Strained power balance If it seems that production and import may not cover the consumption, Fingrid will send a "strained power balance" notice to balance responsible parties. This will make balance responsible parties aware of the situation and plan their production and consumption carefully. If necessary, Fingrid will activate strategic reserve capacity and find out whether any additional capacity or import is available. More up-regulating bids will be also asked by Fingrid.
2. Power shortage The situation is called "power shortage" when the full electricity production capacity in Finland is in use and no more import capacity is available. Fingrid will activate manual frequency restoration reserve (FRR-M) for balance management purposes. FRR-M-capacity in normal use is reserved only for fault situations, and when it is used for any other than the original purpose, the power system cannot stand dimensioning faults anymore. If necessary, intraday-market can be closed in Finland. Network operators will prepare to restrict loads.
3. Serious power shortage When all the power reserves are in use and there is still power shortfall, Fingrid will contact network operators, who restrict loads according to the beforehand prepared plans. The situation is called serious power shortage.

In the case of major disturbance, as serious power shortage, electricity users must be prioritized. There are certain critical functions of society that must be secured under all circumstances. Critical services are e.g communication systems, transport logistics, food supply, healthcare and critical industrial production. (National Emergency Supply Agency; Perttala and Heinonen 2012, 27)

2.3 Missing money problem

Most EU Member States have a price cap in their wholesale electricity markets. In Nord Pool day-ahead market, the price cap is 3000 €. In those Member States, where VoLL has been calculated, VoLL is well above price caps in day ahead market. Instead of current price cap, price cap is recommended to be set at the level of VoLL. (European Commission 2016a)

VoLL is the maximum price that consumer is willing to pay for electricity. In theory, there should not be any reason to limit the market price below the level that consumers are willing to pay for it. Capping the market price below VoLL does not give enough investing signals for peaking power plants. This is called the "missing money" -problem. If the price cap is set above VoLL, or if it does not exist at all, unrealistic price signals may be given and it would result in too high and unprofitable capacity. Setting the price cap at the level of VoLL would, in theory, result in optimal amount of capacity and optimal level of supply security. (Newbery 2015, 7; Cramton et al. 2013, 28-29)

As an example of energy-only market, where capacity market is not implemented: VoLL is 10 000 €/MWh. Without a price cap, scarcity situation will raise the price up to 20 000 €/MWh, which will decrease the demand partly. Non-elastic consumers will however pay twice as much that electricity is worth to them. This overpaying will send a signal to the market to build too much capacity. If the price cap is set to 3000 €/MWh, investment in capacity will be too low. The optimal capacity is reached by setting the price cap to VoLL, 10 000 €/MWh. The capacity will be built until an extra MW of production makes revenue that is exactly the same than its cost. Assuming that expected duration of blackouts is 5 hours per year, the rental cost of reliable capacity (RCC) will be 50 000 €/MW (VoLL × Duration) per year. RCC will not rise more than that, because it is not profitable anymore. The capacity is optimal and consumers pay just as much they are willing to pay. However, it is difficult to estimate VoLL. Also, in this example VoLL is the average value, which means that some consumers would still pay more than they are willing to pay for reliability. (Cramton et al. 2013)

In the future, it might be possible that consumers could state the maximum amount that they are willing to pay for electricity and when the price increases, their smart meters start to disconnect some appliances. This would help to avoid missing money problem. (Newbery 2015, 7)

2.4 Demand response

Demand response is a way to manage power balance during peak load hours and to avoid black-outs. In the future, demand response will play a significant role when fluctuating renewable energy production will increase. There are two alternatives how demand response can be implemented: implicit and explicit. In the implicit demand response, electricity user is aware of electricity price and uses price-signals to make decision to shift load from expensive to cheaper hours. Explicit demand response is based on a request to shed load. Usually an incentive is needed to participate in explicit demand response. For example, electricity users can allow a market participant to control their appliances, and they receive compensation for their participation. It is possible, that in the future, market parties, such as balance responsible parties will be more interested in the use of demand response in order to avoid purchasing expensive imbalance power.

Households with electric heating are typically the most potential households to participate in demand response. In the future, electric cars will also present significant potential of flexible load. This thesis studies how explicit demand response could be used in the case of power shortage situation and how much compensation electricity users would like to have for participating in demand response.

3 LITERATURE REVIEW

3.1 Different methods for estimating VoLL

There are several methods for estimating VoLL. It can be estimated using macroeconomic methods, customer surveys or case studies. Methods based on customer surveys are “stated preference” and “revealed preference” -methods, though the latter can also be based on other data collection methods. Stated preference method studies what people would do in a hypothetical situation, and revealed preference method studies what people have actually done in real situations.

Customer surveys are used to obtain information from electricity users. Direct method is to ask directly the interruption cost. Usually direct approach can be used for sectors that can estimate the consequences of an electricity interruption, such as industrial sector and other large electricity users with good knowledge of their electricity usage. For household electricity users, more suitable method is indirect approach, which means that VoLL is estimated by using indirect questions. (Linares and Rey 2012, 7)

3.1.1 Macroeconomic methods

Macroeconomic approach, also known as production function approach, may be the simplest way to estimate the value of lost load. The method is based on publicly available data. The objective is to find a value for one unit of electricity. It uses an economic measure, typically gross value added, and electricity consumed. VoLL is then calculated by dividing gross value added by electricity consumed. In the case of household consumers, this method is usually based on an estimated value of leisure time divided by electricity consumed.

In this method, excluding private customers, VoLL measures the amount of economic outputs produced per one unit of electricity. Thus, VoLL is the inverse of electricity intensity. In highly electricity intensive industrial sector, VoLL may be low, because output produced per unit of electricity is low compared to less electricity intensive sector. For example, in the construction sector, output produced per electricity consumed is usually high, which raises the VoLL high and does not always give a good estimate of electricity interruptions costs. The method doesn’t take into account, that production can be postponed or displaced to other locations. In some sectors, electricity interruptions do not cause production breaks at all, but in other sectors, this method can give very relevant estimates of interruption costs. (Linares and Rey 2012. 7)

3.1.2 Stated preference

Stated preference methods are based on customer surveys and their purpose is find a monetary value for something that does not really have a market, such as a beautiful landscape. The level of supply security neither has a market, and stated preference method is a good indirect way to estimate how people value it. The questions are related to hypothetical situations. Stated preference methods are usually based on questions about willingness to pay (WTP) for particular benefit and willingness to accept (WTA) compensation if a benefit is taken away from them. In theory, WTP and WTA should give similar values for supply security. Previous studies, however, show that WTA tend to be higher than WTP. The reason is that consumers may feel that they have a right to good level of electricity supply and they are not willing to pay for it. Still, when the amount of compensation for cutting off the electricity is asked, they may value it more than electricity is really worth to them. (Champ et al. 2017; London Economics 2013)

In contingent valuation (CV) method, respondents are asked how much they are willing to pay for improved level of supply security or how much they would like to have compensation for reduced level of reliability. The questions can be open or close ended. Open ended questions ask for example how much a customer is willing to pay to avoid a power outage of a certain duration or what would be a sufficient compensation if that outage happened. Respondents can set a value without limits. Close ended questions also ask WTP and WTA, but they have certain alternatives to choose from. For example, they ask if a customer is willing to pay a specific price to avoid an outage with certain duration, or willing to accept a specific amount of money for such an outage. (Oakley Greenwood 2011, 7-8)

Contingent valuation surveys usually face one or more of the following biases. Information bias means that respondent has not enough information about the topic and is not able to give a proper answer. Hypothetical bias occurs if respondents answer hypothetical questions differently than they would really do. Starting point bias may occur if the answer must be given within a certain range or if some numbers are given as an example. Strategic bias occurs when respondents try to manipulate the results on purpose. They may assume that they can influence the politics and response accordingly. (Brown)

Another stated preference -method is choice experiment (CE), also known as conjoint analysis. A choice experiment method is also based on WTP and WTA questions. Respondents are given alternative scenarios and they are asked to choose, which one they prefer. Statistical techniques and econometric estimation are used to convert the results into VoLL. The CE method have some advantages over the CV approach. For example, it can reduce strategic bias. Also, the CE method does not have a “zero response” -problem, which occurs in CV method. (London Economics 2013. 3-4)

3.1.3 Revealed preference

In contrast to stated preference method, revealed preference method is based on observations, not hypothetical situations. Revealed preference method uses information about what consumers have actually done to avoid outages and what have been the cost. For example, the survey can focus on the price of back-up equipment that electricity users have purchased for power outages. An advantage of this method is, that it uses actual data, which is quite reliable. However, not all electricity users invest in back up equipment, and conducting a survey using revealed preference method would result in inaccurate estimates of VoLL for some electricity user sectors. Also, the cost-benefit ratio of using a back-up equipment may differ between different countries, because number of outages and their durations are different. Thus, comparison between different countries is difficult. (Deloitte Consulting, 2014)

3.1.4 Case studies

One method to estimate VoLL is case studies. It can be based on real power outages or a data of a simulation tool. (Reichl et al. 2012).

A rare opportunity to study real losses was provided in 2011: there was an explosion in Cyprus, which destroyed around 60 % of the national generating capacity. The VoLL was estimated with the help of real life data and production function approach. They also estimated, what would have been the economic losses without any measures (additional power production and demand response) and compared them with incurred additional costs. (Zachariadis and Poullikkas 2012)

3.2 Recent studies in other countries

This section introduces recent VoLL and WTP studies in other countries. These studies, as well as previous surveys in Finland, were used as a basis when the method of this study was chosen. These studies gave ideas when planning the questionnaires and helped to realize, what should be considered when analyzing the results.

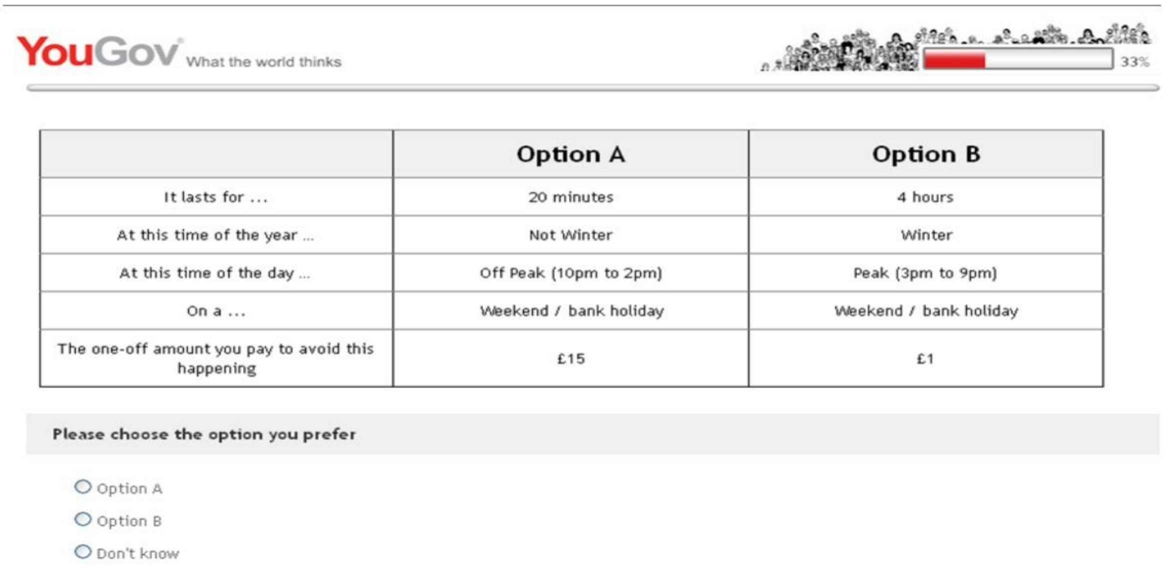
3.2.1 UK

The VoLL was estimated in UK in 2013. A stated preference choice experiment was used for households and small and medium sized enterprises (SME). Open-ended CV questions were also asked. For industrial and commercial (I&C) electricity consumers, production function approach was used. (London Economics 2013)

The household survey was conducted via online (n=1520) and face to face (n=150). Face to face interviews were conducted for “vulnerable” electricity users, which are pensioners, households with low income or respondents, who themselves have, or another member of their household has a long-term illness. Both online and face to face surveys, respondents had to be responsible for the electricity bills, and if they lived in a rental apartment, they had to pay the electricity bill separately. Respondents’ electricity consumption was estimated by asking what is their annual electricity bill, and bills were converted into consumption by dividing them by electricity price. (Ibid.)

The SME survey was conducted by telephone interviews, and it consisted of 550 interviews. The sample was representative of SMEs in the UK. SMEs have less than 250 employees. Electricity consumption was estimated not only by asking the amount of electricity bill, but also by asking where/how electricity is used. (Ibid.)

The choice experiment for domestic and SME users consisted of 12 choice cards with two alternatives at a time, and respondents were asked to choose the one they prefer. “Don’t know” -alternative was also included. Choice cards asked both willingness to pay and willingness to accept -questions. Figure 7 shows an example of a choice card asking WTP question. Based on the choices, numerical values for VoLL were calculated for different time periods (winter/not winter, peak/not peak and weekend/not weekend). The values were calculated separately for WTP and WTA.



	Option A	Option B
It lasts for ...	20 minutes	4 hours
At this time of the year ...	Not Winter	Winter
At this time of the day ...	Off Peak (10pm to 2pm)	Peak (3pm to 9pm)
On a ...	Weekend / bank holiday	Weekend / bank holiday
The one-off amount you pay to avoid this happening	£15	£1

Please choose the option you prefer

- Option A
- Option B
- Don't know

Figure 7. An example of a choice card used in domestic and SME surveys. (London Economics 2013, 8)

The results showed that in all time periods WTA was higher than WTP. For household customers, VoLL based on WTP ranged from £100/MWh to £2 800/MWh, and VoLL based on WTA ranged from £7 000/MWh to £11 800/MWh. For SMEs, VoLL (WTP) ranged from £19 300/MWh to £27 900/MWh and VoLL (WTA) from £33 400/MWh to £44 100/MWh. (Ibid.)

For household customers, CV method was also used as a sense check for the CE results. Both WTP and WTA questions were asked regarding a one-hour outage in the winter on weekday at a peak time. Table 2 shows the results of CV questions. An average WTP was £6,35 and WTA was £19,55. In WTP question, 62 % of responses were zero-responses and in WTA question the share was 15 %. (Ibid.)

Table 2. Results of CV questions. (London Economics 2013, 23-24)

	Average [£]	Median [£]	Max [£]	Min [£]	Std. Dev. [£]	Sample %
WTP						
Full sample	6,35	0	1000	0	48,93	100 %
Limited sample: Mean +/-2 std. dev.	3,61	0	100	0	9,85	100 %
Limited sample: Mean +/-1 std. Dev	3,04	0	50	0	6,82	99 %
Limited sample: Mean +/-0.5 std. dev	2,52	0	30	0	4,79	98 %
Excluding zero responses	16,74	5	1000	1	73,38	38 %
WTA						
Full sample	19,55	10	2000	0	100,49	1 %
Limited sample: Mean +/-2 std. dev.	12,91	10	201	0	20,66	99 %
Limited sample: Mean +/-1 std. Dev	11,84	10	100	0	15,39	99 %
Limited sample: Mean +/-0.5 std. dev	10,5	10	65	0	11,06	97 %
Excluding zero responses	23,13	10	2000	1	108,93	85 %

The VoLL for I&C electricity users was estimated by using gross value added (GVA) method. GVA method took into account each industrial sector's gross value added (£/yr) and electricity consumption (MWh/yr). The VoLL of these sectors was simply calculated by dividing GVA by electricity consumption. Overall VoLL for I&C was £1 654/MWh, and it was calculated by summing up all GVAs and dividing it by total electricity consumption. (Ibid.)

“Critical electricity consumption” method was also used to achieve more accurate results. The method considered the final purpose of electricity and separated the amount of electricity that is critical to the production process. Scenario 1 assumed that space heating, lighting and “other purposes” were non-critical use of electricity. Scenario 2 was like scenario 1, but 50 % of electricity consumed for motors was also non-critical. Scenario 1 indicated that GVA-method gave around 20 % too high VoLL estimates, and according to scenario 2, the number was around 35 %. (Ibid.)

Another method for adjusting VoLL for I&C was capacity utilization method. Usually firms are not producing at 100 % capacity, and can therefore increase production in the future if production is lost due to electricity outage. The theoretical maximum production capacity for each sector was estimated and compared to real production. The results showed that the VoLL was 91 % of the estimate of GVA-method. (Ibid.)

3.2.2 North Cyprus

In North Cyprus, households’ willingness to pay for improved reliability of electricity service was studied in 2008. Later, in 2014, it was estimated, how capacity could be increased if residents paid more on electricity. (Ozbafli & Jenkins 2015)

In 2014, electricity production capacity in North Cyprus was 376 MW. There are generation plants that are too old and unreliable. Electricity consumption has increased because of tourism and foreign students. Power cuts happen throughout the year. Air conditioners are used during the summer and electric heaters during the winter, which causes peak loads and increases the number of blackouts. (Ibid.)

The method was contingent valuation (CV) and the questionnaire included one WTP question. The question asked what would be the highest amount the respondent would pay per month to have a battery and an inverter system, which ensures that outages will never happen again. Respondents’ opinions about current electricity service were also asked. (Ibid.)

350 face-to-face interviews were conducted. 115 responses for WTP question were zero-responses. Because the amount of zero-responses was quite high, a “spike model” was used when results were analyzed. An average household was willing to pay around 13,5 % more on its monthly electricity bill to avoid outages. Compared to the duration of the outages, an average WTP per hour was around 1,03 USD in 2008 prices. (Ibid.)

The average WTP per household converted into 2014 value was around 21 USD per month, and the total annual payment of 150 000 households in North Cyprus would be 37,8 million USD. It was estimated, that North Cyprus would need nine 17,5 MW diesel generation plants to replace current two steam turbine plants. Total investment cost would be around 86,6 million USD. Households’ willingness to pay would be enough to cover the initial capital costs in just three years. Also, fuel savings would be 44,6 million USD annually if steam turbines were replaced with diesel generators and the whole power system was optimized. Consumers would benefit from increased reliability, and in a long run, electricity price would be lower. (Ibid.)

3.2.3 Sweden

In 2004, a WTP-survey was conducted in Sweden. In January 2005, there was a big storm in southeastern part of Sweden, which caused power outages in more than 660 000 households. After the storm, the same survey was conducted again to different sample of respondents to see how the storm has affected to people’s opinions. In the new survey the effect of “cheap talk” was also studied. (Carlsson & Martinsson 2006)

1680 respondents participated in the first survey in 2004. In 2005, 235 respondents participated in the survey without cheap talk script and 245 in the survey with cheap talk script. In all three surveys, the sample was representative of Swedish population in terms of gender, age and location. (Ibid.)

The study was conducted using an open-ended contingent valuation method. Respondents were asked how much they would be willing to pay to avoid a power outage, that happen at 6pm on a January evening. The same question was asked for both planned and unplanned outages lasting 1, 4, 8 and 24 hours. In addition, one scenario was unplanned outage that lasts 2-6 hours and can end at any time during this time period. (Ibid.)

Cheap talk was used to reduce hypothetical bias. Before the WTP question, there was a cheap talk -script. The script said that sometimes respondents want to give protest answers and people state their WTP lower or higher that they would actually be willing to pay. Respondents were also asked to write down if they had any thoughts on the subject. The reason to use the script was to make respondents answer honestly and to reduce zero-responses. (Ibid.)

Table 3 shows the results of the surveys. When the results between before and after the storm were compared, it could be seen that in all cases the average WTP had decreased whereas the number of zero-responses had increased. Cheap talk script seemed to have an effect, because in all cases the number of zero-responses was lower, and in most cases average WTP was higher, when results between surveys with and without cheap talks script were compared. (Ibid.)

Table 3. Average WTPs in SEK and share of zero-responses before and after the storm (Carlsson & Martinsson 2006).

	Before the storm		**After the storm**		**After the storm + cheap talk**	
	WTP [SEK]	Share WTP=0	WTP [SEK]	Share WTP=0	WTP [SEK]	Share WTP=0
Planned						
1 hour	6,3	90 %	3	93 %	10,2	88 %
4 hours	28,5	74 %	24,3	84 %	30,3	73 %
8 hours	84,4	51 %	82,1	57 %	71,6	49 %
24 hours	189,3	39 %	157,7	43 %	185,8	35 %
Unplanned						
1 hour	9,4	86 %	4,8	93 %	14,2	84 %
4 hours	37,3	68 %	30,6	79 %	46,6	68 %
8 hours	108,1	46 %	96,2	55 %	103,7	44 %
24 hours	223	36 %	188,9	41 %	237,3	31 %
Between 2 and 6 hours	68,8	59 %	64,8	68 %	68,6	58 %

3.2.4 European Union Member States

Households' VoLL was estimated in all EU Member States in 2017. This was the first time VoLL was estimated in all Member States using the same method, enabling comparison between the countries. The method was production-function approach, based on an estimate of leisure time value. The results were adjusted in terms of purchasing power parity (PPP). The lowest annual average VoLL was 3,20 €/kWh in Bulgaria and the highest was 15,80 €/kWh in the Netherlands. In Finland it was 4,46 €/kWh and in whole EU 8,7 €/kWh. (Shivakumar et al. 2017)

The method assumed that an hour of leisure is worth hourly wage for employed person, and for non-employed person it is worth half the hourly wage of those who are employed. Also, the fraction of leisure activities that are electricity-based was assumed to be 0,5 (substitutability factor). Personal care, such as sleeping, eating, washing and dressing, takes 11 hours per day. The leisure value (LV) of each Member State was calculated using equation 1. (Ibid.)

$$LV_{MS} = \big((hours\ per\ year - days\ per\ year\ \cdot hours\ on\ personal\ care\ per\ day - hours\ worked_{MS}) \cdot hourly\ wage_{MS}\big) \cdot substitutability\ factor \cdot (number\ of\ employed\ persons_{MS} + 0.5 \cdot number\ of\ unemployed\ persons_{MS}) \tag{1}$$

Where "MS" refers to Member State, "hours on personal care per day" is 11 hours, hourly wage is the average hourly wage of a Member State and substitutability factor is 0,5. LV is the total annual leisure value in each Member State. VoLL was calculated by dividing the total leisure value by total annual household sector electricity consumption. As an example, the values for Finland are shown in Table 4. The Voll in Finland would be 5,47 €/kWh without PPP adjusting. (Ibid.)

Table 4. Households' VoLL in Finland in 2013 based on production function approach (Shivakumar et al. 2017)

Hours worked	[h/a]	1918,8
Hourly wage	[€/h]	16
Unemployment	[%]	8,1
Population	[-]	5 426 674
Value of leisure	[million € / a]	117 332
Elelctricity consumption (households)	[GWh/a]	21 460
VoLL (PPP adjusted)	[€/kWh]	4,46

The above mentioned VoLL was an annual average. VoLL was also calculated for each hour of the year with equation 2.

$$VoLL_{MS,t} = \frac{LV_{MS}}{ELC_{MS}} * ELC_{MS,t} \quad (2)$$

Where $VoLL_{MS,t}$ VoLL in a Member State in hour t

ELC_{MS} Annual household sector electricity consumption of a Member State

$ELC_{MS,t}$ Hourly household sector electricity consumption of a Member State in hour t

Figure 8 shows the results for Finland. It can be seen, that time-varying VoLL behaves like electricity consumption in Finland: during summer months it is lower than during winter months and peaks occur in the mornings and evenings.

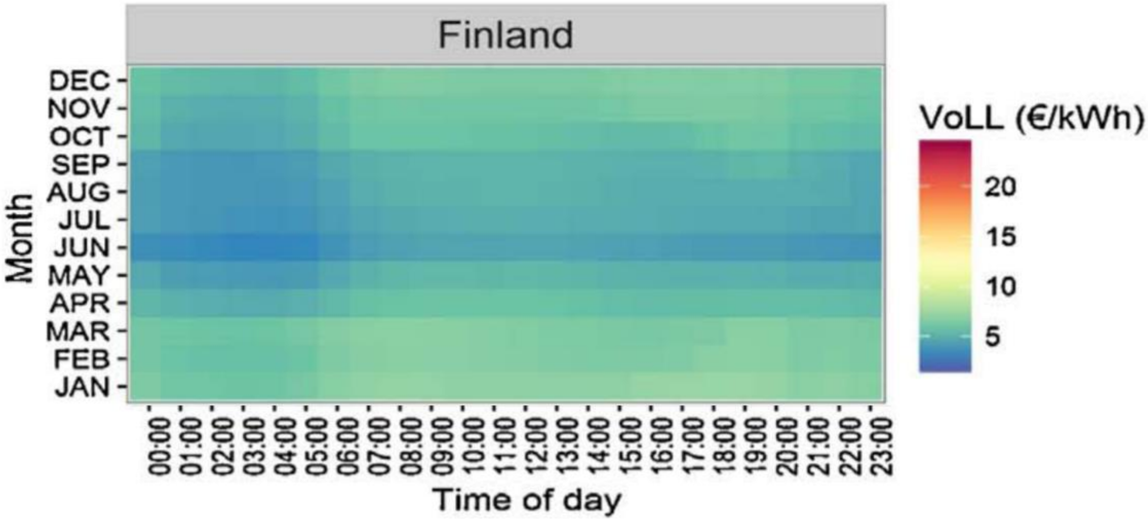


Figure 8. Time-varying VoLL in Finland. (Shivakumar et al. 2017)

4 SURVEY

In this thesis, a survey method was used to estimate VoLL for household- and leisure residence sectors. The objective was to find an efficient way to conduct a survey using high-standard statistical methods. A big question was, how to choose a sample, that represents Finnish population and the confidence level is scientifically accepted.

We ended up using online-panel and the data collection was conducted by YouGov Finland Oy. The sample consisted of 1010 respondents, and contingent valuation (CV) method was used. Surveys in general and different data collection methods are discussed in this chapter. This chapter also discusses how this survey was designed.

4.1 Surveys in general

4.1.1 Sampling

"Population" means the object to be studied, in this study the Finnish household electricity users. In some cases, it might be possible to collect data from every possible member of a population. Then it is called “census”. However, in most cases, data cannot be collected from the whole population and sampling is necessary. A sample is a part of the population, which represent the whole population. For example, if 70 % of respondents answer a question in a certain way, it can be assumed that 70 % of the whole population would answer accordingly. Figure 9 illustrates how the sample is selected from the population.

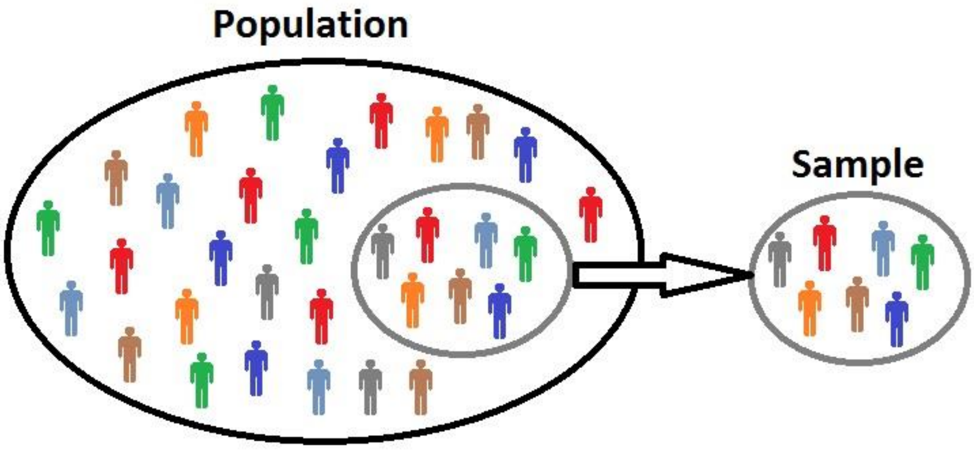


Figure 9. Population and sample

To get the most accurate results, representative sampling is needed. The sample is representative of the population, when it accurately reflects the distribution of the population. For example, if 52 % of the population is male, 52 % of the sample must be male to be representative in terms of gender. The representativeness can also occur in terms of age, location, wealth etc. If the population is industrial companies, and it is known that 10 % of industrial companies represent forest industry, a representative sample contains 10 % of forest industry companies.

A confidence level is a level of certainty that the results of the data collected will represent the total population. On the other hand, it is the probability of getting the same results if the survey is repeated. Usually researchers use 95 % confidence level. “Margin of error” is the accuracy for any estimate made from the sample. The larger the sample is, the smaller the margin of error is. Table 5 shows sample sizes at 95 % confidence level. It can be seen, that when population is small, sample size must be almost the size of the population to get accurate estimates. On the other hand, when the population is high enough, the sample size can be relatively small to be accurate. When population size grows from 1 000 000 to 10 000 000, there is hardly any difference between sample sizes. For example, for the population of Finland, at 95 % confidence level and 3 % margin of error, the sample size is around 1060. (Saunders et al. 2009, 218)

Table 5. Sample sizes at a 95 % confidence level (Saunders et al. 2009, 219)

	Margin of error			
Population	5 %	3 %	2 %	1 %
50	44	48	49	50
100	79	91	96	99
150	108	132	141	148
200	132	168	185	196
250	151	203	226	244
300	168	234	267	291
400	196	291	343	384
500	217	340	414	475
750	254	440	571	696
1000	278	516	706	906
2000	322	696	1091	1655
5000	357	879	1622	3288
10 000	370	964	1936	4899
100 000	383	1056	2354	8762
1 000 000	384	1056	2395	9513
10 000 000	384	1067	2400	9595

There are several sampling methods. Main categories are probability- and non-probability sampling. Probability sampling methods are based on randomly selected respondents. Each member of the population has a known probability of being included in the sample. Probability sampling is the only method where statistical inference can be applied on full scale. Non-probability sampling uses other methods than random selection. The sample can be chosen using respondents who are easiest to reach, or choosing certain number of respondents from certain groups, for example based on age, to make the sample more representative. Many non-probability sampling methods do not guarantee that the sample is representative of the population, or at least representativeness should be questioned. (Saunders et al. 2009; de Leeuw et al. 2008)

In practice, response rates tend to be relatively low, which means that there are always non-responses. The reason for non-responses may be that respondent refuses to respond or is unreachable. Sometimes the respondent may not be eligible to respond. In the case of electricity consumer survey, the respondent usually must be a person who pays his own electricity bill. Thus, a person whose electricity usage belongs to the rental agreement, is ineligible to respond. Careful planning of data collection can improve response rate. Some data collection methods will lead to better response rates than others. Also rewards, material or psychological, can raise the response rates. Psychological reward means that respondents feel that they are important for the study. (Saunders et al. 2009, 219; de Leeuw et al. 2008, 246)

4.1.2 Measurement error and biases

During the data collection process, there might occur measurement errors, which are also called error of observation. Measurement errors can be caused by the questionnaire, the respondent or the method of data collection. It is important, that the questionnaire is clear and all respondents can understand the questions in the same way. If a question is unclear, respondents may make errors while answering the question or do not know how to answer. The questionnaire should be pretested, because even a carefully designed questionnaire may contain errors. Respondents can also cause errors on purpose. For example, if a question is too sensitive, the respondent may not want to answer honestly. To minimize respondent errors, the questionnaire should be respondent-friendly and easy to answer. The third source of measurement error is the method of data collection. In face to face or telephone interview, there might be different ways how questions are asked, or the interviewer may even help the respondent to find correct answer. In telephone interview, respondent do not see the questions and they only have to rely on what they hear. Problems may occur especially in multiple-choice questions when there is a long list of alternatives to be chosen. (de Leeuw et al. 2007, 11)

People, who are invited to survey, but do not participate, can cause nonresponse error. Nonresponse error does not occur, if people refuse to participate randomly. But if people's choice to participate in the survey is based on their interest in the subject, nonresponse error occurs. People, who are not interested in the subject may refuse to answer and certain groups will be underrepresented. (de Leeuw et al. 2007, 10)

4.2 Planning the survey

In the beginning of the survey planning, several data collection methods were discussed. Because some of the questions were quite challenging, we wanted that respondents can see the questionnaires and use as much time as they need. Thus, phone interviews were excluded. We noticed, that it would be too difficult to collect representative data without any help and we decided to use the help of a survey company. We set a requirement, that 1000 responses must be collected and the data must be representative of Finnish population. We asked eight survey companies for offers. Four companies gave their offers and we chose the best one based on evaluation criteria.

The data was collected using an online panel. Online panels have many advantages compared to another data collection methods. Online panels consist of people who take part in surveys regularly and they usually get a reward after responding to enough questionnaires. Data can be collected quickly: the data collection usually takes from few days to few weeks. The method is often cheaper than other data collection methods. In this survey, we required 1000 responses from representative sample. YouGov promised representative sample in terms of age, gender and location. Location covered the whole Finland excluding Åland Islands. The invitation to the survey was send so that the respondent did not know the topic before opening the questionnaire. This prevented above mentioned non-response error. Respondents were not told, who conducted the survey.

We designed the questionnaires so that they contain only questions that are relevant. While designing each question, we planned how we are going to analyze the results of that question and whether the information is necessary or not. We wanted to keep the questionnaire simple. The main part of the questionnaire mostly contained questions where respondents needed to estimate monetary values. Because estimating can be time consuming for respondents, we did not want to burden them with too many questions. It was important that respondents kept the focus on the main questions, because they gave us the most important data we wanted to collect.

We decided to use contingent valuation method, and the main questions were WTP and WTA -questions. Another useful method could have been choice experiment, which is more respondent-friendly. However, designing the choice experiment would have required the knowledge we do not have. Since an average consumer cannot evaluate the direct monetary value for electricity not being supplied, we expected that WTP and WTA questions would be the best way to estimate the VoLL in the household sector.

The questionnaire was designed in Finnish, but it was also translated into Swedish. Swedish is the second official language in Finland, and around 5 % of Finland's population has Swedish as a mother tongue. However, in this sample the share of Swedish-speakers was less than 5 % because Åland islands were excluded from the sample.

4.2.1 The questionnaire

The questionnaire in Finnish is shown in Appendix 1. The first question of the questionnaire asked if respondent's household is responsible for its own electricity bill. If the answer was "no", for example if the electricity belongs to the monthly rent, the respondent could not continue with the questionnaire.

Because the respondents were part of the online panel and their background were known, there were no reason to ask same background questions again. Two background questions were still asked. Even though the location was roughly known, we decided to ask whether the respondent lived in zoned area or not. The term "zoned area" occurs in the Finnish Electricity Market Act and in some previous studies, so comparing this study to another studies would be easier when the same terminology is used. Another background question was whether the respondent owns a leisure residence. Only them who answered "yes", saw the questions about leisure residence. We assumed, that in a representative sample the percentage of leisure residence owners should also be representative.

Questions 3–8 were questions about household's electricity usage. The main purpose of these questions was to estimate respondent's annual electricity consumption. On the other hand, these questions were partly background questions as well. Type of accommodation, total living space, number of residents, heating source and electrical devices were asked. Question number 9 asked if respondent has small-scale electricity production. Question number 10 asked directly respondent's annual electricity consumption and question number 11 asked the amount he/she pays for electricity. Both question 10 and 11 were open questions and they included "don't know" choices. The idea was to ask electricity consumption in three ways in order to get at least one estimate of annual electricity consumption.

The main section of the questionnaire contained questions 12–16. In the beginning of this section it was shortly explained, what "electricity shortage" means. The reason for the explanation was to lead the respondent to the topic and indirectly explain that blackouts in this survey are not due to a local network company. A reputation of a network company could affect the answers, which we wanted to exclude. Questions 12 and 13 asked what would be the longest electricity cut-off that can be accepted in case of power shortage with and without prior notification. Question number 14 asked if household had acquired back-up power in case of any kind of blackouts. Question number 15 was willingness to pay (WTP) -question and question number 16 was willingness to accept (WTA) -question.

The last part of household-questionnaire was about partial limitation of electricity usage. It consisted of one question (17) about demand response. In the beginning of this section there was a short explanation about partial limitation of electricity usage.

After the household questionnaire, there were six questions for those who owned a leisure residence. Questions 18–21 were about electricity usage, question number 22 was WTP and 23 was WTA-question. The leisure residence -questionnaire did not have a section for demand response, because we assumed that leisure residences do not have that much potential for demand response, and on the other hand, we wanted to keep the questionnaire as short as possible.

5 RESULTS

The sample was representative in terms of gender, age and region and the sample size was 1010. The confidence level was 95 % and the margin of error was 2,8 % according to Yougov. The sample consisted only of respondents whose households managed their own electricity contracts. Thus, respondents whose electricity belonged to rental agreement were excluded. All the respondents were at least 18 years old.

5.1 Background

Table 6 shows the most essential background data. “Gender” “Major region” and “Urbanization” are based on Yougov’s own background data and other parts of Table 6 are based on our own questions. Urbanization may not give exactly correct distribution, because the original question has been a multiple-choice question and the respondent has had to choose one. The problem, in our opinion, is that people who live in countryside, still belong to a municipality, and they have had to choose either a municipality or countryside. Thus, the number of respondents living in the countryside might be more than 8 %. In our own question about zoned and non-zoned areas, 13 % have responded that they live outside zoned areas. Probably the number of respondents living in the countryside is thus between 8 % and 13 %.

In the sample, the share of people living in detached house is too low compared to the real situation in Finland and the share of people living in apartments is too high. 50 % of Finnish population were living in detached houses, 36 % in apartments and 13 % in attached houses in 2016 (Statistics Finland 2017). On the other hand, the sample consisted of 18-year old and older respondents, and children living in detached houses makes the real share bigger than in this sample.

Table 6. Background information.

Sample size	1010	
Gender		
Men	494	49 %
Women	516	51 %
Major region		
Helsinki-Uusimaa	303	30 %
Southern Finland	196	19 %
Western Finland	272	27 %
Northern and Eastern Finland	239	24 %
Urbanization		
Helsinki Metropolitan Area	250	25 %
City of more than 100 000 residents outside Helsinki Metropolitan Area	251	25 %
City of 50 000 - 100 000 residents	146	14 %
City of 10 000 - 50 000 residents	194	19 %
Municipality of less than 10 000 residents	85	8 %
Countryside	84	8 %
Zoned area		
Inside zoned area	863	85 %
Outside zoned are	130	13 %
Don't know	17	2 %
Type of building		
Detached house	310	31 %
Apartment house	498	49 %
Row-house or semi-detached house	193	19 %
Else	7	1 %
Don't know	2	0 %
Primary heating		
District heating	592	59 %
Direct electric heating	184	18 %
Storage electric heating	25	2 %
Oil heating	64	6 %
Heat pump (e.g. geothermal heat pump)	60	6 %
Wood heating	54	5 %
Else	12	1 %
Don't know	19	2 %
Other background information		
Electric-car owners	9	1 %
Own electricity production	18	2 %
Leisure residence owners	285	28 %
Respondents who responded in Swedish	16	2 %

The last part of Table 6 is other background information. Nine respondents said that they own an electric-car. However, it is unclear whether these respondents have understood the question correctly or responded honestly. At least in one case there is a doubt that the person does not really own an electric car. 18 respondents said that they have own electricity production. Again, it is very uncertain that the information is correct, because seven of them responded that they live in apartment house. The question was most likely misunderstood. The number of respondents who responded in Swedish was 16, which is only 2 % of all respondents. However, according to open feedback, they appreciated that they could use their own mother tongue.

Question 12 asked what would be the longest electricity cut off in power shortage situation that a respondent would accept, if a prior notification was given 1–2 hours before the cut off. Question 13 was the same question but without a prior notification.

Table ***7*** shows the results of questions 12 and 13. Figure 10 and Figure 11 show results of these questions separately for respondents living in zoned and non-zoned areas. A prior notification seemed to have an effect. 29 % of respondents said that they are not ready to electricity cut off at all without a prior notification, but with a prior notification, the percentage was only 12 %. “2 hours” got the most responses in the case of power cut with a prior notification. There were not significant differences between responses of people living in zoned area and people living outside zoned area, albeit outside zoned area the importance of prior notification seemed to be clearer.

Question 14 asked whether the household has acquired back-up power in case of power cut. 6 % of respondents answered “yes”, 92 % “no” and 2 % “don’t know”. 45 % of those who answered “yes”, lived outside zoned-area. 22 % of all of them who lived outside zoned area had acquired back-up power.

Table 7. The results of the question 12 and 13.

Electricity cut off with prior notification (1-2h) *The longest acceptable electricity cut off in power shortage situation*		
Not at all	122	12 %
15 minutes	114	11 %
1 hour	223	22 %
2 hours	251	25 %
6 hours	126	12 %
12 hours	42	4 %
24 hours	31	3 %
36 hours	2	0 %
48 hours	14	1 %
More than 48 hours	12	1 %
Don't know	73	7 %
Electricity cut off without notification *The longest acceptable electricity cut off in power shortage situation*		
Not at all	292	29 %
15 minutes	200	20 %
1 hour	192	19 %
2 hours	144	14 %
6 hours	68	7 %
12 hours	25	2 %
24 hours	11	1 %
36 hours	2	0 %
48 hours	9	1 %
More than 48 hours	3	0 %
Don't know	64	6 %

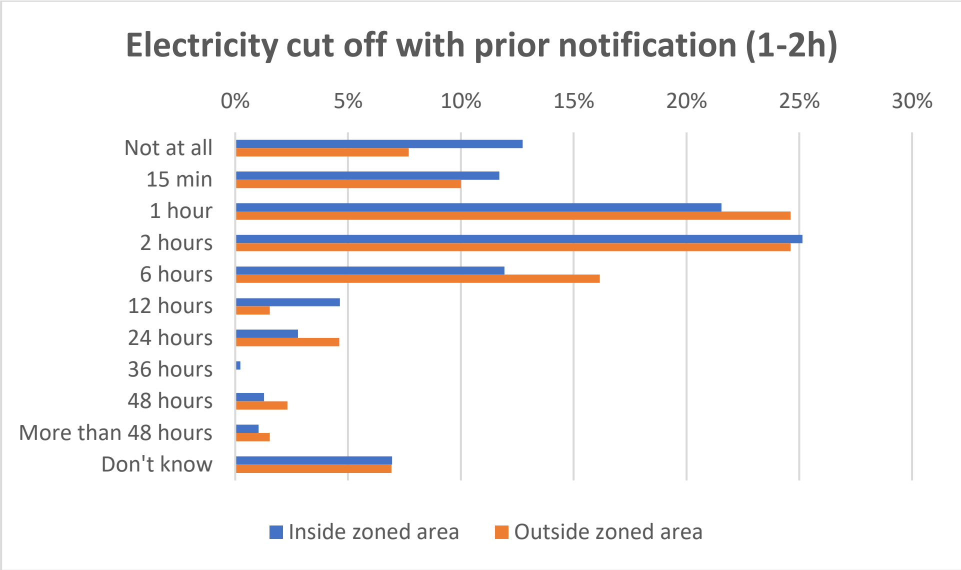


Figure 10. Results of question 12 divided into zoned and non-zoned area

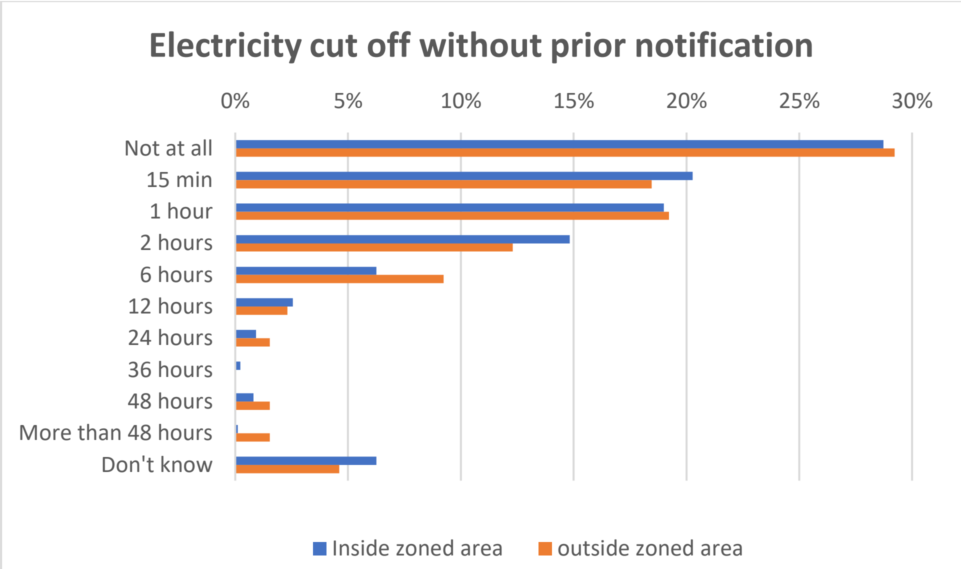


Figure 11. Results of question 13 divided into zoned and non-zoned area

5.2 Analysis of the data

5.2.1 Households

The results of WTP and WTA questions are shown in Table 8. It is worth noting, that 41 %–46 % of these questions got “don’t know” -response. On one hand, it tells that that it is difficult to answer such questions, but on the other hand the reason for quite high “don’t know” -percentage may be in the data collection method. Probably some respondents have hurried up with the questionnaire and just ignored the difficult questions. The average response-time in this survey was six minutes. “Zero-responses” and “1000-responses” -columns show how many of respondents stated their WTP or WTA 0 € or 1000 €, which were the limits. The percentage is calculated from all those respondents who gave an answer. “Mean” and “Median” -columns show the mean and the median of the results without any processing. Observations on the results of household-questionnaire is shown in Appendix 2.

Table 8. Results of household WTP and WTA questions (n=1010).

	Don't know -respones	%	Zero-responses	% of accepted responses	1000-responses	% of accepted responses	Mean [€]	Median [€]
WTP								
15 min	450	45 %	448	80 %	0	0 %	5,02	0
1h	452	45 %	391	70 %	0	0 %	6,12	0
2h	455	45 %	336	61 %	0	0 %	10,32	0
4h	467	46 %	268	49 %	0	0 %	19,07	1
WTA								
15 min	428	42 %	323	55 %	13	2 %	37,63	0
1h	418	41 %	223	38 %	18	3 %	63,42	10
2h	415	41 %	135	23 %	22	4 %	93,45	20
4h	418	41 %	73	12 %	28	5 %	154,61	50

A zero-response can mean that the power cut is not long enough to put any monetary value on it. Part of the zero-WTP:s are for sure “protest responses”, which means that the respondents feel that they have a right to good security of supply without paying anything. Zero-response could also mean that the respondent is not ready to participate in such “security of supply -market”. 1000 € was the upper limit in WTP and WTA questions. The reason for putting the upper limit was to prevent respondents to give pointless values, and Yougov asked us to put a limit so that they don't need to reject any response. However, the upper limit seemed to cause "starting point bias". Probably those who responded 1000 €, would have responded 2000 € if the upper limit had been 2000 €. However, it is not 100 % clear that all those answers were protest-answers. Table 9 shows means and medians of the WTP and WTA results without zero- and 1000- responses.

Table 9. Results of household WTP and WTA questions without zero- and 1000-responses.

	Mean without zero-responses [€]	Median without zero-responses [€]	Mean without 1000-responses [€]	Median without 1000-responses [€]
WTP				
15 min	25,10	10	5,02	0
1h	20,45	10	6,12	0
2h	26,14	10	10,32	0
4h	37,65	20	19,07	1
WTA				
15 min	84,85	10	15,64	0
1h	101,89	20	34,05	10
2h	120,92	50	58,64	20
4h	175,74	80	112,64	50

VoLL was calculated to each household separately. To calculate VoLL, an estimate of electricity consumption was needed. Electricity consumption and the annual price of electricity were asked directly. 33 % of the respondents gave an answer to electricity consumption -question and 45 % to electricity price -question. Some respondents who answered both questions, had significant difference between their usage and what they pay for electricity, which means that they were not able to give a good estimate of their electricity consumption. The results of these questions were only used as a benchmark when following method was used.

The estimate of annual electricity consumption was made partly according to the survey, and partly assuming that every household had some basic electricity usage. Calculation parameters are shown in Table 10 and in Table 11. The need for electric heating was estimated to be 100 kWh/m^2, partly based on an example where 120 m^2 detached house consumes around 10 000 kWh per year (Adato Energia 2011, 42). We assumed that heat pumps have coefficient of performance (COP) of 3. Thus, if heat pump is a primary heating source, it needs one third of electricity compared to electric heating. Secondary heating source reduces electricity consumption, unless air source heat pump is used in a household without electric heating, when electricity consumption increases. The effect of secondary heating was just an estimate, because it is impossible to say how much secondary heating is used. In this study, we estimated that fireplace reduces the need of electric heating 30 %. Air source heat pump also reduces it 30 %, but it also needs electricity according to COP 3, why the effect is smaller. If secondary heating source was “else”, the reduction was assumed to be 10 kWh/m^2. In the survey it was asked if household had appliances listed in **Virhe. Viitteen lähdettä ei löytynyt.**. Electricity consumption of these appliances were based on average values in Finland (Helen 2013; Vattenfall). Electricity use for lighting was calculated according to an example where 120 m^2 house consumes 1000 kWh annually for lighting (Sähkönkulutus.fi).

Table 10. Calculation parameters of annual electricity consumption for heating. (Adato Energia 2011; Vattenfall)

Primary heating	**Annual electricity consumption**	
Electric heating	100	kWh/m^2
*Heat pump (COP 3)	33,3	kWh/m^2
Oil burner	350	kWh
Domestic hot water	1000	kWh/person
Secondary heating		
*Air source heat pump[1]	10	kWh/m^2
*Air Source heat pump[2]	-20	kWh/m^2
*Fireplace	-30	kWh/m^2
*Else	-10	kWh/m^2

[1] In a household without electric heating
[2] In a household with electric heating
* Based on our own estimation

Table 11. Calculation parameters of annual electricity consumption for appliances (Helen 2013; Vattenfall; Sähkönkulutus.fi)

Electricity consumption according to the survey	**Annual consumption**	
Dishwasher	273	kWh
Fridge-freezer	456,5	kWh
Fridge + chest freezer	567	kWh
Electric stove (1-2 residents)	182	kWh
Electric stove (3+ residents)	365	kWh
Electric sauna	832	kWh
Underfloor heating (6m2)	2520	kWh
Ventilation (dwelling < 70 m2)	1080	kWh
Ventilation (dwelling > 70 m2)	1800	kWh
Washing machine	299	kWh
Clothes dryer	962	kWh
Other electricity consumption		
Lighting	8,3	kWh/m2
Car heater (detached houses)	300	kWh
Other devices	1209	kWh
Personal consumption	100	kWh/person

After calculating annual electricity consumption, hourly electricity consumption during a weekday evening in January was calculated. The hourly consumption was based on load curves that are used in “Government Decree on Determination of Electricity supply and Metering (66/2009)” (Finlex 2009). Hourly consumption was calculated using equation 3. Coefficient C_{LC} is the hourly electricity consumption based on load curves, and in this survey, hour 18–19 was used. For households whose annual electricity consumption were less than 10 000 kWh, coefficient C_{LC} was 2,524 kWh, and for households whose annual consumption were more than 10 000 kWh, it was 1,873 kWh.

$$E_h = \frac{E_a}{10\ 000\ kWh} * \ C_{LC} \tag{3}$$

Where,

E_h	Hourly electricity consumption (kWh)
E_a	Annual electricity consumption (kWh)

C_{LC}	Hourly consumption based on load curve (kWh)

VoLL for power cuts of different lengths was calculated using equation 4.

$$VoLL_l = \frac{WTP\ or\ WTA}{E_h * l} \tag{4}$$

Where,

$VoLL_l$	VoLL for power cut of length l (€/kWh)
E_h	Hourly electricity consumption (kWh/h)
l	Length of a power cut (h)

Table 12 shows means and medians for VoLL. Means and medians were also calculated without zero-VoLLs and without 1000-WTAs.

Table 12. Household VoLL based on WTP and WTA

	Mean [€/kWh]	Median [€/kWh]	Mean (VoLL>0) [€/kWh]	Median (VoLL>0) [€/kWh]	Mean (WTA<1000) [€/kWh]	Median (WTA<1000) [€/kWh]
VoLL - WTP						
15 min	14,3	0	71,6	22,7		
1h	4,6	0	15,3	7,0		
2h	3,8	0	9,6	4,4		
4h	3,5	0,1	7,0	2,8		
VoLL - WTA						
15 min	104,9	0	235,8	36,5	36,7	0,00
1h	42,5	5,5	68,2	16,4	22,3	4,9
2h	30,8	7,8	39,8	13,3	19,1	7,3
4h	25,7	9,5	29,3	12,1	18,2	8,5

The last question for households was about the compensation that respondent would like to have if power use was limited three times a year not more than two hours at a time. The limitation would apply electric heating, chest freezer, ventilation and electric car. The distribution of responses of demand response -question is shown in Figure 12 and other results and analysis of the question shown in Table 13.

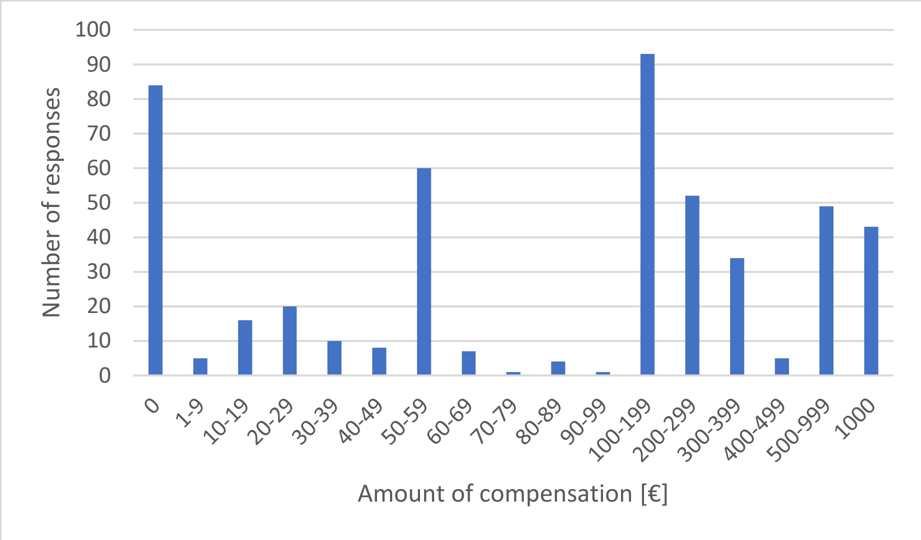


Figure 12. Distribution of responses of demand response -question excluding "don't know" responses.

51 % of respondents answered "don't know" to this question, indicating that the question was difficult, but on the other hand, not all of them had flexible load. Average compensation was 216 €, including also compensations from respondents who do not have any of above-mentioned flexible load. Focusing on respondents who have flexible load, the average compensation was 224 €, and dividing each compensation by each flexible load, the average was 1130 €/kW/year. We noticed that some households have only very little flexibility which makes the average €/kW quite high. For that reason, we reviewed only households with electricity-based heating which decreased the average compensation to 130 €/kW/year. In addition, assuming that zero or 1000-response means that the respondent is not interested in capacity-controlling, we calculated the mean for "interested" households with electric heating. The effect of electric cars was also removed. According to this assumption, 22 % of all respondents who responded to that question would belong to that group, and the average compensation among them would be 90 €/kW/year.

Above-mentioned flexible load was calculated with parameters shown in Table 14. The parameters are our own estimates of what typical power could be. The estimations are based on information from Table 10 and Table 11.

Table 13. Results and analysis of demand response -question.

All households	1010	
"Don't know" -responses	518	51 %
Accepted responses	492	49 %
of which zero-responses	84	17 %
of which 1000-responses	43	9 %
Mean [€/year]	216	
Households with flexibility	360	*73 %
of which zero-responses	60	17 %
of which 1000-responses	32	9 %
Mean [€/year]	224	
Mean [€/kW/year]	1130	
Households with electric heating	144	*29 %
of which zero-responses	19	13 %
of which 1000-responses	15	10 %
Mean [€/year]	265	
Mean [€/kW/year]	130	
"Interested" households with electric heating	110	*22 %
Mean [€/year]	210	
Mean [€/kW/year]	90	
* % of accepted responses (n=492)		

Table 14. Calculation parameters of flexible load

Electric heating	0,03	kW/m2
Heat pump	0,01	kW/m2
Chest freezer	0,1	kW
Ventilation	0,1	kW
Electric car	80	kW

It is strange, that in all cases shown in Table 13, the average compensation that electricity users would like to have was bigger than average compensation for 4-hour electricity cut off, which was 155 € (see Table 8.). That was more than we expected, and the reason might be that respondents did not understand the question, or the whole concept was too unfamiliar for them. We reviewed those 55 households with electric heating, who responded more than

0 € but less than 155 €. The average compensation among them was 68 € and compensation per kW was 30 €/kW/year.

5.2.2 Leisure residences

The survey included 285 leisure residence owners. However, 53 of leisure residences were not electrified or consumption could not be determined. These 53 leisure residences were left out of the study. There are many types of leisure residences and leisure residence owners in Finland. Some owners use their leisure residence only in the summer, others only in the winter. Some leisure residences have the same characteristics than a modern detached house and they can be used throughout the year. If a leisure residence has a water supply, the electric heating is usually kept on all winter to prevent water pipes from freezing, even if it is used only randomly. Thus, electricity consumption in different kind of leisure residences differs a lot and it is hard to estimate single leisure residence's consumption using the general method and the average VoLL may be distorted.

Table 15 shows the results of WTP and WTA questions. The share of "don't know" -responses was 42 % - 45 %. Percentage of zero-responses was higher than in household surveys in each question. One respondent answered "1000 €" to each question.

Table 15. Results of leisure residence WTP and WTA questions (n=232)

	Don't know -responses	%	Zero-responses	% of accepted responses	1000-responses	% of accepted responses	Mean [€]	Median [€]
WTP								
15 min	99	43 %	108	81 %	1	1 %	11,5	0
1h	98	42 %	103	77 %	1	1 %	17,2	0
2h	99	43 %	96	72 %	1	1 %	24,0	0
4h	98	42 %	83	62 %	1	1 %	41,1	0
WTA								
15 min	103	44 %	87	67 %	2	2 %	35,2	0
1h	104	45 %	75	59 %	3	2 %	54,9	0
2h	102	44 %	58	45 %	4	3 %	76,4	5
4h	100	43 %	45	34 %	5	4 %	110,7	20

Table 17 shows the results of WTP and WTA -questions without zero- and 1000-responses.

Table 16. Results of WTP and WTA questions without zero- and 1000-responses.

	Mean without zero-responses [€]	Median without zero-responses [€]	Mean without 1000-responses [€]	Median without 1000-responses [€]
WTP				
15 min	61,3	10	4,0	0
1h	74,4	20	9,8	0
2h	86,3	30	16,6	0
4h	107,9	40	33,8	0
WTA				
15 min	108,2	17,5	20,0	0
1h	132,7	25	32,3	0
2h	137,9	50	47,1	5
4h	168,0	50	75,7	20

Electricity consumption for leisure residence was calculated with parameters shown in Table 17. The parameters are based on our own estimation of what annual consumption in a Finnish leisure residence would be, if it was used throughout the year. “Consumption coefficient” is dependent on utilization of leisure residence.

Table 17. Calculation parameters of leisure residence’s electricity consumption.

	Annual consumption [kWh]	**Usage of leisure residence**	**Consumption coefficient**
Electric heating	9 000	Use throughout the year	1
Air source heat pump*	3000	Use only in the summer	0,4
Air Source heat pump**	-2000	Use only in the winter	0,6
Water heater	1000	Use mainly in the summer, but randomly in autumn, winter and spring	0,5
Water pump	100		
Electric sauna	400		
Dishwasher	100	Don't know	0,5
Washing machine	150		
Clothes dryer	450		
Electric stove	200		
Electric oven	90		
Other consumption	1000		
*In a leisure residence without electric heating *In a leisure residence with electric heating			

Hourly electricity consumption in January weekday evening at 18–19 was calculated with equation 3. Coefficient C_{LC} was 1,168 kWh, which comes from load curve for "group 3" (Finlex 2009). Table 18 shows means and medians of leisure residence -VoLL.

Table 18. Leisure residence VoLL based on WTP and WTA.

	Mean [€/kWh]	Median [€/kWh]	Mean (VoLL>0) [€/kWh]	Median (VoLL>0) [€/kWh]	Mean (WTP or WTA<1000) [€/kWh]	Median (WTP or WTA<1000) [€/kWh]
VoLL - WTP						
15 min	125,3	0	666,4	98,9	79,9	0
1h	54,0	0	233,3	39,8	42,9	0
2h	42,4	0	152,5	22,0	37,0	0
4h	38,4	0	100,9	18,2	35,8	0
VoLL - WTA						
15 min	339,5	0	1042,8	178,1	274,0	0
1h	147,8	0	356,9	75,2	121,8	0
2h	112,7	3,4	203,5	40,9	73,8	2,4
4h	96,6	9,5	146,6	36,6	75,6	8,2

5.3 Final results and discussion

This survey studied values that cannot be directly measured. It is impossible to say what is exactly the VoLL or what is a fair compensation if electricity consumption is limited. In this section, we will give our own estimates of VoLL and discuss about the demand response potential and its price. It is worth noting, that all electricity consumptions in this study are based on our own estimates and can differ from real consumption. If the study was repeated with actual consumption data, the results would be more accurate.

5.3.1 VoLL

We assumed that all the 1000 €-WTA-responses were either protest-responses or responses without any deepening into the question. 1000 € is more than many people pay for electricity per year and we assumed that no one would really need that much compensation for a short power cut. That's why we estimated the VoLL without 1000-WTA-responses. VoLL based on WTP may be too low, because people tend to underestimate the value of electricity when WTP is asked. On the other hand, people tend to overestimate the value when WTA is asked. Thus, we used WTP-based VoLL as a lower limit and WTA-based VoLL as an upper limit of final VoLL estimation. The limits were average values of VoLLs based on 1h, 2h and 4h power cuts. VoLL based on 15 minutes power cut were excluded from the average, because relatively low electricity consumption makes the VoLL quite high. Upper and lower limits of VoLL for households and leisure residences are shown in Table 19.

Table 19. Upper and lower limits of VoLL

	Lower limit [€/MWh]	Upper Limit [€/MWh]
Households	3900	19800
Leisure residences	38600	90300

Our own estimation is, that VoLL is between those limits. The range is however quite large. European Commission's definition of VoLL is: "Value of lost load means an estimation in €/MWh, of the maximum electricity price that customers are willing to pay to avoid an outage" (European Commission 2016b). Based on the definition, we can assume that the "real" VoLL is closer to lower limit than upper limit.

Leisure residences seem to have considerably higher VoLL than households. Probably the reason is that we underestimated leisure residences' electricity consumptions. It can also be a sign, that people appreciate good security of supply especially during holidays. On the other hand, VoLL has been calculated among all leisure residence electricity users, also them who don't use leisure residence in the winter. For those who use leisure residence throughout the year or only in the winter, VoLL was 65 000–67 000 €/MWh.

According to study based on production function approach, VoLL was 5470 €/MWh in Finland without PPP adjusting (Shivakumar et al. 2017). Cost of electricity distribution interruptions was estimated to be around 3000–7000 €/MWh for households and 2000–17 000 €/MWh for leisure residences in 2004 in Finland (Silvast et al. 2005). Table 20 shows the comparison between this study and those previous studies in Finland. There is also a household-VoLL estimate from UK, based on WTP and WTA, regarding winter weekday peak hour, in Table 20.

Table 20. Household-VoLL of this study compared to other studies in Finland and UK.

Finland – Households	**VoLL [€/MWh]**
This study 2018	3900 - 19 800
Silvast et al. 2005	3000 - 7000
Shivakumar et al. 2017 (Without PPP adjusting)	5470
UK - Households*	**VoLL [£/MWh]**
London Economics 2013	210 - 10 300
*winter, weekday, peak hour	

For further comparison, Figure 13 shows previous VoLL-estimates for private customers from different countries.

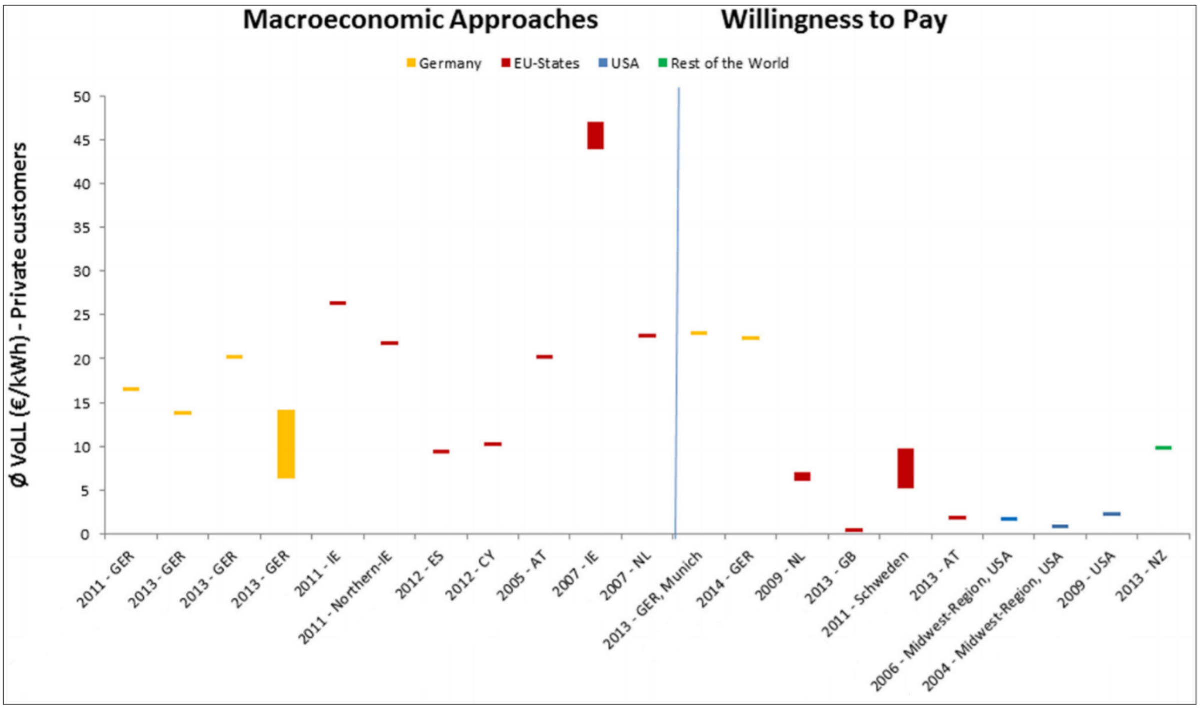


Figure 13. Previous VoLL-estimates for private customers from different countries.

5.3.2 Demand response

The purpose of the "demand response" question was to find out what is the compensation electricity users would like to have if electricity consumption is limited. We studied how demand response suits the maintenance of power balance in a power shortage situation. Roughly half of the respondents did not give any answer, which indicates that the idea of demand response is still strange. In a survey conducted in Finland in 2016, only around 10 % of the respondents said that they have heard the term "demand response" before (Ruokamo et al. 2017).

Some of those who responded to the demand response -question did not have flexible load at all. Some respondents with only a little flexibility gave values that are unreasonably large compared to their flexibility. We ended up studying only households with electric heating, which are basically the most potential source of household-level flexibility. Assuming that those who responded "0€" or "1000€", are not willing to take part in demand response, the average annual compensation per kilowatt was 90 €/kW. However, the value was more than we expected, and we believe that respondents did not understand the question or the concept of demand response was too unfamiliar for them.

For comparison: the strategic reserve system in Finland has 729 MW of capacity and the annual fixed cost is around 13,8 million euros (Energy Authority 2017). Thus, the annual fixed cost per kilowatt is around 19 €/kW, which is much cheaper than 90 €/kW, that households with electric heating can provide. Strategic reserve system has also variable costs and the total cost depends on how much the system is needed. However, the use of the capacity has been very rare and minimal. The conclusion is, that using demand response as a "reserve capacity" only is not the most cost-effective solution in the current situation. However, it can provide extra balancing capacity in case of serious power shortage.

6 VOLL FOR INDUSTRY

Simple estimates of VoLL for different industrial sectors were conducted using production function approach, based on data from the year 2016. VoLL was calculated by dividing gross value added (GVA) by electricity consumption. It is worth noting, that the value is the opposite of electricity intensity. Industrial sectors, that have high electricity consumption seem to have low VoLL, and vice versa. Table 21 shows annual electricity consumption, GVA and VoLL for each industrial sector separately. Figure 14 shows a summary of VoLLs. VoLL for the whole industrial sector was 824 €/MWh and it was calculated by dividing the sum of all GVAs by the sum of all electricity consumptions shown in Table 21.

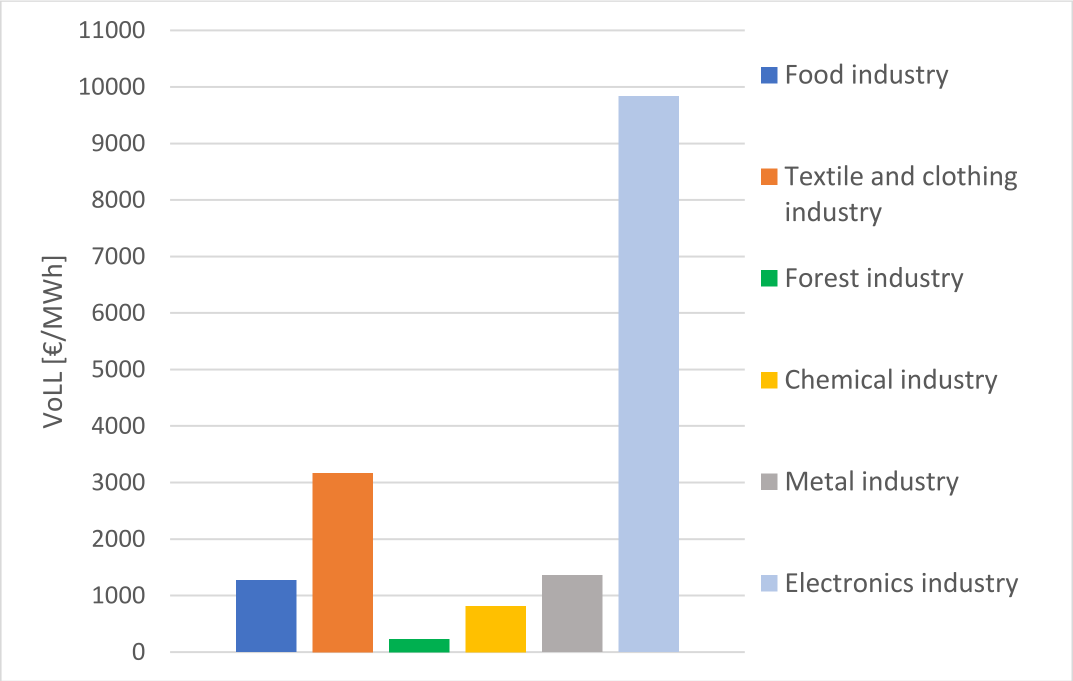


Figure 14. VoLL for industrial sectors calculated by using production function approach

This method is a way to find a relation between industrial production and electricity consumption. However, the VoLL is not necessarily the same that industrial sectors would itself set. Conducting a large survey among industrial sector would indicate how the sectors really value the electricity supply.

Table 21. Electricity consumption, gross value added and VoLL for different industrial sectors in 2016 (Statistics Finland's PX-Web databases)

	E [GWh]	GVA [million €]	VoLL [€/MWh]
07 Mining of metal ores	1114	294	264
08–09 Other mining and quarrying and mining support service activities	257	371	1444
10 Manufacture of food products	1776	2231	1256
11 Manufacture of beverages	267	337	1262
12 Manufacture of tobacco products	0	0	0
13 Manufacture of textiles	80	212	2650
14 Manufacture of wearing apparel	26	112	4308
15 Manufacture of leather and related products	17	69	4059
16 Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	1481	1170	790
17 Manufacture of paper and paper products	17212	3123	181
18 Printing and reproduction of recorded media	460	467	1015
19 Manufacture of coke and refined petroleum products	1132	801	708
20 Manufacture of chemicals and chemical products	4437	2042	460
21 Manufacture of basic pharmaceutical products and pharmaceutical preparations	89	1481	16640
22 Manufacture of rubber and plastic products	910	1039	1142
23 Manufacture of other non-metallic mineral products	703	1083	1541
24 Manufacture of basic metals	6181	1434	232
25 Manufacture of fabricated metal products, except machinery and equipment	788	2608	3310
26 Manufacture of computer, electronic and optical products	253	3776	14925
27 Manufacture of electrical equipment	311	1772	5698
28 Manufacture of machinery and equipment n.e.c.	683	4615	6757
29 Manufacture of motor vehicles, trailers and semi-trailers	151	498	3298
30 Manufacture of other transport equipment	178	479	2691
31 Manufacture of furniture	93	324	3484
32 Other manufacturing	95	278	2926
33 Repair and installation of machinery and equipment	120	1375	11458

7 CONCLUSION

The objective of this thesis was to find a way to estimate value of lost load (VoLL) in Finland. For households and leisure residences, contingent valuation customer survey was used. The sample of the survey (n=1010) was representative of Finnish population in terms of age, gender and location. Among respondents, there were 285 leisure residence owners who responded to leisure residence survey. For industry, simple estimation of VoLL was conducted using production function approach.

Households and leisure residences were asked their willingness to pay (WTP) to avoid power outages of different lengths and willingness to accept (WTA) compensation if these outages happened. The VoLL was calculated by dividing WTP or WTA by estimated electricity consumption in January weekday at 6 pm. For households, average VoLL based on WTP ranged from 3500 €/MWh to 14 300 €/MWh depending on the length of an outage, and average VoLL based on WTA ranged from 25 700 €/MWh to 104 900 €/MWh. For leisure residences, average VoLL based on WTP ranged from 38 400 €/MWh to 125 300 €/MWh and average VoLL based on WTA ranged from 96 600 €/MWh to 339 500 €/MWh.

To make our own estimates of VoLL, we removed all WTPs and WTAs which were 1000 € (the upper limit of rating scale) and calculated average VoLLs for power outages of 1 hour, 2 hours and 4 hours. We used WTP-based average VoLL as a lower limit and WTA-based average VoLL as an upper limit of final VoLL estimate. We assumed that the “real” VoLL is between those limits, being however closer to lower than upper limit. The lower limit of household-VoLL was 3900 €/MWh and the upper limit was 19 800 €/MWh. The lower limit of leisure residence -VoLL was 38 600 €/MWh and the upper limit was 90 300 €/MWh.

This study estimated also households’ willingness to participate in demand response. Respondents were asked how much compensation they would like to have if their electricity consumption was limited three times a year not more than two hours at a time. The average annual compensation among households, which had electric heating and which were assumed to be willing to participate in demand response, was 90 €/kW. Table 22 shows the most important results of this study.

Table 22 The most important results.

VoLL - Households	3900–19 800	€/MWh
VoLL - Leisure residences	38 600–90 300	€/MWh
Demand response - Annual compensation (Households with electric heating)	90	€/kW

VoLL for different industrial sectors was calculated by dividing annual gross value added by annual electricity consumption. The data was from the year 2016. The VoLL for the whole industrial sector was around 800 €/MWh. Forest industry had the lowest VoLL, around 200 €/MWh and electronics industry had the highest, around 9800 €/MWh. It is worth noting, that VoLL based on this method is inversely proportional to electricity intensity. The method does not take into account the possibility, that production can be postponed to cover the lost production.

We think that our estimate of household-VoLL is good, although the range is quite large. Studies for other electricity user sectors in Finland are needed to make a single estimate of VoLL for all electricity users.

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APPENDIX 1. THE QUESTIONNAIRE IN FINNISH

In YouGov's online panel, respondents saw one question at a time. Each scenario was shown separately in questions 15, 16, 22 and 23.

Päätetäänkö kotitaloudessasi itsenäisesti sähkösopimuksiin liittyvistä asioista?

- ◯ Kyllä
- ◯ Ei, joku muu päättää kotimme sähkösopimuksista (esim. vuokranantaja)

1. **Asutko**
   - ◯ Asemakaava-alueella? (kaupunkialue, asutuskeskus tai tiheään asuttu alue)
   - ◯ Asemakaava-alueen ulkopuolella? (maaseutu tai harvaan asuttu alue)
   - ◯ En osaa sanoa

2. **Omistatko/Omistatteko vapaa-ajan asunnon?**
   - ◯ kyllä
   - ◯ en

3. **Asumismuotosi?**
   - ◯ Omakotitalo
   - ◯ Kerrostalo
   - ◯ Rivitalo/Paritalo
   - ◯ Luhtitalo
   - ◯ Joku Muu
   - ◯ En osaa sanoa

4. **Mikä on asuntosi asuinpinta-ala?**
   - ◯ Alle 30 m^2
   - ◯ 30 – 60 m^2
   - ◯ 60 – 90 m^2
   - ◯ 90 – 120 m^2
   - ◯ 120 – 150 m^2
   - ◯ yli 150 m^2
   - ◯ En osaa sanoa

5. **Kuinka monta henkilöä kotitaloudessasi asuu?**
   - ◯ 1
   - ◯ 2
   - ◯ 3
   - ◯ 4
   - ◯ 5 tai enemmän

6. **Mikä on kotitaloutesi ensisijainen lämmitysmuoto**
   - ◯ Kaukolämpö (kerrostalot pääsääntöisesti kaukolämmön piirissä)
   - ◯ Suora sähkölämmitys
   - ◯ Varaava sähkölämmitys
   - ◯ Öljylämmitys
   - ◯ Lämpöpumppu (esim. maalämpö)
   - ◯ Puulämmitys
   - ◯ Muu
   - ◯ En osaa sanoa

7. **Onko asunnossasi ensisijaisen lämmitysmuodon lisäksi toinen lämmitysmuoto?**
   - ☐ Takka
   - ☐ Ilmalämpöpumppu
   - ☐ Muu
   - ☐ Ei toissijaista lämmitysmuotoa
   - ☐ En osaa sanoa

8. **Mitä seuraavista sähkölaitteista kotitaloudessasi on?**
   - ☐ Sähkökiuas
   - ☐ Lämminvesivaraaja
   - ☐ Koneellinen ilmanvaihto
   - ☐ Sähköinen lattialämmitys (esim. kylpyhuoneessa)
   - ☐ Astianpesukone
   - ☐ Pyykinpesukone
   - ☐ Kuivausrumpu
   - ☐ Arkkupakastin
   - ☐ Sähköauto
   - ☐ Ei mitään edellä mainituista

9. **Onko kotitaloudessasi sähkön pientuotantoa (esim. aurinkopaneelit)?**
   - ◯ kyllä
   - ◯ ei
   - ◯ en osaa sanoa

10. **Mikä on kotitaloutesi sähkönkulutus vuodessa? Syöttäkää vastaus kokonaislukuna välillä 0 – 100 000 kWh.**
    - ◯ ___________kWh/vuosi
    - ◯ En osaa sanoa

11. **Paljonko maksatte sähköstä vuodessa kokonaisuudessaan (energia + siirto + verot)? Syötä vastaus kokonaislukuna välillä 0 – 10 000 €.**
    - ◯ ___________€
    - ◯ En osaa sanoa

Jos sähkön tuotantoa ei ole saatavilla yhtä paljon kuin sähköä kulutetaan, voi seurauksena olla pahimmillaan sähköpula. Tällöin osalta sähkönkäyttäjistä voidaan katkaista sähköt tai rajoittaa sähkön käyttöä.

12. **Kuinka pitkän yhtämittaisen sähköjen katkaisemisen olisit enimmillään valmis sähköpulatilanteessa hyväksymään, jos saisitte siitä ennakkoilmoituksen 1-2 tuntia ennen katkaisua?**
    - ◯ En lainkaan
    - ◯ 15 min
    - ◯ 1 tunti
    - ◯ 2 tuntia
    - ◯ 6 tuntia
    - ◯ 12 tuntia
    - ◯ 24 tuntia
    - ◯ 36 tuntia
    - ◯ 48 tuntia
    - ◯ Enemmän kuin 48 tuntia
    - ◯ En osaa sanoa

13. **Kuinka pitkän yhtämittaisen sähköjen katkaisemisen olisit enimmillään valmis sähköpulatilanteessa hyväksymään ilman ennakkoilmoitusta?**
    - ◯ En lainkaan
    - ◯ 15 min
    - ◯ 1 tunti
    - ◯ 2 tuntia
    - ◯ 6 tuntia
    - ◯ 12 tuntia
    - ◯ 24 tuntia
    - ◯ 36 tuntia

◯ 48 tuntia
◯ Enemmän kuin 48 tuntia
◯ En osaa sanoa

14. Oletko/oletteko hankkineet varavoimaa (esim. aggregaatti) sähkökatkojen tai sähköpulatilanteen varalle?

◯ Kyllä
◯ En
◯ En osaa sanoa

Tulevaisuudessa voi olla mahdollista, että sähköpulan uhatessa sähkönkäyttäjä voi turvata oman sähkön saannin maksamalla sähköstä enemmän. Vaihtoehtona on se, että sähkön saantia rajoitetaan lyhyeksi ajaksi.

15. Kuinka paljon lisää olisit valmis maksamaan sähköstä välttääksesi sähköjen katkaisun (1 kpl/vuosi), joka osuu kylmälle tammikuiselle arki-illalle? Syöttäkää vastaus kokonaislukuina välillä 0 – 1000 €.

Välttääksesi 15 minuutin sähköjen katkaisun _______€/vuosi

◯ En osaa sanoa

Välttääksesi 1 tunnin sähköjen katkaisun_______€/vuosi

◯ En osaa sanoa

Välttääksesi 2 tunnin sähköjen katkaisun_______€/vuosi

◯ En osaa sanoa

Välttääksesi 4 tunnin sähköjen katkaisun_______€/vuosi

◯ En osaa sanoa

16. **Millaisen rahallisen korvauksen haluaisit, mikäli kylmälle tammikuiselle arki-illalle osuvia sähköjen katkaisuja tulisi jatkossa 1 kpl/vuosi? Syötä vastaus kokonaislukuina välillä 0 – 1000 €.**

Sähköt katkaistaisiin 15 minuutiksi_______€/vuosi

◯ En osaa sanoa

Sähköt katkaistaisiin 1 tunniksi_______€/vuosi

◯ En osaa sanoa

Sähköt katkaistaisiin 2 tunniksi_______€/vuosi

◯ En osaa sanoa

Sähköt katkaistaisiin 4 tunniksi_______€/vuosi

◯ En osaa sanoa

Sähkönkäyttöä voidaan rajoittaa myös osittain, esimerkiksi rajoittamalla tietyn laitteen käyttöä.

17. **Sähkönkäyttöäsi rajoitettaisiin niiden laitteiden osalta, joiden hetkellisellä rajoittamisella olisi vain minimaalinen vaikutus asuinmukavuuteen. Näitä laitteita ovat sähkölämmitys, pakastin, koneellinen ilmanvaihto ja sähköauton lataus. Kuinka paljon haluaisit korvausta, mikäli kaikkien näiden laitteiden käyttöä rajoitettaisiin samanaikaisesti kolme kertaa vuodessa enimmillään kahden tunnin ajan? Syötä vastaus kokonaislukuina välillä 0 – 1000 €.**

◯ ____________________ €/vuosi

◯ En osaa sanoa

Seuraavat kysymykset koskevat vapaa-ajan asuntoa.

18. **Kuinka paljon on vapaa-ajan asuntosi vuotuinen sähkönkulutus? Syötä vastaus kokonaislukuna välillä 0 – 100 000 kWh.**

◯ ____________________ kWh/vuosi

◯ En osaa sanoa

19. Paljonko maksat/maksatte vapaa-ajan asuntonne sähköstä vuodessa (energia + siirto + verot)? Syöttäkää vastaus kokonaislukuina välillä 0 – 10 000 €.

◯ ____________________€/vuosi
◯ En osaa sanoa

20. Mitä sähkölaitteita vapaa-ajan asunnollasi on?

- ☐ Sähkölämmitys
- ☐ Ilmalämpöpumppu
- ☐ Lämminvesivaraaja
- ☐ Vesipumppu
- ☐ Sähkökiuas
- ☐ Astianpesukone
- ☐ Pyykinpesukone
- ☐ Kuivausrumpu
- ☐ Sähköliesi
- ☐ Sähköuuni
- ☐ Ei mitään edellä mainituista

21. Kuinka suurella käyttöasteella vapaa-ajan asuntosi on?

◯ Ympärivuotinen käyttö
◯ Käyttö vain kesällä
◯ Käyttö vain talvella
◯ Käyttö pääasiassa kesällä, mutta lisäksi satunnaisesti syksyllä, talvella ja keväällä
◯ En osaa sanoa

22. Kuinka paljon lisää olisitte valmis maksamaan vapaa-ajan asuntosisähköstä välttääksesi sähköjen katkaisun (1 kpl/vuosi), joka osuu kylmälle tammikuiselle arki-illalle. Syötä vastaus kokonaislukuina välillä 0 – 1000 €.

Välttääksesi 15 minuutin sähköjen katkaisun_______€/vuosi

◯ En osaa sanoa

Välttääksesi 1 tunnin sähköjen katkaisun_______€/vuosi

◯ En osaa sanoa

Välttääksesi 2 tunnin sähköjen katkaisun_______€/vuosi

◯ En osaa sanoa

Välttääksesi 4 tunnin sähköjen katkaisun_______€/vuosi

◯ En osaa sanoa

23. Millaisen rahallisen korvauksen haluaisit, mikäli kylmälle tammikuiselle arki-illalle osuvia sähköjen katkaisuja tulisi jatkossa 1 kpl/vuosi? Syötä vastaus kokonaislukuina välillä 0 – 1000 €.

Sähköt katkaistaisiin 15 minuutiksi_______€/vuosi

◯ En osaa sanoa

Sähköt katkaistaisiin 1 tunniksi_______€/vuosi

◯ En osaa sanoa

Sähköt katkaistaisiin 2 tunniksi_______€/vuosi

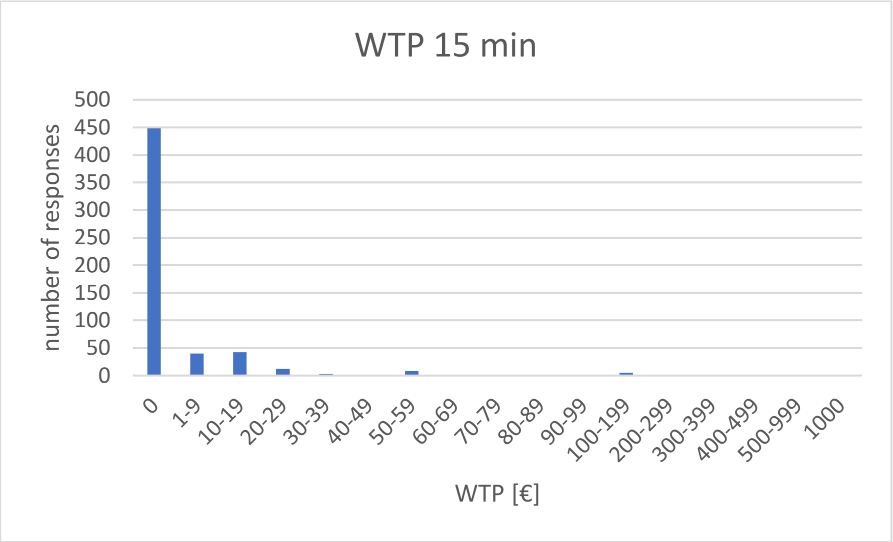
◯ En osaa sanoa

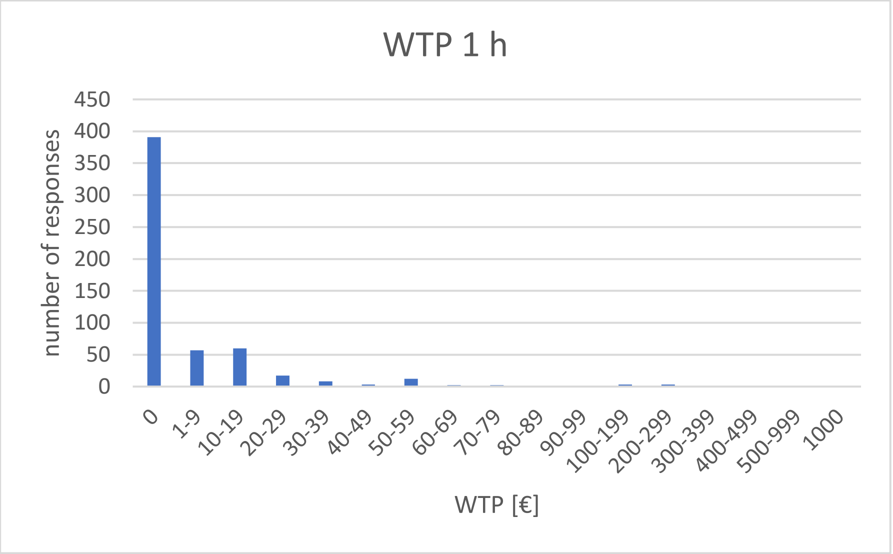
Sähköt katkaistaisiin 4 tunniksi_______€/vuosi

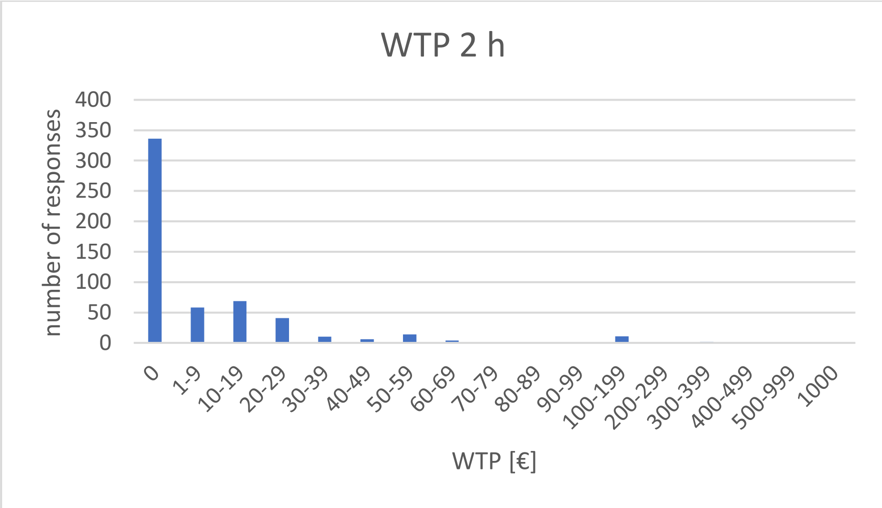
◯ En osaa sanoa

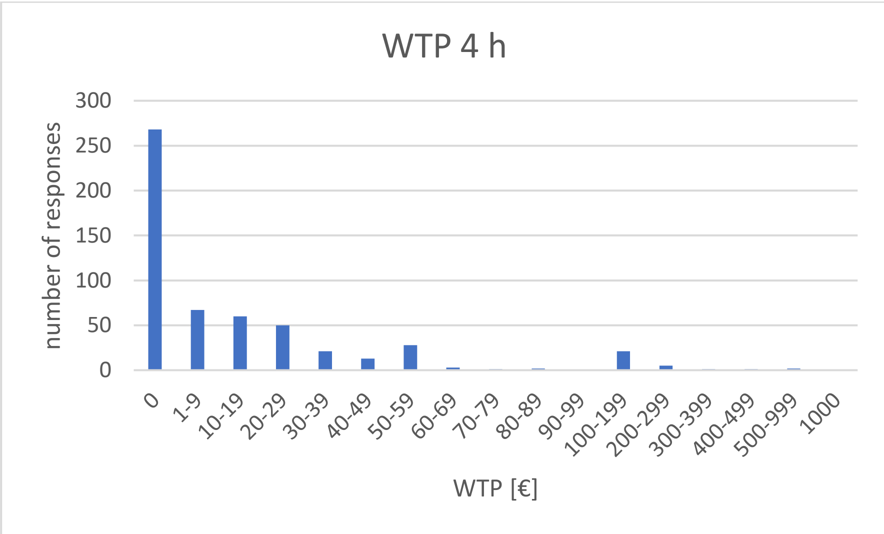
APPENDIX 2. OBSERVATIONS ON THE RESULTS OF THE HOUSEHOLD SURVEY

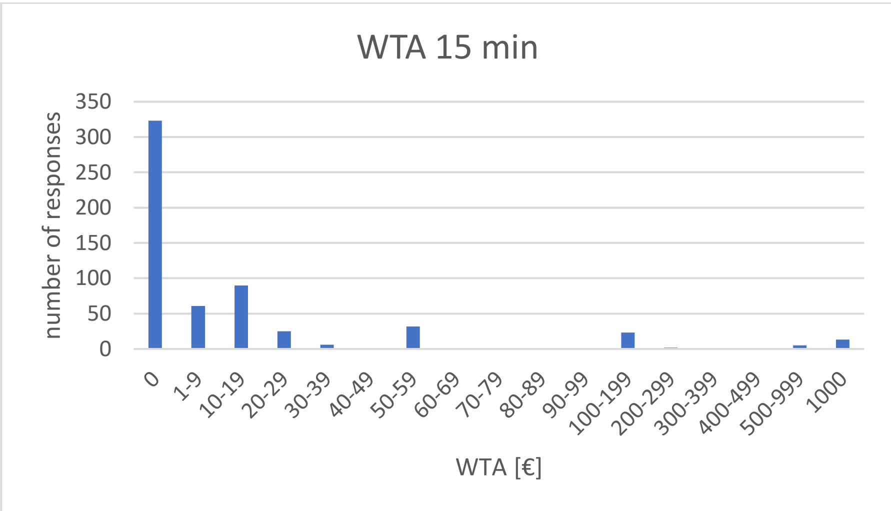
Distribution of responses in WTP and WTA -questions

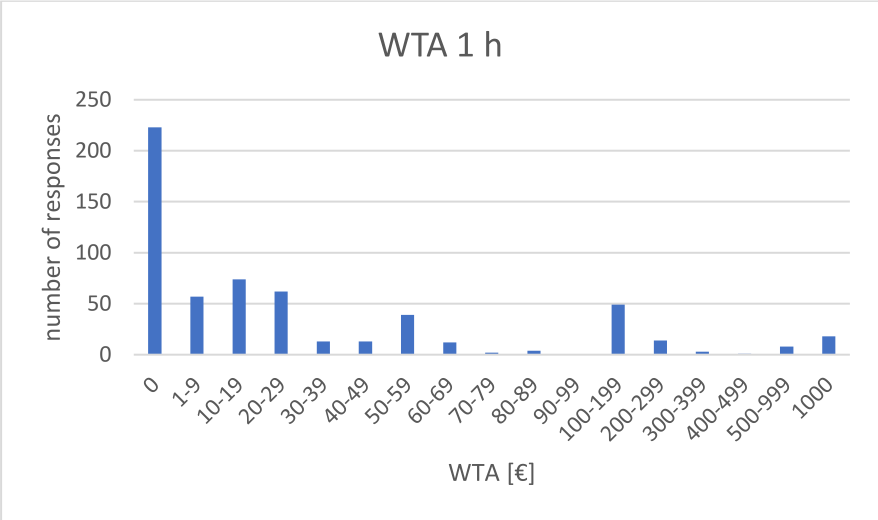




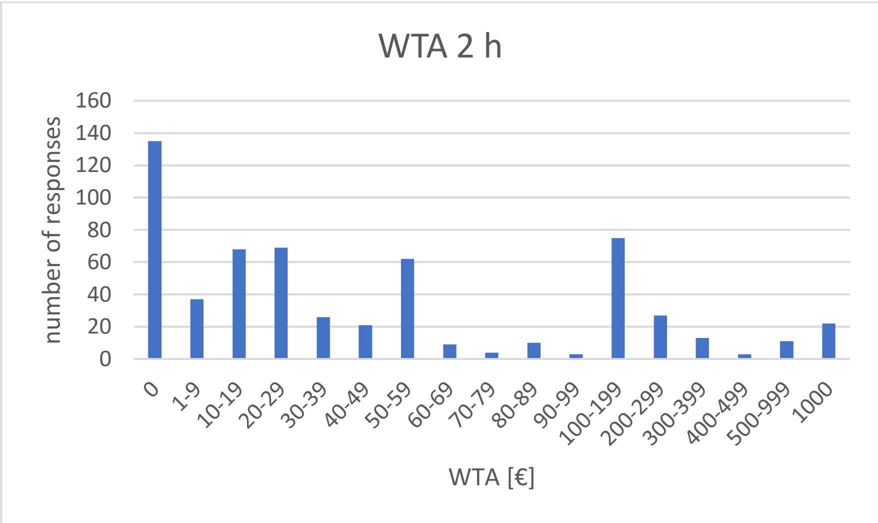

WTP 2 h
number of responses
400
350
300
250
200
150
100
50
0
0
1-9
10-19
20-29
30-39
40-49
50-59
60-69
70-79
80-89
90-99
100-199
200-299
300-399
400-499
500-999
1000
WTP [€]


WTP 4 h
number of responses
300
250
200
150
100
50
0
0
1-9
10-19
20-29
30-39
40-49
50-59
60-69
70-79
80-89
90-99
100-199
200-299
300-399
400-499
500-999
1000
WTP [€]

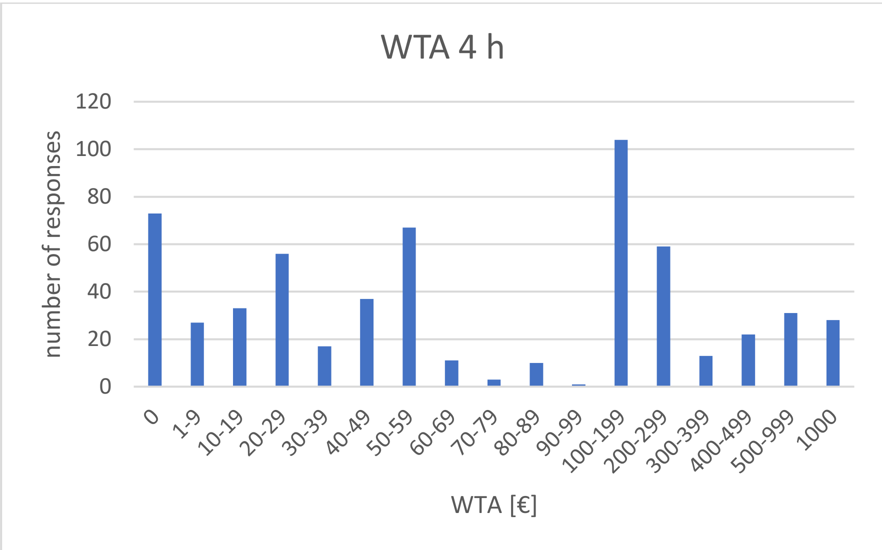

WTA 15 min
number of responses
350
300
250
200
150
100
50
0
0
1-9
10-19
20-29
30-39
40-49
50-59
60-69
70-79
80-89
90-99
100-199
200-299
300-399
400-499
500-999
1000
WTA [€]



WTA 1 h
number of responses
250
200
150
100
50
0
0
1-9
10-19
20-29
30-39
40-49
50-59
60-69
70-79
80-89
90-99
100-199
200-299
300-399
400-499
500-999
1000
WTA [€]



WTA 2 h
number of responses
160
140
120
100
80
60
40
20
0
0
1-9
10-19
20-29
30-39
40-49
50-59
60-69
70-79
80-89
90-99
100-199
200-299
300-399
400-499
500-999
1000
WTA [€]



WTA 4 h
number of responses
120
100
80
60
40
20
0
0
1-9
10-19
20-29
30-39
40-49
50-59
60-69
70-79
80-89
90-99
100-199
200-299
300-399
400-499
500-999
1000
WTA [€]

Percentages of "don't know" responses among different age-groups in household WTP and WTA questions:

Age group	WTP 15 min	WTP 1h	WTP 2h	WTP 4h	WTA 15 min	WTA 1h	WTA 2h	WTA 4h
18-19	63 %	63 %	63 %	63 %	53 %	53 %	53 %	58 %
20-29	46 %	46 %	47 %	48 %	47 %	47 %	47 %	45 %
30-39	37 %	37 %	39 %	39 %	36 %	35 %	35 %	35 %
40-49	40 %	40 %	41 %	41 %	38 %	36 %	37 %	38 %
50-59	46 %	44 %	43 %	45 %	43 %	42 %	38 %	40 %
60-69	47 %	48 %	48 %	49 %	44 %	44 %	43 %	42 %
70-79	55 %	56 %	57 %	60 %	49 %	45 %	51 %	50 %
80-89	40 %	40 %	60 %	60 %	60 %	60 %	60 %	60 %

Average values of household WTP and WTA responses among different age groups (€):

Age-group	WTP 15 min	WTP 1h	WTP 2h	WTP 4h	WTA 15 min	WTA 1h	WTA 2h	WTA 4h
18-19	2,9	5,0	7,9	17,1	130,0	141,7	161,1	221,3
20-29	5,5	10,8	18,0	34,3	25,9	42,3	64,9	117,8
30-39	2,5	4,9	8,0	13,8	35,8	53,7	88,5	158,6
40-49	1,8	4,1	7,7	16,7	59,7	105,6	133,8	189,4
50-59	2,8	5,2	9,5	15,6	40,8	67,2	101,2	166,4
60-69	8,2	5,7	9,7	17,3	26,0	51,7	80,6	142,4
70-79	16,9	10,7	15,2	31,5	17,6	32,4	58,0	112,3
80-89	3,3	10,0	10,0	20,0	0,0	25,0	50,0	150,0

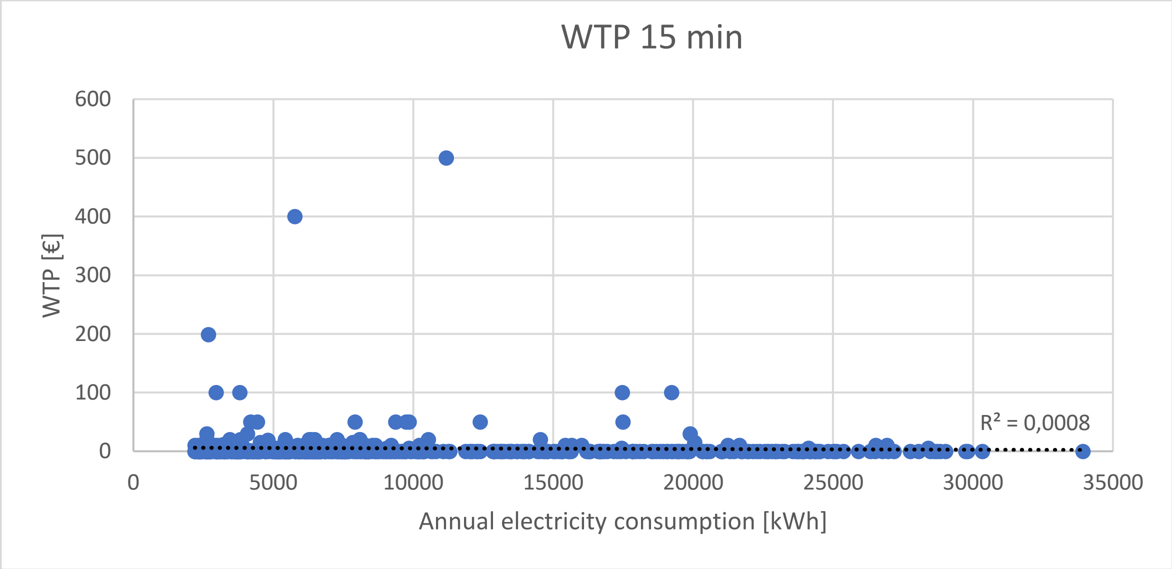
Average values of household WTP and WTA responses in different major regions (€):

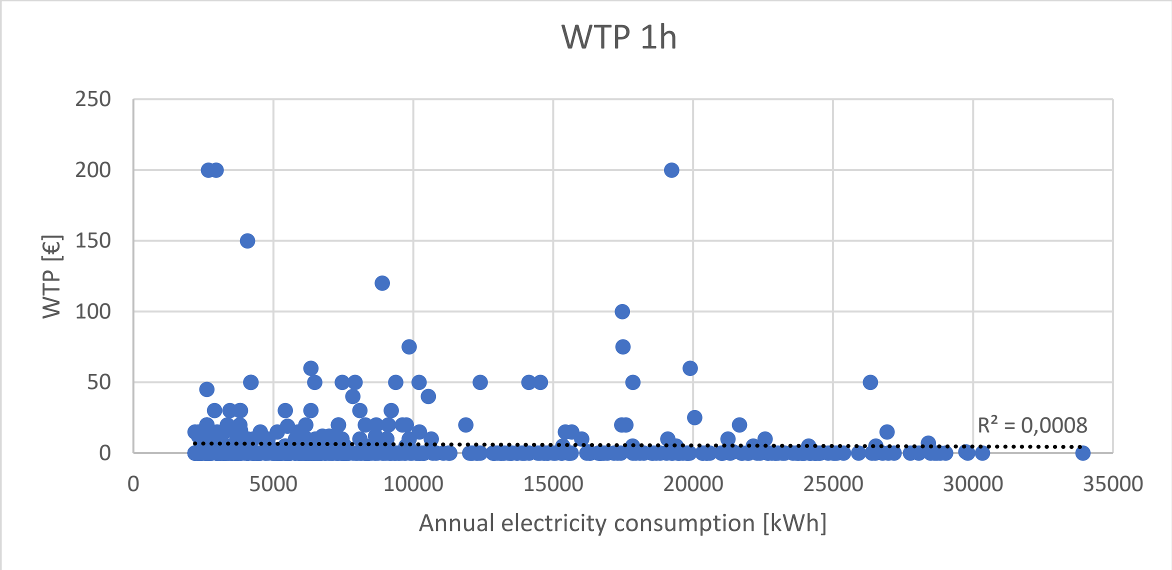
Major region	WTP 15 min	WTP 1h	WTP 2h	WTP 4h	WTA 15 min	WTA 1h	WTA 2h	WTA 4h
Helsinki - Uusimaa	2,1	4,1	7,0	13,9	35,9	59,1	91,3	163,4
Southern Finland	4,8	9,3	14,8	23,6	32,5	57,0	96,0	173,4
Western Finland	7,6	8,1	13,3	26,1	48,4	84,8	110,4	154,3
Northern and Eastern Finland	5,8	3,4	6,6	13,1	31,2	48,1	72,7	125,2

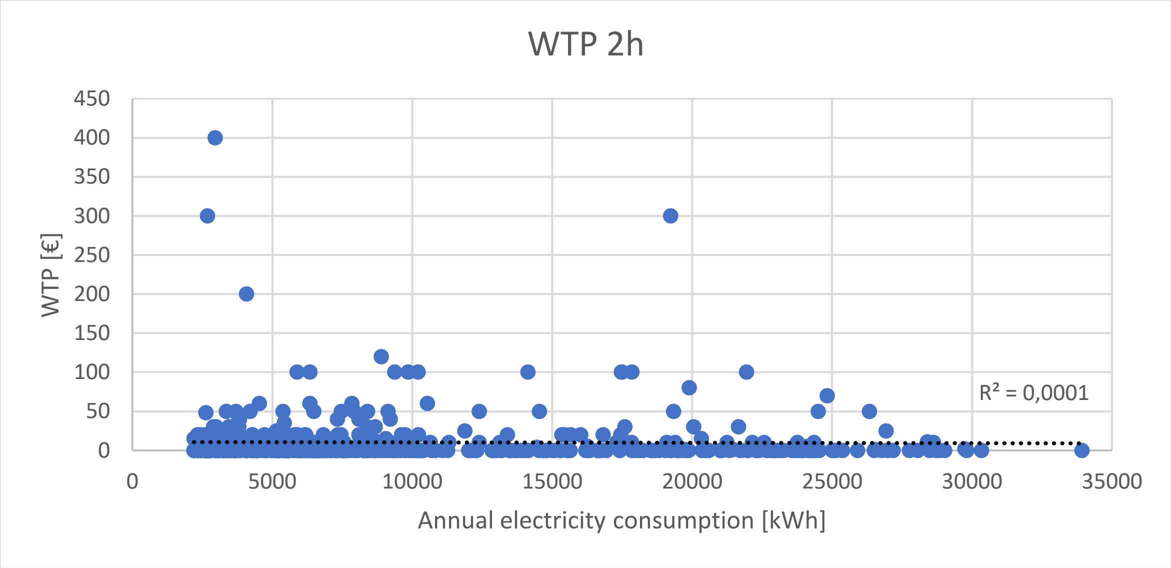
Average values of household WTP and WTA responses inside and outside zoned areas (€):

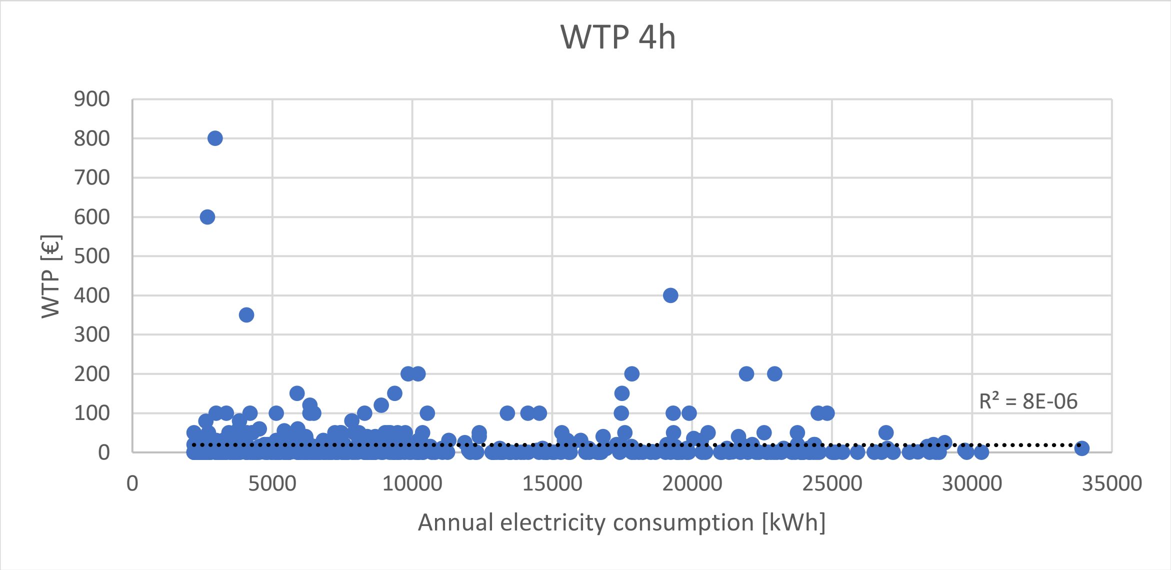
	WTP 15 min	WTP 1h	WTP 2h	WTP 4h	WTA 15 min	WTA 1h	WTA 2h	WTA 4h
Inside zoned area	3,5	5,9	10,1	19,0	38,1	61,1	87,9	142,5
Outside zoned area	2,2	6,9	11,5	19,2	54,4	79,5	113,5	162,1

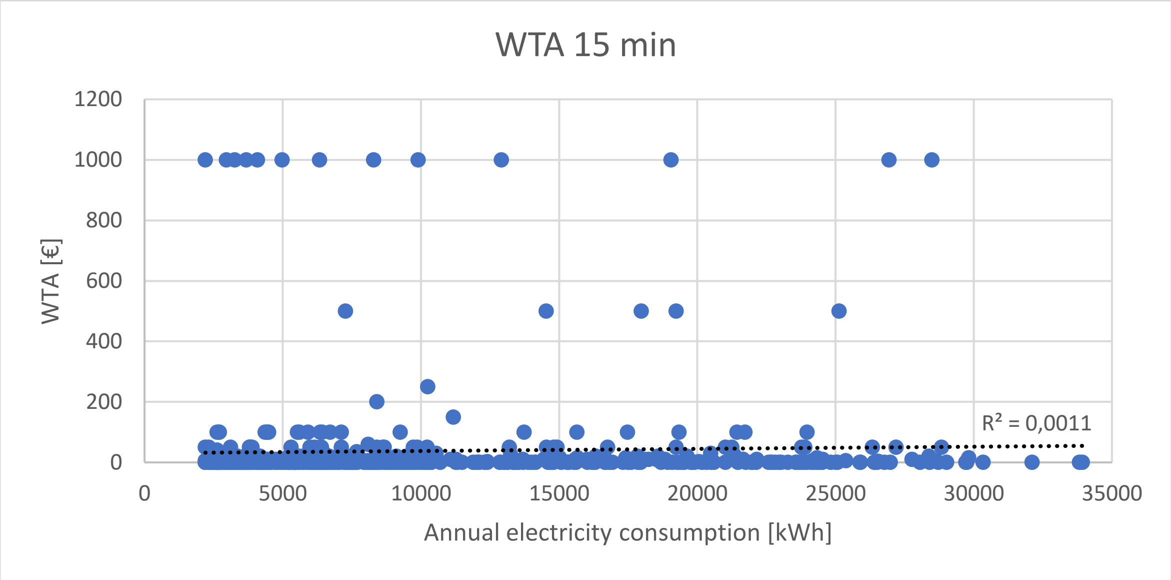
Results of household WTP and WTA questions in relation to household's electricity consumption in all eight cases:

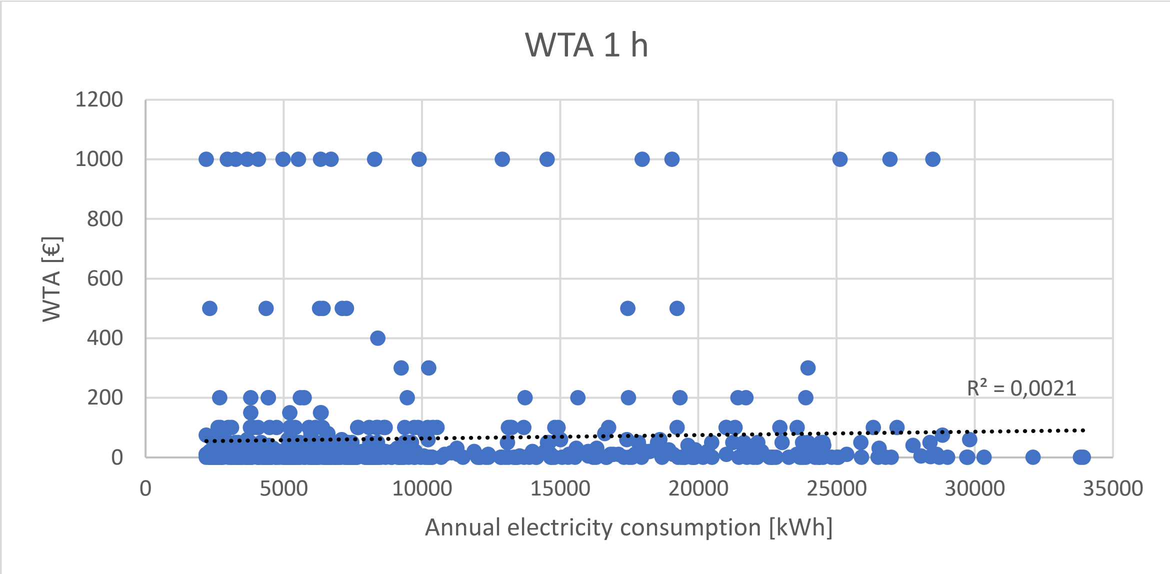


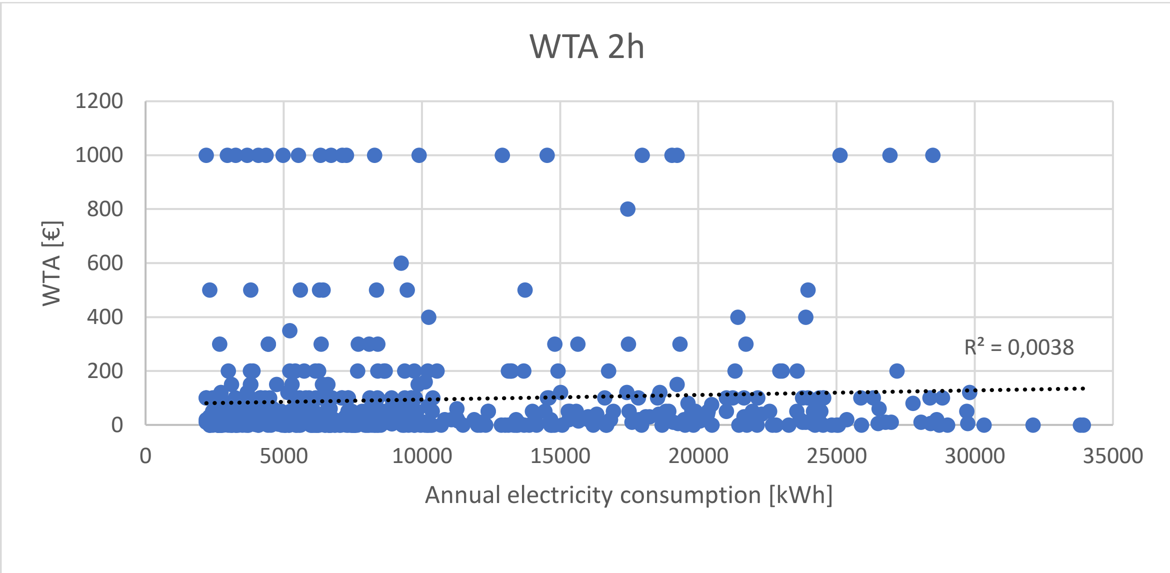


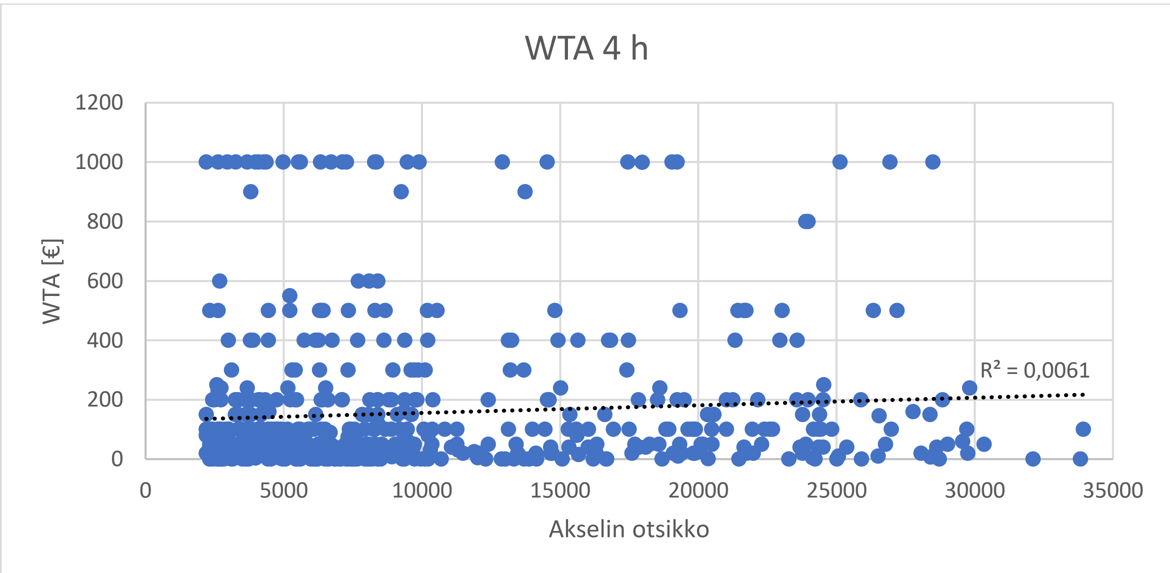

WTP 2h
WTP [€]
0
50
100
150
200
250
300
350
400
450
0
5000
10000
15000
20000
25000
30000
35000
Annual electricity consumption [kWh]
R² = 0,0001


WTP 4h
WTP [€]
0
100
200
300
400
500
600
700
800
900
0
5000
10000
15000
20000
25000
30000
35000
Annual electricity consumption [kWh]
R² = 8E-06


WTA 15 min
WTA [€]
0
200
400
600
800
1000
1200
0
5000
10000
15000
20000
25000
30000
35000
Annual electricity consumption [kWh]
R² = 0,0011


WTA 1 h
WTA [€]
Annual electricity consumption [kWh]
R² = 0,0021
0
200
400
600
800
1000
1200
0
5000
10000
15000
20000
25000
30000
35000

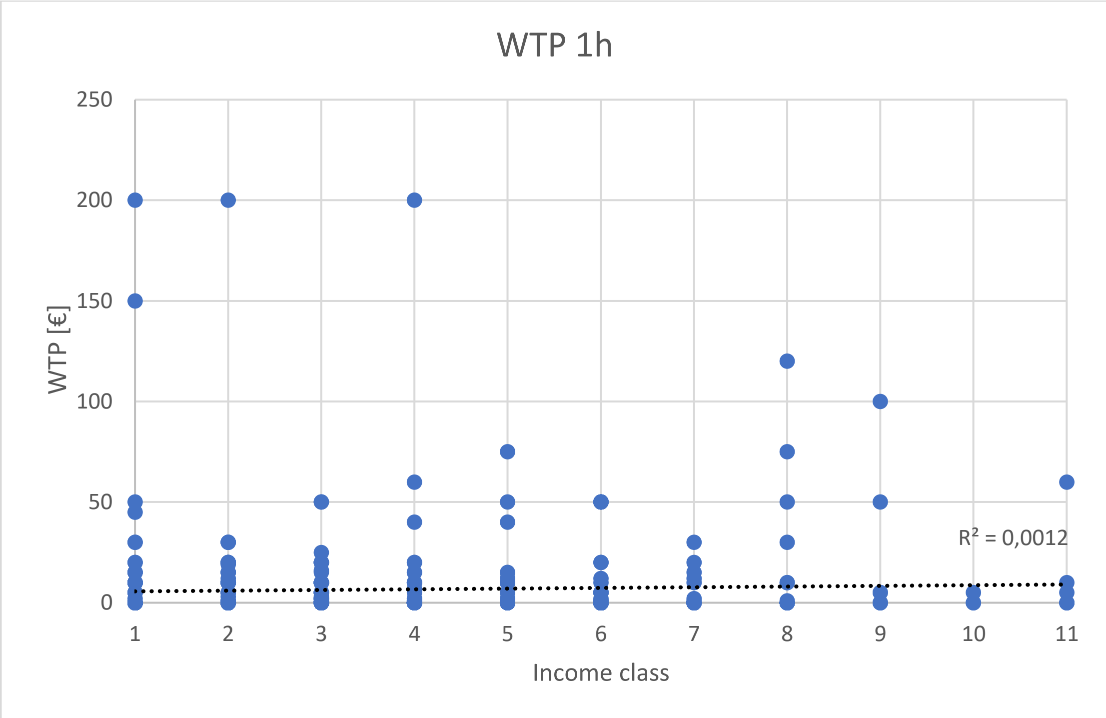

WTA 2h
WTA [€]
Annual electricity consumption [kWh]
R² = 0,0038
0
200
400
600
800
1000
1200
0
5000
10000
15000
20000
25000
30000
35000

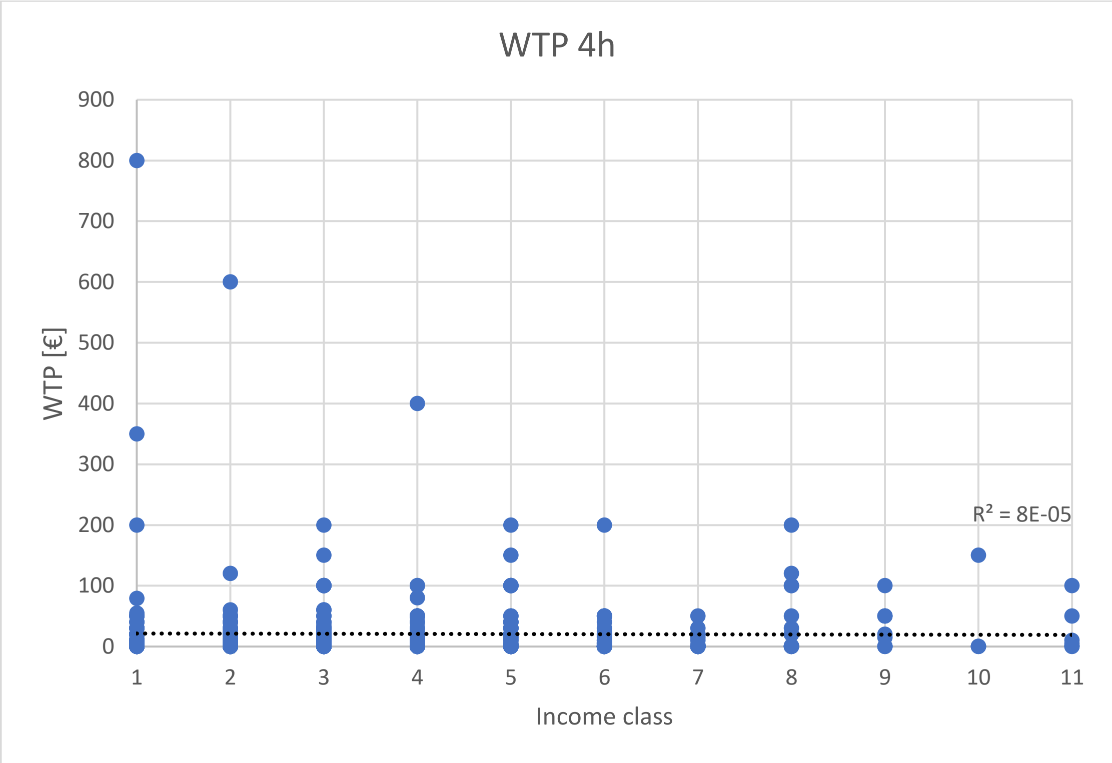

WTA 4 h
WTA [€]
Akselin otsikko
R² = 0,0061
0
200
400
600
800
1000
1200
0
5000
10000
15000
20000
25000
30000
35000

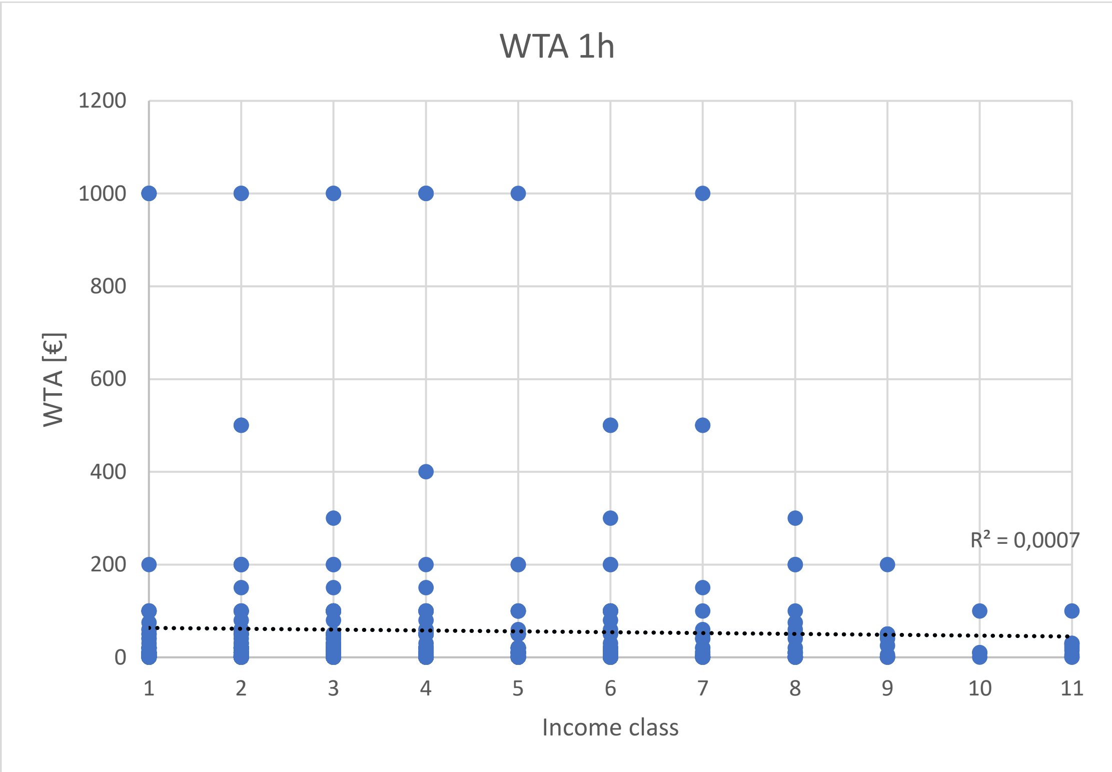
Results of household WTP and WTA questions in relation to household's annual income in four different cases:

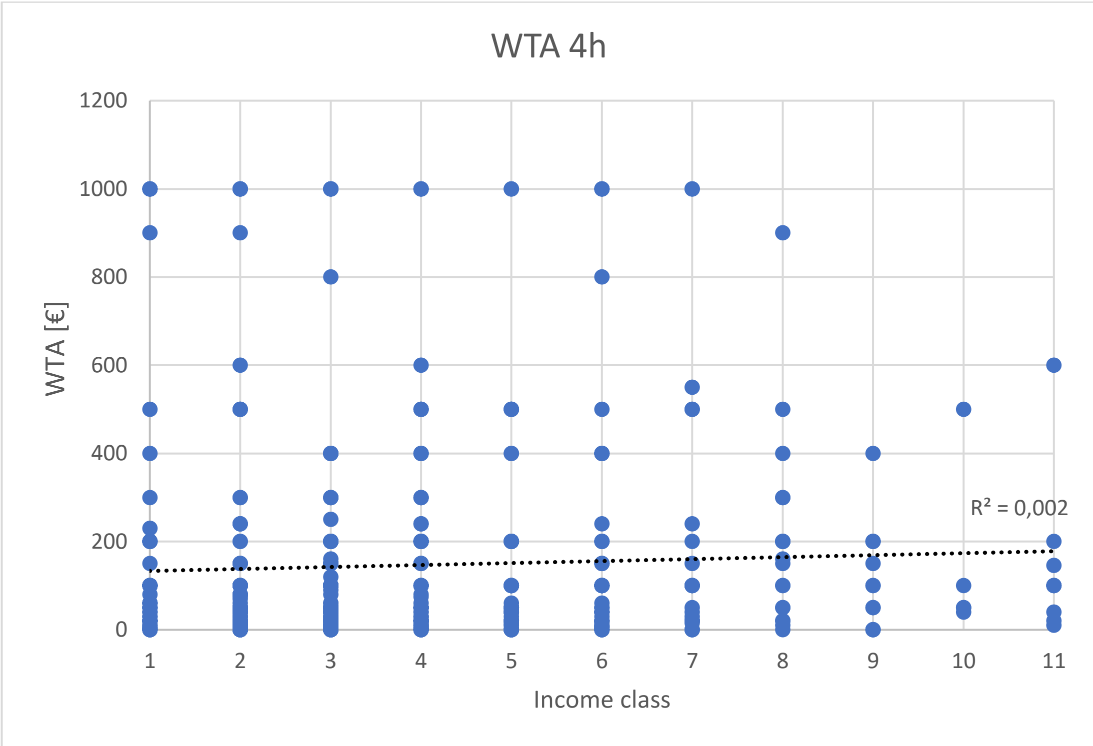
Income classes are as follows:

1	Less than 13.500 €	**7**	81.000 – 94.499 €
2	13.500 – 26.999 €	**8**	94.500 – 107.999 €
3	27.000 – 40.499 €	**9**	108.000 – 121.499 €
4	40.500 – 53.999 €	**10**	121.500 – 134.999 €
5	54.000 – 67.499 €	**11**	135.000 € or more
6	67.500 – 80.999 €		




WTP 4h
WTP [€]
900
800
700
600
500
400
300
200
100
0
R² = 8E-05
1
2
3
4
5
6
7
8
9
10
11
Income class


WTA 1h
WTA [€]
1200
1000
800
600
400
200
0
R² = 0,0007
1
2
3
4
5
6
7
8
9
10
11
Income class


WTA 4h
1200
1000
800
600
400
200
0
WTA [€]
1
2
3
4
5
6
7
8
9
10
11
Income class
R² = 0,002