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Economic Incentive Model for Demand Side Response in a Local Energy System

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Thesis for the degree of Master of Science in Mechanical Engineering

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Department of Energy Sciences
Faculty of Engineering | Lund University

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This degree project for the degree of Master of Science in Engineering has been conducted at the Division of Efficient Energy Systems at the Faculty of Engineering, Lund University, in collaboration with E.ON Elnät AB, Malmö. Supervisor at E.ON Elnät: Staffan Sjölander; Supervisor at LU-LTH: Asst. Prof. Kerstin Sernhed; Examiner at LU-LTH: Assoc. Prof. Patrick Lauenburg.

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Abstract

Change in energy markets, societal and political goals of sustainable energy production have made renewable energy sources increase in scale both in the European and Swedish energy mix. This creates new challenges for electricity networks, to handle intermittent power production. New strategies for energy utilities and modifications of conventional networks are under research and development all over the world.

One strategy is to investigate decentralized electricity systems, where a smaller system of local supply and demand can take advantage of local conditions in both electricity production and consumption. E.ON Elnät AB launched a pilot project in 2017, creating a local decentralized electricity system, to learn how intermittent sources can be used in an optimal way, disconnected from an overlying grid. This study was made during spring 2017, during the construction of the system. The project will test usage of energy storage systems and integration of costumers' flexible storage capacity through Demand Side Response (DSR), to handle moments when discrepancy between supply and demand occurs. The aim is for the system to become a self-sustaining micro-grid with electricity production from a local wind turbine and a solar power station.

This study focuses on how customers can be invited to offer their energy storage capacity with heat pumps, hot water boilers and batteries in their households, as a service to the system, so that electricity demand can meet supply. An economic model has been created with the aim to work as an incentive for customers to participate in the project, and with their service. Creating this model, a customer survey and a simulation of energy flow were conducted to understand the customer's and system's point of view of what the flexibility is worth for them both. It was found that customers would not like to experience increased electricity costs when participating, and that their participation should be on an easy and understandable level. From the simulation, it was found that the system is run by different costs over different seasons of the year, and that customers' flexibility can reduce these costs marginal. The design of the model was in the end based on three building blocks; compensation for potential increased electricity costs in the customer household that can rise with participating in DSR, compensation for intrusion, comfort changes and attraction through a fixed incentive, and finally a flexibility incentive based on the revenue the system gains when using customers' households as flexibility resources.

The conclusion of this study is to use a complete fixed economic incentive to customers, in order to make it easy and understandable for customers to participate in DSR. Recommendations for future studies are to do a profound investigation regarding the set-up of a local energy system, and to solve the technical challenges that comes with DSR in a micro-grid.

Keywords: Demand side response, local energy system, energy services, renewable energy sources, customer integration

Sammanfattning

Förändringar på energimarknaden, samhällsdrivna och politiska mål om hållbar energiproduktion har medfört ökade andelar av förnyelsebara energikällor, i Europas och i Sveriges energimix. Detta skapar nya utmaningar för både elnät och elsystem, eftersom en stor mängd intermittent elproduktion tillkommer och energitillförseln blir därmed oförutsägbar. Nya strategier är under utveckling hos energibolag världen över, för att kunna hantera den oförutsägbara energitillförseln på ett optimalt sätt.

En strategi är att decentralisera en del av elsystemet, där ett mindre system kan tillvarata lokala förutsättningar av elproduktion och konsumtion. E.ON Elnät AB lanserade under 2017 ett pilotprojekt, där de under året ska skapa ett decentraliserat elsystem, för att lära sig hur intermittenta källor kan tillvaratas på ett optimalt sätt bortkopplat från överliggande nät. Denna studien gjordes våren 2017, under byggnationen av systemet. Projektet kommer att testa olika energilagringssystem genom att integrera kunder, vilket kallas efterfrågeflexibilitet (Demand Side Response, DSR), för att hantera tillfällen då det råder avvikelse mellan utbud och efterfrågan av el. Målet är att systemet ska bli självförsörjande av elproduktion från vind och sol.

Denna studie fokuserar på hur kunden kan bli inbjuden till att erbjuda sin möjlighet att lagra energi med värmepumpar, varmvattenberedare och egna batterier, som en tjänst till systemet, så att efterfrågan av el kan möta utbudet. En finansiell modell har skapats, med mål att fungera som ett ekonomiskt incitament till kunder att delta i projektet med deras tjänst. Under skapandet av denna modell har en kundundersökning och simulering gjorts för att förstå kundens och systemets perspektiv av flexibilitetstjänsten. Det framkom att kunder inte önskar ökade kostnader för att delta med efterfrågeflexibilitet, och att deras deltagande borde ske på en enkel nivå. Från simuleringen framkom det att systemet drivs av olika kostnader under olika säsonger på året, och att kunders flexibilitet kan reducera dessa kostnader marginellt. Designen på modellen kom till slut att bygga på tre byggnadsblock; kompensering för potentiellt ökade kostnader hos kund, ett fast värde baserat på intrång, komfortförändringar och attraktionsincitament, och till sist ett flexibilitetsincitament baserat på vinsten som systemet kan göra genom att använda hushållskunders flexibilitet istället för andra komponenter.

Studiens slutsats är att en fast ekonomisk ersättning borde ges som incitament till kunder för att göra deltagandet i projektet enkelt för kund. En rekommendation för fortsatta studier är att göra en djupundersökning angående uppsättningen och strukturen på ett lokalt energisystem, och att lösa de tekniska problem som införandet av flexibilitet bidrar med i ett litet nät.

Nyckelord: Efterfrågeflexibilitet, lokalt energisystem, energitjänster, förnyelsebara energiresurser, kundintegrering

Acknowledgment

The study presented in this master thesis was conducted at the Division of Efficient Energy Systems, Faculty of Engineering, Lund University, initiated by and in collaboration with E.ON Elnät AB.

We would like to thank our supervisor at E.ON Elnät in Malmö, Staffan Sjölander, and the other team members of the E.ON local energy system steering group; Stina Albing and Peder Kjellén Zandén. Thank you for your help and guidance, all throughout this project. We would also like to thank other team members of the local energy system project; Rickard Venetjoki, Thomas Ranstorp, Ingmar Leisse and Tomas Johannesson for sharing information, knowledge and providing valuable support. Another vital support for the completion of this thesis is Kerstin Sernhed, our supervisor at Lund University. A big thank you for always answering to all our questions and leading us in the right direction.

We would also like to thank our E.ON master thesis buddies, Richard Luong and Rebecka Domeij, for all the laughs in our thesis-corner. To all Simris inhabitants participating in our survey, and who let us in to your home to interview you: thank you for all your answers, insights, good discussions and the coffee and fika you provided us with. Thank you to the Simrishamn gas station for solving car and snack problems as well as to Europcar for solving last minute car rentals.

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Anna Rydberg and Jesper Ingelson Wendell
Lund, June 2017

Table of Contents

Abbreviations

LES	Local Energy System
RES	Renewable Energy Sources
DSR	Demand Side Response
DSM	Demand Side Management
DSO	Distribution System Operator
DSP	Demand Side Participation
WT	Wind Turbine
PV	Photovoltaic
BUG	Back Up Generator
BESS	Battery Energy Storage System
CBESS	Customer Battery Energy Storage System
HP	Heat Pump
HWB	Hot Water Boiler
SOC	State of Charge
COP	Coefficient of Performance

Chapter 1

Introduction

This chapter introduces the actuality and the context in which this master's thesis has been conducted. The purpose and research questions are stated, as well as the scope and focus of the study's investigations.

1.1 Background and Problem Statement

The energy world is changing. The concern of climate change, visions for sustainable societies and other political goals demand modification of established strategies for energy utilities. In both Sweden and Europe, renewable energy production with intermittent power sources such as wind and solar increase in scale. To maintain electricity supply and delivery security, research and development of infrastructures, systems, technologies, energy storage and services is needed (Ericsson et al, 2016).

Certain strategies regard decentralised systems, where more diverse and dynamic structures are under development. Decentralised systems produce energy close to where it is being consumed, and can therefore take advantage of local resources and conditions, and do not have to rely on large and few national power stations. A decentralised system can also benefit from decreased transmission losses and lower costs to overlying grid (E.ON UK, 2017). Creating a small scale own supplying electricity grid, is not done effortless. A smaller closed energy system powered by intermittent sources will bring unreliable supply, leaving the system sometimes with overproduction, supply exceeding demand, and sometimes underproduction, supply not meeting demand.

This study will observe a decentralised system in the form of a Local Energy System (LES) in Simris, Sweden. This study was conducted during spring 2017, meanwhile the local energy system was being built by E.ON Elnät AB, as a pilot project. Around 150 households will, in late 2017, be disconnected from the main national electricity grid and instead supplied by one Wind Turbine (WT) and one PhotoVoltaic (PV) power park. In electricity generation, supply and demand needs to be in balance at all times. In a self-sustaining LES, it of desire to balance supply and demand in an optimal way, so that wasted energy and outages are avoided. It is therefore of desire to add resources of flexibility or resilience to help balance these potential mismatches. In this study, flexibility is defined as the available capacity offered through different installed equipment, to handle electricity supply discrepancy. Two LES-central flexibility components will be added, a Battery Energy Storage System (BESS) and a Back-Up Generator (BUG) (E.ON Elnät, 2017).

In addition, as a part of meeting the problems of mismatch in supply and demand, the concept of Demand Side Response (DSR) will be introduced, which aims to control customers' consumption to gain balance in, and to optimize, the energy system. The consumption under control will be households' heating technologies run by electricity, enabling benefits from thermal storage and household inertia. Focus is to create and prove a well working local grid in island mode, with voluntary flexibility from customer households (E.ON, n.d.(a)).

When customers provide flexibility to the energy system through DSR, it implies economical value for the system. To waste overproduction is costly. Even though marginal costs are low, investments for solar parks and wind turbines are high (Gsänger, Sawyer and Januairo, 2012). To experience outages due to underproduction is undesirable, and brings costs. Hence, if the demand side can adjust to the supply side, system costs can be reduced.

A customer providing its household electricity consumption as a flexibility resource to the system, is providing the system owner with a service. This service has a commercial value, comparable with providing a room for rental or a car for lease, satisfying a need. This valuable service should be priced and compensated for in order to give the customer an incentive to offer the service (Albadi and El-Saadany, 2008).

This study aims to investigate which value this service has for the customer, and how E.ON Elnät AB can offer this value in order to financially incentivise customer participation in DSR. The value, which the customer offers to the system, can be seen to depend on the electricity system's need for that service, at the time when it is given. In order to find out how E.ON can use this need in incentivising customers to participate in DSR, the study aims to understand two different perspectives; the customer perspective and the system perspective, and which value DSR will bring for the both.

1.2 Purpose and Research Questions

The purpose of this study is to investigate how to incentivise customer participation in demand side response in a local energy system in Simris and to develop an economic model for how customers' participation in demand side response activities should be valued and compensated to provide sufficient incentives for participation, and a fair compensation for customers cost arising in the participation.

The overall research questions (RQ1 and RQ2) of this study are thus:

RQ1: How can demand side response be introduced to household customers?

In order to answer to this question, two sub-questions (RQ1:1 and RQ1:2) have been developed. These are as follows:

> **RQ1:1**: Which driving and restraining forces exist among customers in Simris to participate in demand side response?
>
> **RQ1:2**: How can an economical incentive model look like for demand side response participation in the local energy system project?

RQ2: Which enhancements can demand side response contribute with to the self-sustaining local energy system in Simris?

1.3 Focus and Delimitations

The focus of this study is to investigate implementation of demand side response in a local energy system, through a case study. This case study will specifically look into a local energy system in Simris, Skåne, which is built by E.ON Elnät AB. Therefore, it implies certain limitations. Firstly, it is limited to investigate the specific conditions existing in the area, both regarding energy production and customer target group. Secondly, it is limited to investigate the solutions that E.ON has chosen to incorporate in this project. Energy system design, DSR coverall concept and the technical components for this project are already selected and set by E.ON which leaves no room for us to change certain settings.

One of the already set conditions is the household technical components that will be available for demand side participation; hot water boilers with heating cartridge, air/water heat pumps and customer owned household batteries. Solely these will be investigated as customers' potential flexibility resources.

If the customer does not have any of the three technologies above, an investment incentive will be given to the customer. This study will not investigate investment incentives, only the incentive for participation when a customer does own the mentioned equipment.

Further, this study will presume that a DSR financial service agreement is possible to implement without no constraints regarding energy legislative or regulatory frameworks. This will be dealt with by company attorneys.

Chapter 2

Methodology

This chapter explains the case study and theory triangulation method, motivating why they have chosen as overall method approaches in this thesis work. It will further present the different methods chosen to support theory triangulation; data collection, assumptions, computations and a simulation.

2.1 Case Study Method

This master’s thesis work will use a case study research method, where a specific case and its situation will be considered. A case study investigates a contemporary phenomenon within its real-life context and covers contextual conditions which are relevant to the problem studied (Yin, 2003). In this study, the case of the E.ON LES project in Simris will be examined, its specific context and conditions.

2.2 Theory Triangulation Method

In this study, we wanted to investigate how an energy company can incentivise DSR participation through an economic incentive model. How the customer itself value its flexibility service, is the core of this investigation. Further, the flexibility service the customer is providing, is a resource for the electricity system. We understood that, how the system benefits from a flexibility resource at a specific time, is important for this investigation and we therefore chose the method of theory triangulation, as overall methodology for this study.

Theory triangulation is a method within social science and case study research, using competing theories or hypotheses to asses one and the same subject. It involves testing different theories or alternative explanations of the same phenomenon, as well as using multiple perspectives to interpret one set of data (Denzel, 2006).

To find diverse interpretations for the one phenomena (the economic incentive), the perspectives chosen to investigate were the one of the customer, and the one of the local electricity system. To understand the customer perspective, we chose to conduct a customer survey, and to investigate the system perspective, we chose to do a simulation.

The two perspectives gave further insights; we needed to support the methods chosen with assumptions and computations. Finally, building blocks of an economic incentive model were created from the insights. In addition, a literature review was made to understand an external perspective of our problem. We did this in three steps, as presented below and in Figure 1.

1. Investigating the two perspectives.
2. Investigating insights from perspectives.
3. Creating building blocks for an economic incentive model based on the insights.
4. Creating economic incentive models from the building blocks.

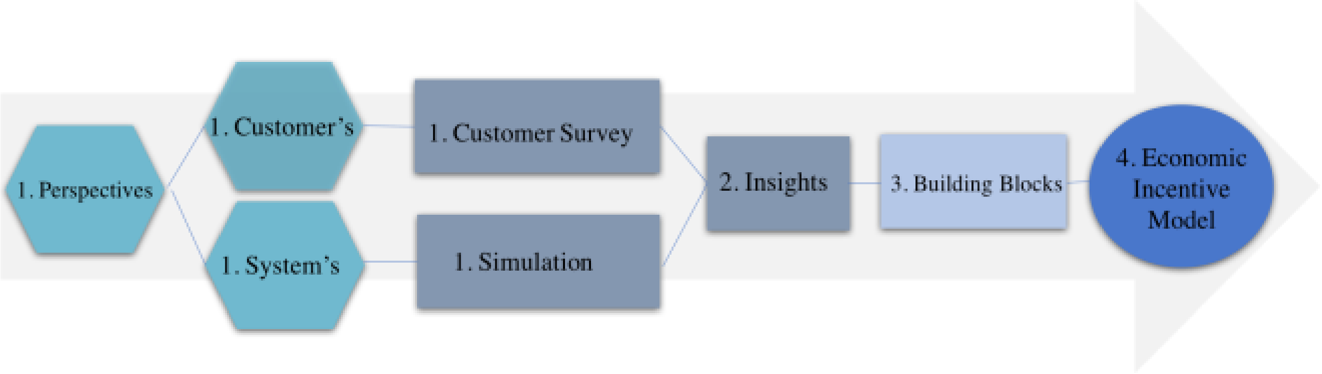


Figure 1 - Method of this study.

2.2.1 Customer Survey

A customer survey was made to understand the customer perspective of the subject investigated, and to collect primary data for this case study. Primary data is data collected for the current research relevant to fit its purpose (Björklund and Paulsson, 2012). A mixed-mode method was chosen, where two ways of conducting a survey was done in order to counterbalance one method's disadvantages with the other method's strengths. Both face-to-face interviews and a written survey have been done for this work. A detailed description of the method and set-up for the customer survey is presented in Chapter 5.

2.2.2 Simulation

A simulation was made in order to understand the system perspective of the subject investigated. The simulation was supported by user data and assumptions, explained below. The simulation tool was built in Matlab, in order to understand the DSR value from a system perspective and the system utility. The simulations were run in three different scenarios based on time series, with and without DSR, to map power flows through the system and its components. A detailed simulation method and assumptions made will be discussed in Chapter 6.

2.2.3 Production and Consumption Data

Primary data to support simulations and computations in the form of user data, as well as production data was gathered from E.ON internal measurements and readings. Data has also been collected from the Swedish Meteorological and Hydrological Institute (SMHI) and Nord Pool ASA. These are collected and analysed via Microsoft Excel.

2.2.4 Assumptions

Since not all DSR conditions in Simris were set by the time this study was made, several reasoned assumptions had to be taken in investigations to support our simulation and computations. Priority order of equipment usage, potential flexibility resources in installed kW and time for activation and deactivation of equipment has been assumed. These assumptions have been set together with E.ON and Lund University employees and supervisors, and will be noted and discussed in relevant chapters.

2.2.5 Literature Review

A literature study was made to comprehend the theoretical framework; existing technical, financial, and system facts and processes connected to the thesis topic. Recent publications, company internal information, articles and books are used to understand the external perspective of this investigation. It has been important to remember that literature is considered as secondary data, which means that facts presented in written material might have been developed and produced to fit another purpose than the one of this work (Björklund and Paulsson, 2012).

A benchmark is made to further understand the external perspective of this thesis work's problem formulation. Similar DSR projects are chosen to be explained to compare approaches, goals, and if possible, results, with the DSR project studied in this work. Information regarding these projects has mostly been collected online and from their pre-study reports since companies in development project are sparse with what they make public. The aim is to understand how other projects have attracted customers to participate in DSR, and how this pilot project can learn from it.

2.2.6 Computations

Computations have been made to understand and to analyse how household technical components will operate and which costs they potentially will bring, since it was found needed to investigate in the customer survey. Mathematical formulas have been collected through literature and with the help of Thomas Ranstorp, CEO of Ivago AB, expert in energy systems and automation.

Chapter 3

Theoretical background

This chapter will present a theoretical background to the study made. It will commence by describing the actors in the Swedish electricity market, the Swedish grid structure and how a local energy system distinguish from it. Further it will explain what demand side response is, and how previous projects have introduced demand side response.

3.1 Actors in the Swedish electricity market

It is of importance to understand how the different actors operate in Swedish electricity market, in order to understand how these actors are subject to change in a LES. The Swedish electricity market consists of a few key actors between which certain relationships, rules and economic conditions apply.

- *Electric Producers* - Producing electricity from various power plants, sourcing the power system with electricity. Electric producers are suppliers to electricity retail companies.

- *Electricity Retail Companies* - The legal entities purchasing electricity from electric producers, via the electricity power exchange or other retail companies. Retail companies are then selling electricity to customers or users in the form of different agreements or contracts. The retailer can also possess the role as balance controller.

- *Network Owners* - The ones owning, maintaining and operating the electricity network and transmission grid.

- *Electricity Consumers* - Consumers buy electricity from the grid for usage in electric appliances. Electricity consumers can be all from industry consumers to private household consumers and individuals. The Free Dictionary (n.d.) defines a consumer as "*One that consumes, especially one that acquires goods or services for direct use or ownership",* and in the Swedish National Encyclopedia it is defined as "*The end user of a product"*. A customer however, is defined as *"One that buys goods or services"* in the both. Therefore, a consumer connected to an electricity meter, in an agreement with a network owner and a retail company to buy electricity, is a customer for the two actors.

- *Electricity Power Exchange* - The Nordic power exchange actor is called Nord Pool Spot AS and organises electricity trading on short term, day ahead trading for every hour of physical electricity contracts. They also supply the market with the possibility to trade electricity contracts intra-day, up to one hour before delivery, as an adjustment and balancing mean. Nasdaq OMX Commodities organises financial electricity contracts as futures, long term agreements. The spot price of electricity is highly dynamic, dependent on national and international supply and demand.

- *System Operator* - The one managing the transmission grid, making sure production, consumption and import/export is in balance at all hours of the day. Svenska Kraftnät is the system operator in Sweden, as well as the transmission grid owner which will be further explained in Section 2.2 (Samordningsrådet för smarta elnät, n.d).

3.2 The Swedish Power Grid Structure for Electricity

To understand what a local energy system is, it is first necessary to declare the setup of Sweden's distribution grid. Energy distribution grids can be in the form of electricity or heat. In this case study, the scope is to investigate a local electricity grid. The existing Swedish electrical power grid is divided into three levels, distributing electricity in different voltages transmitting it down to end consumers.

The transmission grid is the high voltage grid distributing electricity between 220 kV and 400 kV. Large production sites such as hydropower and nuclear power plants are directly connected to this grid which plays a fundamental role in Swedish infrastructure, transferring electricity over large geographical areas. The state-owned public utility Svenska Kraftnät is the only owner which holds network concession of the transmission grid (Wallnerström and Grahn, 2016).

Connected to the high voltage transmission grid is the sub transmission grid. The sub transmission grid's main function is to transport electricity between the high voltage and low voltage grid networks, with voltage below 220 kV. Normally, the voltage is between 130 kV and 40 kV, spanning across regional areas connected to the distribution grid or large end customers. Over 97% of the sub transmission grid networks in Sweden are governed and owned by the three actors Vattenfall Eldistribution AB, E.ON Elnät AB and Ellevio AB (Energimyndigheten, 2015).

Transformer stations decrease the voltage to low voltages transferable to end customers usually below 40 kV. Most end customers are connected to voltages lower than 1 kV. In 2015, 157 electricity grid distribution owners operated in Sweden, commonly governing grid structures in geographically local cohesive areas (Wallnerström and Grahn, 2016).

3.3 Local and Smart Electricity Grids

A local energy grid, is a grid disconnected to the national power grid presented above. It supplies energy, in this case study electricity, solely to a smaller local geographical area. The aim is to target local needs and to take advantage of the unique local conditions and opportunities in that area in both supply and demand. Local energy systems can be advantageous in areas where the main grid operates far away, on an island or where a neighbourhood can function as a producer selling overbalance of power in a future scenario (E.ON Elnät, 2017).

A smart grid utilizes information and control technology to handle the complexity that comes with the challenge of discrepancy in a LES and is therefore a necessary mean. Smart grids are under research and development in many pilot projects in Sweden today. The definition of a smart grid according to The Council of European Energy Regulators (2014) is:

"Smart Grid is an electricity network that can cost efficiently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety."

3.4 Demand Side Response

Demand side response is defined as the end users' change in electrical consumption from their normal usage behaviour, and as a designed incentive payment to encourage temporary lower electricity use in order to ensure system reliability (Albadi and El-Saadany, 2008). DSR and Demand Side Management (DSM) are often confused. The difference between DSR and DSM is that DSR is used to encourage end-users to provide short-term energy reduction in response to an external signal, meanwhile DSM is used to encourage end-users to be permanent energy efficient, changing energy load over longer time horizons (Rowles 2010). This definition is also stated by Cheng (2015), who, in Figure 2, shows how DSR and DSM affect a load curve with permanent change through DSM and temporary change through DSR.

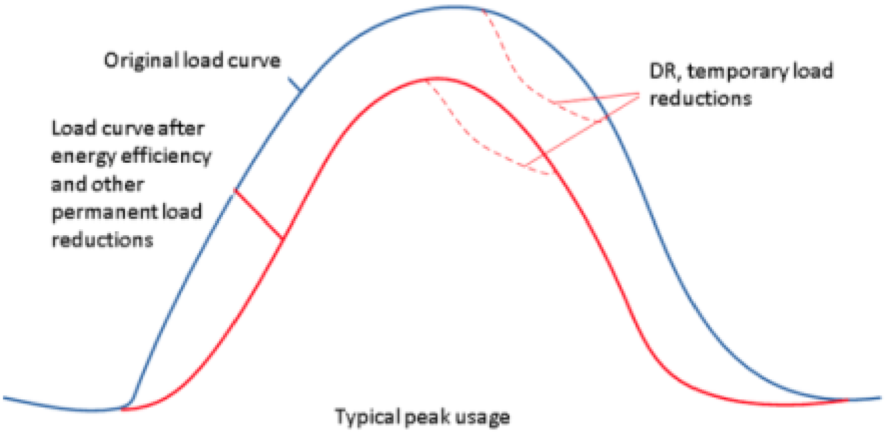


Figure 2 - Shows the difference of DSR and DSM through their impact on a load curve during typical electricity peak usage (Cheng, 2015). The solid red line shows energy usage reduction due to DSM, meanwhile the dotted red lines show temporary energy load reduction due to DSR.

To make the demand side response, adjust consumer consumption match production instead of the other way around, DSR can be introduced in different ways. Two main processes are identified: active DSR and remote DSR. Active DSR is defined as the process when customers actively change their consumption after supply by request. Customers can change their consumption through behavioural changes, deciding themselves when to manually run equipment using energy at home e.g. dishwashers, showers etc. Remote DSR is defined as the process when a customer allows an external aggregator to remotely control their consumption. Power-to-heat systems such as heat pumps (HP) and hot water boilers (HWB) used for space heating and domestic hot water copes well with remote DSR creating decentralised storage capacity (Brodén, 2013).

3.4.1 Benefits of DSR

The benefits of DSR can be categorized in two perspectives: The perspective of the electrical Distribution System Operators (DSO) and the customers.

DSO pays a cost to distribute and transform electricity to household usable voltages from an overlying transmission grid. A part of this cost is based on the maximal electrical power transferred. This can be reduced with DSR, removing the highest power peaks. The cost of electrical power transmission and distribution losses can also be decreased by limiting power peaks, and therefore the total amount of distributed energy. A lower load in the grid reduces the risk of outages, providing a more reliable grid, and the cost of compensating customer for outages decreases. If the maximal load is reduced, the need for reinvestment can be lower than today, and postponed (Nylén, 2011). Transmission power grids are often dimensioned after the maximum power peak that occurs in a year. Figure 3 is an example of a typical load duration curve, showing that the grid is over dimensioned most time of the year. If this peak could be reduced, it would be economically beneficial regarding grid investments. Therefore, to introduce DSR on large scale, in addition, it can possibly reduce grid dimensions and extend cables' life length (Söder, 2013).

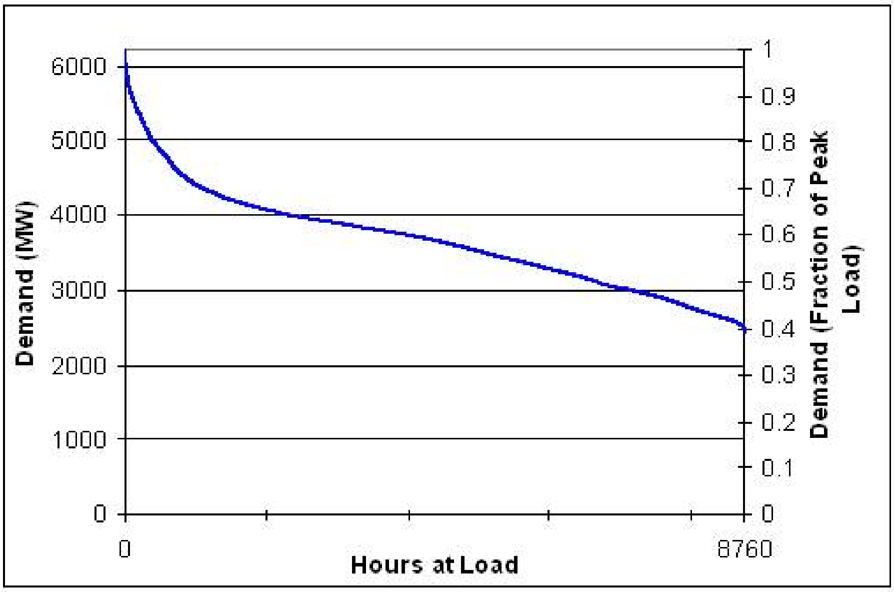


Figure 3 - An example of a typical load duration curve of one year, on which grid dimensioning is normally based on (Mcensustainableenergym, 2011).

DSR can also benefit customers with savings in their electricity bills. Most often, DSR can reduce customers' total energy consumption, but also change their consumption patterns, to consume when the electricity price is low. It can therefore be possible for customers to save money, even if their energy consumption has increased by participating in remote DSR. This is due to the incentive-based DSR theory direct load control, where utilities have the possibility to remotely deactivate customers' equipment on short notice. In these programs, customers usually receive payments or rate discounts for participation providing flexibility, and can therefore offset the increases in cost they might have encountered during increased energy consumption (Albadi and El-Saadany, 2008).

Tariffs

In Sweden, the total electricity price to end customers contains of three parts: electricity fee, network fee and taxes presented in Figure 4. The electricity fee is the only part that customers can influence themselves by changing supplier, or negotiate their existing contract. The network fee is the payment given to the local network owner for transmission of electricity from the production plants to end users. Since customers can not choose network owner, the fee must be reasonable and non- discriminatory according to Swedish regulatory framework. The consumption of electricity is taxed and consists of an energy tax and a value added tax (VAT) (Pyrko and Darby, 2009).

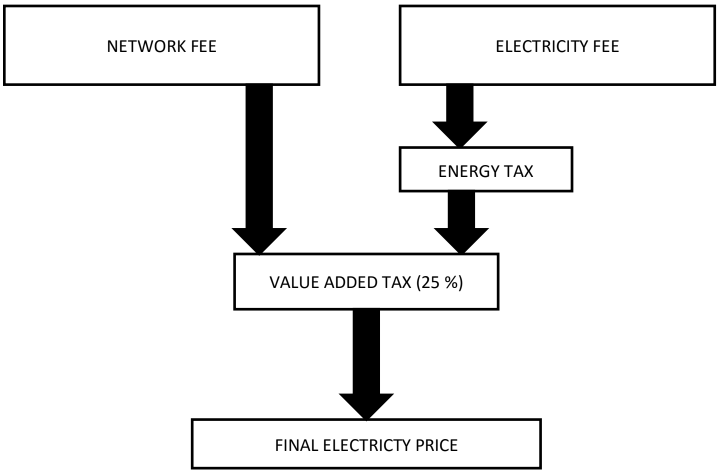


Figure 4 - Residential electricity price structure - Sweden (Pyrko and Darby, 2009).

If direct load control is to be implemented as a DSR program, it could require dynamic pricing and flexible tariffs with real-time-pricing. Real-time-pricing is based on system health and the market condition. Since it is of desire to make consumers change their electricity use at times when system health is bad, the price should be set with an hourly, or higher, granularity. However, with this tariff model, there is a risk of confusion from the customer side if both electricity and network fees are real-time-priced. It requires the customer to have a smart meter to match the granularity of the tariff (Albadi and El-Saadany, 2008; Pyrko, 2005).

3.4.2 Driving forces and boundaries with DSR for customers

How demand flexibility is introduced is of importance for how related driving forces and boundaries are perceived by customers. According to Linnarsson et.al (2013), an incentive reflecting a customer’s need, such as a dynamic price, is not sufficient enough. There are other factors, which are central for flexibility incentives. How feedback, measurements and load control are organized, as well as level of comfort impact and timing of it, has an influence of households’ willingness to adjust their electricity consumption.

Feedback interface systems are discussed by Linnarsson et.al (2013) and are needed for communication between the system and the customer, as well as for customer understanding and increased knowledge of electricity usage. Feedback can be given to the customer either direct or indirect. Direct feedback is when customers instantaneously are given information and can therefore, in real time, observe consumption changes after reaction to signals. Indirect feedback is when a customer retrospectively is given information about impact of used flexibility or consumption changes. Feedback interface systems have proven to be of importance in customer integration. In a DSR project in Gothenburg, a strict correlation was found between reduced consumption and usage of an online webpage presenting hourly information one day later, as well as price forecasts for the next day (Fritz et al, 2009).

Broberg et al (2014) discusses learning, knowledge and information on a more general level. Little communication about electricity consumption from the network owner and electricity retail companies to customers, can be an explanatory factor for different levels and ways of consuming energy in different households. Naturally, demographic and socioeconomic conditions impact electricity usage, but the fact that electricity in a household is "invisible", not showed visible in detail per device, it is not given the same attention and observance as in comparison to grocery shopping for example. Making informed decisions when it comes to energy is regarded as difficult among customers.

Comfort is a central aspect in heating system control, and a boundary for DSR implementation. Keeping an indoor temperature of at least 20°C, is both of desire for residents as well as a recommendation from the Swedish National Board of Health and Welfare (Haimi, 2013). Fritz, Jörgensen and Lindskoug (2009) write that the study made by Göteborgs Energi showed little or no noticed comfort change, due to remote heating system controls, among tested customers. The results also show that three hours of decrease with around 2 kW, gave an indoor temperature decrease of around 0.5°C on average. In a study made by Sernhed (2004) of remote DSR of ten detached houses in Skåne, controlled during three weeks for 1-4 hours, it is shown that the indoor temperature decreased 1°C during complete deactivation of heating system for 4 hours. In the same study however, customers did notice change in indoor temperature, and a perceived reduced comfort. Some customers have used extra clothes or indoor shoes during capacity control periods. Contrary, some households have barely noticed heating system deactivation. Comfort perception is personal and subjective, also discussed in Sernhed's study, where all households have different preferred reference temperatures. Further, other studies have shown that deactivating or decreasing electricity usage of the indoor heating system can be done between 1-3 hours without noticeable comfort change, due to thermal inertia in buildings (Linnarsson et al, 2013).

Another factor, which can be seen as both a boundary and a driving force in DSR, is that energy consumption behaviour can be influenced by the knowledge of other people's behaviours. Broberg et al. (2014) mean that there is a potential of using social pushes when it comes to attraction to change behaviour. Showing that something is "good" and that "good people" follow that something, can create a positive domino effect. Further, sharing usage information is a point of issue expressed for DSP. In a survey made by the authors, only 67% of the answers stated they would let a company map their energy consumption in order to provide personalized saving suggestions. Who and why intrusion is made is important for the customer to understand.

The survey also investigates the propensity to adopt to a contract changing electricity consumption through load control. It is made through a method called choice experiment where customers are faced with a number of offers, containing various attributes, which are then possible to analyse separately. The survey was sent via a web link to 5 900 email addresses of a Swedish online survey panel, 918 answers were noted (15% reply frequency). The aim was for the target group to be statistically representative for Sweden. The choices did not consist of too many attributes so that the cognitive burden would be kept on a reasonable level, and for the customer to completely understand all choices. The customer was faced with three different choices of electricity and household heating system steering, one regarding information dissemination and one regarding a yearly fixed compensation for "changed agreement" together with status quo, in different combinations.

The results show that remote control of heating equipment has no or close to zero demand for any kind of compensation if steering occurs during morning or daytime. This might be explained by the fact that many customers are not home during the day, and do not consider a change in temperature a burden. When it comes to controlling heating equipment in the evening, the customers are more sensitive towards decreased comfort level. In this case, customers demand 650 SEK per year for limited heating availability. However, some customers tend to dislike any kind of restriction in their household and demand almost 2 500 SEK in general to consider such an offer. Further, when asked about electricity consumption, customers demand information in advance and 40 SEK per day for preparation for coming outages.

In Sweden, there is a great potential for demand flexibility. Linnarsson et al (2013) has summarised the potential of savings due to household electric heating capacity decrease to 500-900 MW during average system and external conditions. Corresponding value during cold peaks (higher flexibility potential) is 1 500 MW. Looking at the total flexibility potential in Sweden during cold peaks, this could correspond to around 6% of the total consumption at that time. This is compared with peak capacity usage 6th January 2017 from Svenska Kraftnät, around 25 000 MW (n.d.), which is said to be the coldest day of the year according to SMHI (2017).

3.5 Other projects introducing DSR to household customers

DSR has been and is tested in many different projects all around the world. It is of interest in this study to map their customer approaches and ways of attracting customers to participate in DSR. How do other projects and organisations introduce DSR as a service to household customers?

Göteborgs Energi

Fritz et al (2009) describes a DSR project in Gothenburg made during winter 2007/2008 and 2008/2009. They tested 21 households for remote DSR, and used a business model based on the concept that customers were given incentives to actively control their electric heat usage against the market's spot price. However, the network owner has the incentive to control the customer for grid reasons. The grid owner offered a remuneration of 500 SEK, per customer and per year. This value was based on the assumption that customer usage reductions from the grid could be up to 4 kW, and that the cost for the grid owner to the overlying grid was 200 SEK per kWh, and that the grid owner and the customer would share the revenues.

Smart Grid Gotland

Smart Grid Gotland is a research, development and demonstration project implemented by, and in collaboration between Gotlands Energi AB, Vattenfall AB, ABB AB, Svenska Kraftnät and Schneider Electric. The project started in 2012, with the goal of integrating a larger amount of renewables into the grid with contained or improved electricity quality with the help of DSR. The customer integrations part of the project has been finalized during spring 2017.

To reach its goal, the project has modernized the grid through smart grid solutions and customer integration (Nejman 2017). Comparable to the Simris LES project, new technologies are upgrading an existing power grid. However, there is no aim for Gotland to become a local system, alternately solve a problem of export overload to the mainland, when increased wind power penetration.

All full private customers of Gotland Energi, i.e. distribution as well as electricity customers, were invited to participate in DSR tests. Further, the customer segment was limited to 8-40 MWh usage/year.

The goal was initially to test 20% of this population group, around 2 000 households. The customers were connected mixing both remote and active DSR, depending on household technology. The aim was to test both spot prices and a flexible time grid tariff incentives, but, a limited number of customers were offered more complex solutions with reinforced price signals coupled with local wind production communicated to them as well as peak power tariffs. All customers were given the DSR equipment at no extra cost, a visualization tool, and the customers with complex pricing testing were offered private meetings, consultancy and participation in a web competition (GEAB et al, 2011). The project ended in 280 customers participating in DSR, which is around 14% of the aim (Smart Grid Gotland, 2017).

Fortum Värme and Svenska Kraftnät

The Swedish energy company Fortum has together with the Swedish power balancing state-owned network operator Svenska Kraftnät started a pilot project called *the virtual power plant* in 2016. The aim of the project is to test balancing the system power with household HWB. The boilers will be deactivated at times when supply is low, especially from wind and solar sources, decreasing demand (Fortum 2017a). The project will run for a test period of two months (Fortum, 2017b).

Fortum's approach towards customers is to clearly, and in short descriptions, explain why and how the customer can contribute to higher penetration of RES, through participating with their electrical driven HWB. Information is mainly communicated via the Fortum website where their customers simply can sign up for participating by filling in a form. All Fortum customers also received information and a participation invitation via email. A hundred customers participating in an initial stage was the aim. It was launched in December 2016 and in March 2017, the testing started with close to 100 voluntary household customers. The customers are offered an app which tracks the customer's electricity usage in real time. In addition, the household customer is given the DSR equipment at no extra cost (Fortum, 2017a). The project's manager explains there are no additional benefits for the customer at this initial pilot stage, except for the possibility to increase their consumption knowledge through the app given. In upcoming stages, Fortum hopes the customer can take part of the revenue generated through the flexibility (Krögerström, 2017).

EcoGrid Bornholm

EcoGrid Bornholm is an international DSR demonstration project on the Danish island Bornholm, led by several partners, among them Østkraft. The aim of this project is to test a smart grid system, new technologies and DSR to create flexibility, moving load peaks for higher penetration of RES. The customers connected are given price signals in order to shift their load (EcoGrid Bornholm, 2017).

Participation in DSR is voluntary. Extensive communication strategies and a recruitment plan have been used to attract participants. The aim was for 1 900 households to participate, and ended in 1 948 connected to DSR. Most common reason for not being interested in participating was that the customer did not want the equipment needed. The strongest driving force to participate was to gain knowledge about own energy consumption, contributing to a better environment on Bornholm and lower energy costs. Even though many customer initially signed up for the hope of saving money, most customers claimed that they enjoyed contributing to higher penetration of RES the most.

The recruitment plan covered efforts to gain attention, a demonstration house with smart house equipment was set up, media, politicians and spokespeople, local authorities and direct face-to-face contact was used to meet with participants.

The project promised no financial profit to the participants, but a possible bonus to the electricity bill, however only marginal. On the other hand, they were promised not to lose any money, and that no costs were to be increased. All technology equipment was given and installed for free. A fixed gift was given to all customers at the end of the test period in the form of a box of chocolate and an amount of money. Depending on which testing group, level and amount of time the customer had been steered, 300 to 1 600 DKK was given. Coverage for extra consumption was included in this value (Trong, 2016).

3.6 DSR Equipment

Three different technologies that can be used as power-to-heat and power-to-power decentralised energy storage with DSR will be introduced. The concept of these is to take advantage of their thermal and electricity storage possibilities, controlled through remote DSR, explained in Section 2.2. Therefore, the theory of the three household components under loop in this study are explained below.

3.6.1 Heat Pump

Heat pumps (HP) are power-to-heat systems used for space heating to regulate indoor temperature securing a comfortable living climate. It absorbs heat from one medium in order to heat a volatile evaporating refrigerant, compresses it and transfers heat to another medium. A common type of HP is air/water, transferring heat via the exchanger from outdoor air to water. The water is then distributed in the house heating distribution system exchanging its heat through radiators. HP's require less electricity input, than is released as heat. It is called that a HP has a coefficient of performance (COP), dependent on operating conditions. The COP is on average usually 3 over time, meaning that a HP can emit 3 times more energy of heat than electricity energy used (Dincer and Rosen, 2007).

Heat pumps are usually dimensioned after heat losses emitting from a building, to decide a specific electricity demand based on heat power demand. The theoretical framework of determining heating power demand in buildings is gathered from Warfvinge and Dahlblom (2010):

$$P_{in,electricity} = \frac{P_{out,heat}}{COP} \ (W) \tag{1}$$

Where the heat needed to keep the energy at stable temperatures, is given by:

$$P_{out,heat} = Q_{tot}(T_{Indoors} - T_{outdoors}) - P_{free} \ (W) \tag{2}$$

With the including parameters:

$$Q_{tot} = Q_t + Q_v \ (W/°\mathrm{C}) \tag{3}$$

$$P_{free} = \frac{E_{free}}{8760} \ (W) \tag{4}$$

$$Q_t = Q_{thermal\ bridges} + (U * House\ Area) \ (W/°\mathrm{C}) \tag{5}$$

$$Q_v = \rho * c * q_{vent} * (1 - v) * d + (\rho * c * q_{leakage}) \ (W/°\mathrm{C}) \tag{6}$$

Where:

$Q_{tot} = Total\ thermal\ loss\ factor\ for\ the\ house\ (W/°\mathrm{C})$
$Q_t = Power\ required\ to\ cover\ for\ transmission\ losses\ (W/°\mathrm{C})$
$Q_v = Power\ required\ to\ cover\ for\ ventilation\ and\ air\ leakages\ (W/°\mathrm{C})$
$P_{free} = Free\ energy\ given\ to\ the\ house\ by\ solar\ fluxed, residents\ in\ the\ house\ etc\ (W)$
$U = Measures\ how\ well\ the\ building\ is\ isolated\ towards\ heat\ losses\ (W/°\mathrm{C}m^2)$

$Q_{thermal\ bridges} = Power\ requirement\ due\ to\ weak\ points\ of\ thermal\ insulation\ (W/°\mathrm{C})$
$COP = \ Coefficient\ of\ performance$

3.6.2 Hot Water Boiler

To ensure availability of domestic hot water in a house, it is common to use an electric hot water boiler (HWB) to increase and maintain high water temperatures. This water is mainly used for household activities such as showering, washing and dishing. The temperature of water must at least, during one point in time, be heated above 60°C according to construction restrictions, to avoid procreation of legionella bacteria which can cause the legionella disease (Boverket, 2000).

The theoretical framework used to calculate added energy to water in a tank, increasing its temperature, and heat losses from the water to the ambient surrounding through the tank is calculated with the following equations (Custom Thermoelectric, 2013):

$$E = V_{tank} * \rho_{water} * \beta_{water} * (T_{end} - T_{start})\ (Wh) \tag{7}$$

Where:

$V_{tank} = Volume\ of\ the\ tank\ (m^3)$
$\rho_{water} = Density\ of\ water\ \ (kg/m^3)$
$\beta_{water} = Specific\ heat\ capacity\ of\ water\ (kJ/(kg * K))$
$T_{start} = Starting\ temperature\ of\ the\ water\ (°\mathrm{C})$
$T_{end} = Ending\ temperature\ of\ the\ water (°\mathrm{C})$

And the heat losses from a water tank is the following:

$$HL = \frac{\gamma_{tank} * SA_{tank} * (T_{water} - T_{ambient})}{t_{insulation}}\ (W) \tag{8}$$

Where:
$\gamma_{tank} = Thermal\ conductivity\ (W/(m * K)$
$SA_{tank} = Surface\ area\ of\ tank\ (m^2)$
$T_{water} = Temperature\ of\ water\ (°\mathrm{C})$
$T_{ambient} = Ambient\ themperature\ of\ the\ tank\ (°\mathrm{C})$
$t_{insulation} = Thickness\ of\ insultation\ (m)$

The time it takes for the water temperature to decrease to chosen a specific degree ℃, is calculated with Equation 9, dividing the energy differences in the water temperature interval with the HWB heat loss at that certain temperature (Custom Thermoelectric, 2013).

$$t = \frac{E_{start} - E_{end}}{HL}\ (t) \tag{9}$$

Where:

$E_{start} = Energy\ at\ the\ start\ (Wh)$
$E_{end} = Energy\ at\ the\ end\ (Wh)$

3.6.3 Battery

A lithium-ion battery contains of lithium salt in an organic solution. With a common efficiency of around 90%, and a high-energy density, the battery is popular for energy storage in electrical grids with penetration of renewable energy. For example, the French energy company EDF Energy Networks together with ABB, used lithium-ion battery as energy storage in a demonstration project in 2008 to improve the system's frequency from the volatile wind power production (Larsson and Ståhl, 2012).

Chapter 4

Project Background

This chapter will present the project studied, which is the foundation of this case investigation. It will describe the European Commission project that the LES project is a part of. It will continue describing the LES system and its components, its consumption, as well as production characteristics.

4.1 The Case Study

This case study overlooks an ongoing project called the Local Energy System project. This project is initiated by E.ON SE, being a part of a European Union (EU) development scheme. The local energy system is built in the small village of Simris, south of Sweden, an area where E.ON is the distribution grid owner and where a private owned solar park and wind turbine is placed since 1996 and 2004. The project is a part of Horizon 2020 and Interflex.

Horizon 2020 (H2020) is the largest innovation and research programme ever made within the EU, and is created by the European Commission (EC). The program is a financial instrument with almost 80 billion euros available in the years 2014-2020, to secure Europe's global competitiveness, taking great ideas from the lab to the market. It is initiated as a mean to improve the relationship between the public and private sector to get rid of financial barriers, in order to deliver innovation and make new developing projects go live faster (European Commission, 2017a).

Interflex is a smart grid project selected in the framework of Horizon 2020 to develop clean energy solutions by exploring new ways to use forms of flexibility on a local scale, with the aim of optimising existing and new power systems. The focus of the project is to investigate interactions between the distribution grid and energy market players created with flexibility. Energy storage, demand response, islanding, grid automation and different energy carriers are to be examined more closely. Associates of Interflex are electrical retailers, power component manufacturers and the distribution system operator companies CEZ Distribuce, Enedis, E.ON, Enexis and Avacon, operating in five different countries. Interflex will operate between the years of 2017-2019 (European Commission, 2017b).

The Local Energy System project started by E.ON SE is one out of six Interflex demonstrations. The project consists of two phases. Phase one is to create a micro-grid disconnected from the main grid that can handle up to 100% of renewable electricity penetration from the already existing wind turbine (WT) and photovoltaic (PV) power station. A central battery energy storage system (BESS) will play a key role in the system to make it possible to disconnect from the main grid without risking that the village will be short of electricity supply. The BESS will also handle the discrepancy between production and consumption providing eligible frequency in the system. If BESS fails to handle the negative discrepancy, a back-up generator (BUG) fuelled with renewable hydrogenated vegetable oil (HVO) diesel can be activated to handle negative imbalance. Phase two will invite and include consumers, allowing them to help maintaining system balance by installing technologies creating decentralised storage capacity, which makes it possible to perform DSR. Remote DSR has been chosen as controlling method. The project aims to install DSR equipment on household technologies to remotely control customers' consumption using smart grid technologies. Therefore, this report will from here refer to DSR as remote DSR. Heat pumps (HP) and hot water boilers (HWB) will be used as steerable power-to-heat systems, as well as lithium-ion batteries connected to customers' PV-power production (CBESS) as power-to-power systems.

Customers who own any of the three technologies mentioned will be invited to participate in DSR, meanwhile customers who do not own any of the mentioned equipment will be offered to invest in it. The promised condition is that the indoor temperature will only change ±1 ℃ from the customer's own chosen temperature, if participating with HP technologies (E.ON, n.d.(b); E.ON System Drawing, n.d.).

The most important components of the LES are presented in Figure 5 to give an overall picture, and is summarised in Table 1. The LES project will run between 2017 and 2019. During this period of time, the LES will be disconnected from the main grid 10 weeks, distributed evenly over the year, each year, for island mode testing. This means, it will not work self-sufficient most time of the year.

Table 1 - Summary of the local energy system components.

Production	Wind Turbine
	PV Power Station
	Backup Generator
Central Flexibility Resources	Central Battery Energy Storage System
Potential decentralised storage Resources	Customer Battery Energy Storage System
	Customer Hot Water Boiler
	Customer Heat Pump

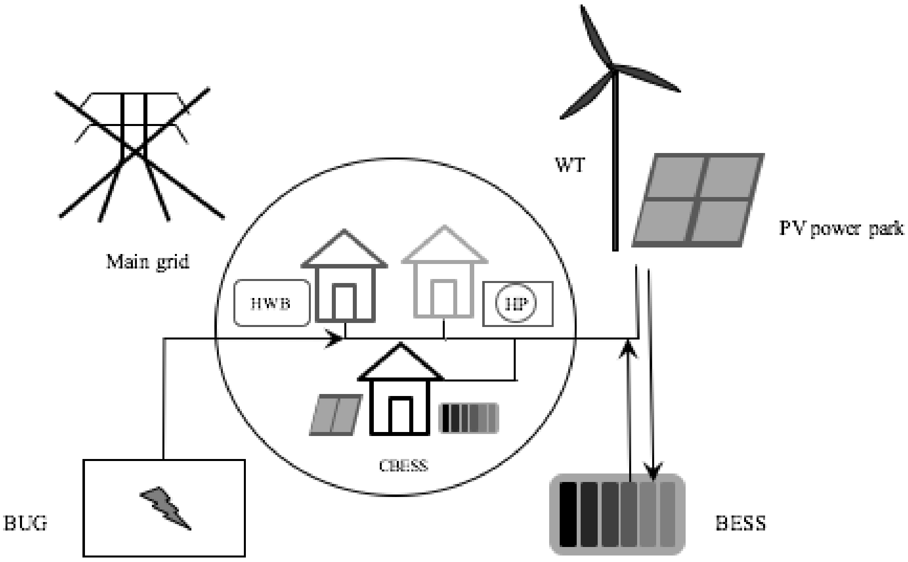


Figure 5 - Picture of the LES in Simris and its components based on E.ON System Drawings (n.d.).

4.2 Simris

The society of Simris is located in the south-east region of Skåne, the southernmost part of Sweden. In 2010, the village registered 211 inhabitants and E.ON has today 149 connection points in the grid supplying the area with electricity (SCB 2016; E.ON n.d(c)). However, these connections are not only private electricity customers (households), a car dealer, a gallery, a church and a few smaller farmer industries are attached as customers via the E.ON distribution grid. Many customers are non-permanent residents, using the house in Sirmis as a holiday home. The population has decreased with a handful inhabitants per year since 1960, leaving a total decrease of 34% since the 60's and a 10% decrease between 2005 and 2010 (SCB 2009). Consequently, the energy consumption profile might be subject to changes during the next coming years if population changes follow the same pattern.

Figure 6 - Picture of Simris in 1964 (Source: Simris Byalag. Image by A/B Flygtrafik).

4.3 E.ON Energy Company

E.ON SE is a European holding company and one of the largest private energy companies in the world. E.ON's headquarter is placed in Essen, Germany, and operates in over 30 countries worldwide.

Before E.ON SE acquired E.ON Sverige AB it was called *Sydkraft* and in 2016, E.ON separated their fossil-fuel assets into a new group, Uniper SE. Uniper strives to ensure security of energy supply through global energy trading business and conventional power generation such as nuclear power and fossil-fuels (E.ON 2017a). The new E.ON strategy has its focus on three core businesses: renewables, energy networks, and customer solutions. These businesses reflect global trends in energy markets to tackle climate changes with the help of high shares of solar and wind power in the power generation mix, to go from yesterday's power lines to smart energy networks and to manage the increasing demand of innovative customer solution (E.ON 2017b). The local energy system project is ruled under E.ON Elnät AB, but with resources from E.ON Sverige and E.ON SE, see Figure 7.

Confidential

Figure 7 - The E.ON Sweden corporate structure and hierarchy (E.ON, 2017c).

4.4 Production and Consumption Characteristics

In order to understand the problem that the LES may experience in balancing the system to an eligible frequency, it is important to know the capacity of the production, its characteristics as well as the consumption in the village. The installed capacity and average production of the WT and PV power station in Simris is presented in this section together with the inhabitants' consumption from the 149 connection points to the grid. The available measured data, taken from E.ON data acquisition, is between 2014 and 2016. The characteristics of year 2016 is here presented to give an overall understanding how the production and consumption may look like. The added reserve capacity BUG and BESS are also described below.

Production

The installed capacity of the wind turbine is 550 kW. It has average annual production of 1.439 GWh, 2 616 full load hours per year and a capacity factor of 30 %. Figure 8 presents hourly measured data of the total wind production during year 2016 showing its volatile production.

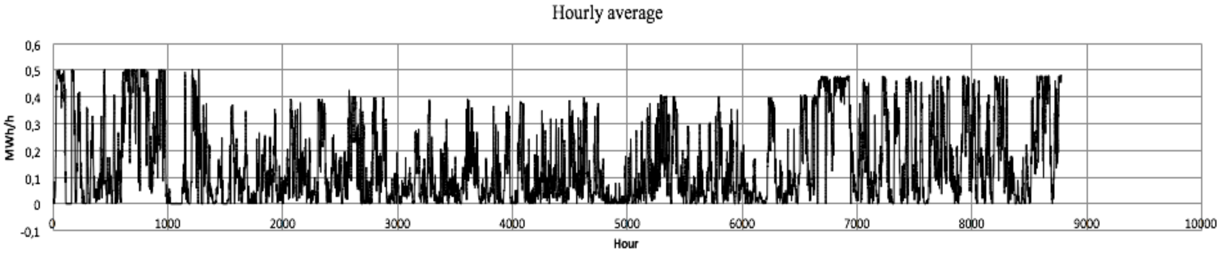


Figure 8 - Hourly measured data of the total wind power production in MWh/h, during year 2016.

The PV power station has an installed capacity of 422 kW, an average annual production of 0.472 GWh, 1 120 full load hours per year and a capacity factor of 13%. Figure 9 presents hourly measured data of the total PV production during year 2016, showing that most of its production is made in the in the spring, autumn and summer (E.ON System Drawings, n.d.).

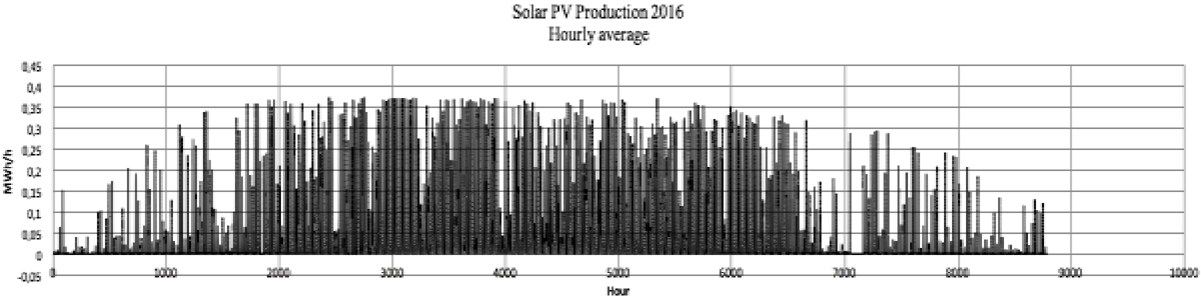


Figure 9 - Hourly measured data of the total solar power production in MWh/h during year 2016.

Together, the WT and PV power station has an installed capacity of 972 kW, an average annual production of 1.911 kWh, 3 736 full load hours per year and a capacity factor of 43 %. Figure 10 shows hourly measured data of the total wind and PV production combined during year 2016 (E.ON System Drawings, n.d.).

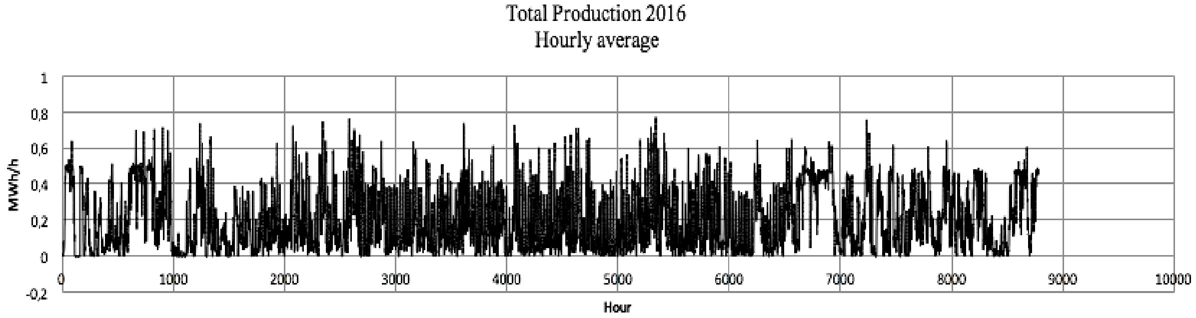


Figure 10 - Hourly measured data on the total power production, wind and solar combined, in MWh/h during year 2016.

Consumption

The consumption is in average 2.27 GWh annually. Figure 11 presents hourly measured data of the consumption from the 149 connection points in year 2016.

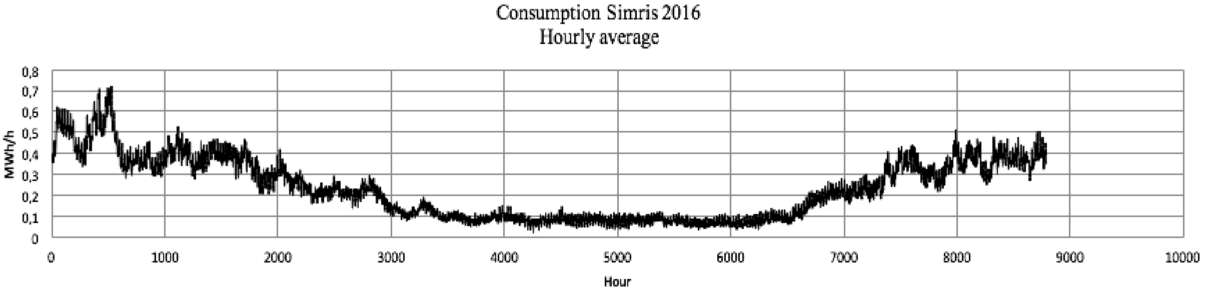


Figure 11 - Hourly averages on total consumption in MWh/h during year 2016.

Discrepancy

In most DSR project peak shaving of demand is used to match supply, but in the LES project both peak shaving of demand to match supply and peak shaving of supply to match demand is needed to hold an eligible frequency in the system. This situation is common when there is a high penetration of intermittent energy sources, as of the situation for an LES. The system strives to have a discrepancy of zero at all time and it is required to do so in order to work disconnected from an overlying grid.

To show how well the local supply of electricity meets the local demand, an example of the discrepancy in year 2016 is presented. A clear mismatch between supply and demand is detected. During winter, the system will struggle to meet demand, and during summer, the system will generate energy exceeding demand, see plot and red line of complete balance, in Figure 12. Positive and negative discrepancy must be peak shaved too zero for the grid to work in complete island mode.

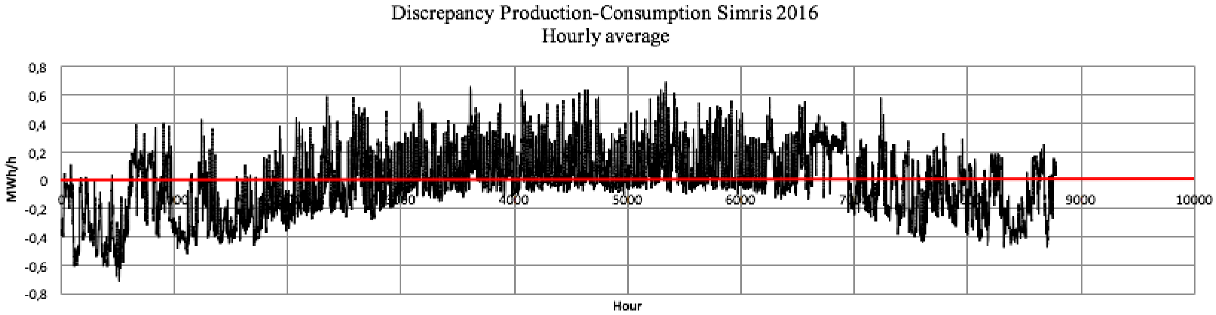


Figure 12 - Hourly averages on discrepancy in MWh/h between consumption and production in 2016.

Reserve capacity

A BUG can handle negative discrepancy of installed capacity 480 kW, when other sources are unable to supply the system. The BESS has an energy storage capacity of 330 kWh, with an output capacity of 830 kW, meaning that at full load operation, BESS will discharge from full load in 24 minutes.

4.5 Actors in the LES

Above in Section 2.1, it was described how different actors operate in the Swedish electricity market. Now, when an LES is created and customers are integrated as a flexibility resource, the actors within the local market changes in relation to the traditional market. The situation of the LES is, as explained, a new system situation. Therefore, new actor conditions apply.

- *Electric Producers* - Two producers operate in the LES, however, during the time of the pilot project, the owner is under agreement with E.ON allowing them to control the production of the WT and PV power park.

- *Electricity Retail Companies* - The household customers purchasing electricity which is distributed through the LES, have various contracts with different retailers, which are unknown.

- *Network Owners* - E.ON owns the LES power grid.

- *Electricity consumers* - All inhabitants and electricity users in Simris are electricity consumers. Customers purchasing the electricity however, are both private households and companies.

- *Electricity Power Exchange* - Since the LES is still in cooperation with existing retail companies, the Nord Pool spot exchange market will still apply. In a real local scenario however, the pricing market changes. The instantaneous balance of supply and demand, affected by the costs of the supply resources, and creates a new local exchange market. Together with customer integration, the market becomes even more complex.

- *System Operator* - The one managing the LES grid will be E.ON. E.ON is here in charge of constant managing mismatch in supply and demand when in island mode.

New actor:

- *Aggregator* - This is a new actor added to the LES compared with the classic actors in the Swedish electrical market. The aggregator can through remote control, use customers' flexibility resources to help the system operator manage the discrepancy between supply and demand when in island mode.

Chapter 5

The Customer Perspective

This chapter explains the interview and survey methods, and presents results from the customer survey conducted. It will explain, analyse and discuss the data collected, as well as introduce conclusions on which driving forces exists in Simris for participating in DSR. Finally, the credibility of this customer research will also be discussed.

5.1 Introduction

Enabling household technologies and equipment to be a part of an interactive energy system, it implies the customer to understand the setup of the system, and its own functional role. Even more importantly; it requires the company to understand the customer and the customer's point of view in acting as a balance device. It will be presumed that this is a role the customer has not possessed before.

DSR through heating household equipment will be used as a resource of flexibility. Therefore, an inventory of the technical components in households must be carried out in order to understand the potential and technical conditions of DSR.

After inventory is done, the next step is to investigate the households' driving forces in being a part of the demand side measurement, which is a research question of this study. The customer's perception of the value of their flexibility; thoughts, opinions, willingness to let a company control their heating equipment, and their driving force to participate should be investigated. In the end, it is the customer's choice to decide whether they want to take an active part in the project or not. The most important part of the DSR implementation is therefore the customer, its behaviour and attitude towards the project.

5.2 Survey Method

We chose to combine two survey methods, which is called a mixed-mode survey design. This is a method where two or more modes of data collections are combined to counterbalance the disadvantages by the advantages of another. Essentially, it is about conducting more than one research in more than one way, to find trustworthy results (De Leeuw, Hox and Dillman, 2008). In this study, both face-to-face interviews and a mail/online survey have been conducted as data collection modes. This was because we wanted to reach out to as many Simris customers as possible, still meeting a part of the target face-to-face to understand their points of views on a more profound level.

5.2.1 Face-to-face Interviews

Face-to-face interviews was chosen as a qualitative research method to fully understand customers' thoughts and point of views. This method can answer non-measureable questions as well as to compare impressions, such as customer's spontaneous reactions and understanding, with quantitative data. During an interview, follow up questions can be asked, background information can be explained and made sure to be completely understood.

In search for patterns to find correlations between qualitative and quantitative concepts, a half-structured interview model was chosen. This model is credible if all interviews are made within the same theme, keeping the same focus and in addition, give opportunities for quantitative analyses. The degree to which a quantitative analysis can be made, is highly dependent on the numbers of open questions in the interview (Lantz, 1993). The quantitative measures searched for, were in specific the technical heating equipment that needed to be mapped for the potential DSR flexibility resources, and customer demographics to understand who lives in Simris.

The interviews were made face-to-face so that the customer's answers can be interpreted via behaviour, voice and tone. Interviewer has potentially less impact on respondent behaviour during a phone interview, but with phone interviews, there are risks of losing dimensions to analyse (Lantz 1993, 21).

All customers were given a choice of location for the interview within areas of Simris, Lund and Malmö. The meeting time was set to a slot of 60 minutes. However, time usage for each interview varied due to customers' previous knowledge of the LES project, openness and length of answers. The interviewees were selected in three different steps.

1. Customers who attended the first E.ON customer information meeting in Tomarp (village in Skåne, close to Simris) were given the option to voluntarily register for an interview.
2. Meeting attendants, but non-volunteers, were contacted by email and phone.
3. Customers who did not attend any of the two meetings, were contacted.

Altogether, 20 interviews were conducted. After 20 interviews, the investigation reached a saturation point where little, almost no, new information was given, or insights gained. We then chose to limit our survey to 20 interviews, and after that, complementing with a quantitative survey.

5.2.2 Mail and Online Survey

As quantitative research method, to systematically gather information from a larger sample of population, a survey method was chosen. This methodology worked as a complement to the qualitative research, and to statistically prove interview findings in line with the mixed-mode survey method (De Leeuw, Hox and Dillman 2008, 299).

In the case for this study, where the inhabitants of Simris was the target group, a coverage error due to lack of internet connection, or use of it, caused an issue. To solve this issue, the survey was made in two versions; a printed version that was sent out by traditional mail, and an online survey accessible via an internet link. However, containing the same content. The two versions aimed to increase the chance of targeting a higher share of the population. The survey was sent to 138 households connected to E.ON's transmission grid within the area. Not all 149 households were targeted due to the fact that some permanent addresses were registered abroad.

Both mail and online surveys limited the complexity of the questions. There is a risk of misinterpretation and misunderstanding due to questions asked in text, both regarding single questions and in worst case; the whole survey. No question can be further explained or rephrased once the customer has the survey in its hands. It is therefore of importance to keep the survey simple to eliminate the risk of misinterpretation (De Leeuw, Hox and Dillman 2008, 243). The written survey was therefore made of short questions, mostly check questions, with multiple choices. The respondent's credibility may also suffer since it is impossible to know if the respondent is truly honest or not in its responses. During an interview, it is easier to interpret trustworthiness since reasoning and behaviour can be studied meanwhile. The written survey and face-to-face interviews are therefore complementing each other.

To reduce the risk of number of non-use, non-value questions in the written survey, the survey was created after face-to-face interviews were conducted.

5.2.3 Households as Customers

DSR is a flexibility service offered from a building's heating equipment and system. This system is (most often) shared within a household. Both the production of heat and the costs it brings are usually shared with all residents living in the house. It is therefore of value for our study to understand the willingness to participate in DSR from a shared point of view of the household as a unit. In addition, the customers from a network point of view, are connections points with electric meters to the power grid, not individual consumers which also brings the unit of households into consideration. We have therefore chosen to look at households as a unit for customer responses. The study subjects are hence households, not individuals and in our survey investigation, we have asked for the household's point of view.

Using the concept of households as study objects, explained in Sernhed (2014), this study can benefit from the same definition used:

"*A domestic unit consisting of the members of a family who live together along with nonrelatives such asservants"* and *"The living spaces and possessions belonging to such a unit"* (The Free Dictionary, n.d.)

Further, Niehof (2011) discusses the household as an important role in the field of Home Economics since the beginning of the 1900's. She explains that the household can be seen as a conceptual unit, which reveals the way people structure their daily lives in a certain setting.

According to Guggenheim (1990), a household can be called a moral economy, which is "*A system of transactions which are defined as socially desirable (i.e. moral), because through them social ties are recognised and balanced social relationships are maintained*".

One conflict that should be considered however, is the one that many opinions can live under one and the same roof. Different generations, sexes, ages, salaries, sensitivities to changed comfort, attitudes to renewable energy etc can make the unit of the household internally diverse. Nelson (1988) explains that the topic of intra-family conflicts are often neglected in the light of individual decision making, and that there are various ways decisions can be made within a household. We have therefore asked for *your* (plural, Swedish: er/ni) point of view. During interviews, we asked for meeting with as many residents as possible, if possible. In survey answers, it is difficult to analyse the internal discussion, and who have been the respondent. We will assume that the one responding to the survey has answered from a shared household point of view. One question was however directed to the single respondent, the one about gender, to get an insight who in the family answers if the household consists of a family.

5.2.4 The Notion of Active Participation

When survey material was created, the question of how to initially explain the concept of demand side response to customers rose. Since all customers are potential flexibility resources, choice of words connected to DSR was carefully considered. By no mean, we wanted to frighten, scare, give a wrong picture or make customers sceptical about demand side response. The word “steering” was eliminated from survey material. A definition was built which we named *active participation*. Since all customers were already participants of the system (they own a house in the LES area), a notion where the word *active* was added to the explanation was used in the survey material and during interviews. This would mean that the customer is actively contributing to system balance. The definition expressed to customers was the following:

> *“To participate actively means that you let E.ON install controllable equipment on your heating system in your home, to investigate in which way households can contribute to future energy systems”.*

5.2.5 Hypothetical Factors

With this survey, we wanted to find out why a customer would like to participate actively in a local energy system, and which driving forces that exists among customers to enable DSR. During interview and survey question construction, we therefore based our questions on a few hypothetical factors that is the core of the LES system, with support in previous studies in literature, presented in Chapter 3. These were environmental benefits, renewable energy, new technology, local matters, and engagement in local matters/community.

5.3 Analysis Method

When analysing findings from the customer survey, it is important to note that the two methods generate two different sets of data that need to be handled differently. Therefore, the two data collections are analysed separately in this work. A survey answer and an interview answer have not been analysed under the same condition even though they might cover the same topic. A combined conclusion will follow in Chapter 5.5 where findings and results from the both collection methods will be summarised.

The steps used to analyse data collected is based on Annika Lantz method from *Intervjumetodik*, following five steps shown in Figure 13 and Table 2.

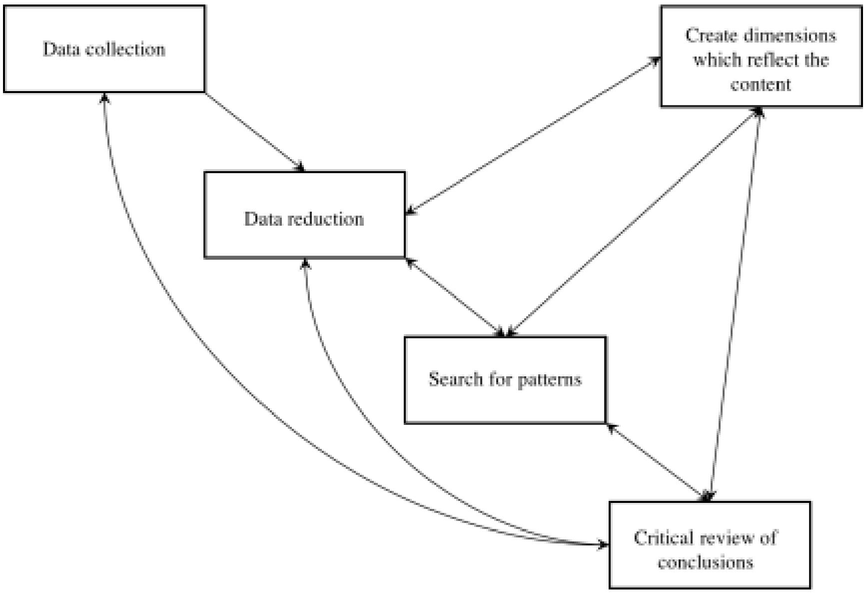


Figure 13 - Steps used for analysing interview and survey data (Lantz, 1993).

Table 2 - Table with steps based on Lantz (1993) method, used for analysing interview and survey data.

	Interview	***Survey***
Data collection	All face-to-face interviews were recorded and notes were taken during the interviews. Some interviews, or parts of them, were re-listened to and more extensive notes were taken.	A written survey with a total of 30 questions sent out to 138 households. Answers sent back via letter received at E.ON office and digitized.
Data reduction	Data was inserted in an excel document and thereafter sorted on level of relevance, with customers' driving forces of participating in DSR as highest relevance. Quotes were noted.	Data was inserted in an excel document and thereafter sorted on level of relevance, with customers' driving forces of participating in DSR as highest relevance. Added non-response error to statistical graphs.
Search for patterns	Comprehensive data scanning, summaries, summations and evaluations were made. Connections between different questions and answers were investigated.	Comprehensive data scanning, summaries, summations and evaluations were made. Connections between different questions and answers were investigated. Patterns were compared with interview findings.
Create dimensions which reflect the content	Data was reconstructed and grouped in new sub-themes.	Themes were matched with interview sub-themes.
Critical review of conclusions	Conclusions were discussed (critical comments are presented in Section 5.7).	Conclusions were made and compared with interview findings (critical comments are presented in Section 5.7).

5.4 Results and Analysis

In this section, results will be explained comprehensively and analysed. When compared with real statistical data of Sweden, source is mentioned. A critical review regarding target group statistics and selection will follow in Section 5.7 Critical Review. This section contains a complete and detailed presentation of the customer survey. For a conclusion and analysis, go directly to section 5.5.

5.4.1. Face-to-face Interviews

Demography and households

The average age of interviewees was high: 65 years of age. Most interviewees were between 55 and 75 years of age. This can be compared with the average mean age of the inhabitants in the nearby city of Simrishamn, which is 48.6, and of Sweden, which is 41.2. Simrishamn is the sixth municipality with highest mean age in Sweden (Statistiska Centralbyrån, 2017a). Further, most interviewed customers were single households or two people households. Only 4 out of the 20 households contained of more than two residents, these were all couples with teenage kids. All interviewed customers were permanently resident in Simris.

The high age had a high correlation with employment; half of the households included at least one retired resident and in addition, eight households which includes one non-retired resident today will enter retirement age within 3 years. Hence, 14 of the interviewed households will include at least one retired resident by the end of the LES project timeline. During interviews, it was understood that age had an impact on behaviour and opinions. Quotes such as "I *am too old to care*", "*I am too old to make changes*" and "*That is up to the next generation*" were noted. This might have a negative impact on participation willingness since the project will require change or engagement in some way. On the other hand, the high mean age and the low employment rate might also contribute positively since retired customers tend to have time. For example, customers interviewed were available and highly positive to schedule an appointment in the middle of the day on short notice. The level of participants in DSR might therefore benefit from many interested inhabitants with time for engagement and a positive attitude towards new meetings. Presumably, when introducing DSR, curiosity, time and desire for engagement might exist, but changing habits, everyday situations, or introducing something unknown, might not be of acceptance in the area. DSP can therefore be affected both positively and negatively by high average age and high share of retired customers.

Most interviewees have been living in Simris for many years, but some have recently moved to the village. One customer had lived in Simris for his/her whole life, and another one had just moved back from a few years in another village close by. Another interviewee had just moved back from a few years abroad, but had spent all childhood summers in Simris. It seemed like most interviewees had a connection to Simris, or the close by area, if recently moved to the village. Further, it was understood that many Simris inhabitants know each other and that they have a good neighbourhood cooperation. For example, some interviewees had heard about the project from a neighbour, and some recommended other neighbours for further interviews in this study. During one interview, heading to the next, a customer said; "*Tell the next interviewee I said hi*!". That there is a local interest association in Simris was also mentioned a couple of times. The "Byalag", is working to improve the village's common utilities and to increase the community feeling. A project anchored in building something local can possibly contribute from a neighbourhood with long time settled customers and low moving turnover. Presumably, it can also benefit from the already well working neighbourhood cooperation.

The interviews gave insight about energy system knowledge among Simris customers. Knowledge about energy systems, new technologies, future outlooks, resources and costs varied largely between customers. For example, one household gave detailed and research based explanations about why they would like to invest in solar panels in the future. Another household elaborated long and thoroughly about future transport infrastructures. Other households gave answers such as "*Renewable energy sounds good for the environment*". A handful of customers who did not agree to be interviewed, explained it with the fact that *"I am not an E.ON customer".* This proves little knowledge about energy systems, and confusion between sales and grid structures. Understanding that level of knowledge about energy and electricity varies in Simris, it might affect the way E.ON must communicate with customers. Firstly, since electricity is a complex subject, communication must be trustworthy, so that no customer feel like they have been fooled by the company, to enter a complex agreement which they did not understand. E.ON might also have to communicate in a clear educational way, to reach customers who do not understand how or why they involuntarily are a part of a research project.

Attitude towards LES project

Most common reactions to the LES project, when first faced with information about it from the interviewers, were positive. The three most common comments about the project in general were: "*I am positive to it*", "*It is exciting*" and "*I am interested in it*". The impression from the interviews is that Simris inhabitants are positive or very positive to the new energy system being built. Most initial reactions were due to the positive perception of helping the environment using renewable energy production. This was also what customers' state they think is the best thing about the project. Most common answers to this question were: "*It is good for the environment"*, "*It is good for the future society*", "*It brings attention to the Swedish countryside*", and "*It brings lower electricity costs (hopefully)*". Moreover, negative comments mostly regarded the island mode test period of 10 weeks per year. Many customers thought that this does not correspond to reality to a sufficient extent: "*We hoped for a continuous renewable system*" and "*I want a local renewable energy system always".* Negative reactions also concerned worries towards the risk of outages, the risk of higher electricity costs and the risk of lower comfort standards in households. "*Will it really work*?" and "*I want my electricity supply to work exactly as it does today*" are two common negative comments.

By the time interviews were held, the project had been communicated by E.ON through a letter, a customer meeting (which around 60 customers attended) and an open house event in Simris (which around 30 customers attended). However, only 9 of the 20 customers interviewed had first heard about the project from E.ON's own letter. The rest of the interviewed households, had learnt about the project via the local newspaper or via a neighbour. Only two customers got the information online. These findings might have a connection with high mean age. For example, according to Findahl (2010), the usage of internet is less common in higher population ages.

Attitude towards local and renewable energy

12 out of the 20 interviewed households, claim that they care about where the energy they use comes from. The most common answers were that the interviewees did not prefer coal, nuclear or international imported energy. However, that the energy is locally produced in Simris seems not to be of high importance among the target group. Almost no household said they think it is important that the electricity comes directly from the WT and PV power park in Simris. Still, interviewed customers believe the project might help Simris gain national recognition, higher attention by the municipality or become a role model for future local systems in other parts of Sweden or the world. This show that there is an interest and proudness of living in an area targeted for a pilot project, and that there is a hope for infrastructural improvements in the area.

The topic of future energy systems provides many thoughts, opinions and point of views. The question about energy in the future can indicate how knowledged the customer is about energy systems, how interested the customer is in the field, and what he/she might think of the LES project. Most interviewees believe in an increase of renewable energy resources. Some think the systems of today's society must change due to decreasing access of oil and coal. Although most respondents are positive towards PV technologies and wind turbines as a growing energy resource (one customer had financial shares in the Simris wind turbine when it was built), factors such as sound, destruction of nature, intervention with animal species and non-attractive aesthetics were mentioned. For example, one customer explained: "*I do not really like wind mills with their huge pillars, and high sound. If we want a real effect from it we will be flooded with them*". Another comment about wind turbines were: "*They are okay as long as I live far away from them*". This can indicate both acceptance and resistance to the LES project in Simris, and that how and in which way the project is to be communicated should be adjustable to the different point of views.

Attitude towards technology

Since the local energy system will consist of technical components relatively new on the market such as DSR control equipment, a visualization platform and household batteries, it is interesting to understand if customers are interested in this kind of technology. DSR participation requires instalment of new household or control equipment. Hypothetically, a customer can be driven by energy related technical solutions, and because of this be interested in DSP. Further, it is of aim to give the participating customers a visualization tool, preferably via an app or online, where the customer can view the system situation and its own participation in it. The qualitative study gave an impression that most customers have low interest in new technology. This means most customers do not have an interest in using new technically innovative products or technological communication tools. Two interviewees did not use cell phone at all and traditional media was used to a greater extent than new/online media. Presumably, this can relate to the high average age of the inhabitants. The study can be influenced by the low technology interest in the way that technology is a non-existing driving force in Simris households, and therefore uninteresting to use as incentive. In addition, E.ON might have to, help with installation of DSR equipment, and also with education of how it works. Customers might also have a fear of new, complex, installations, if they feel like they do not understand them.

Attitude towards DSR

More than half of the interviewed households were positive towards participating in DSR. In many cases, why DSR is needed and how it will operate in households' components had to be explained during the interview occasion. Consequently, the number is uncertain and the non-interested might have changed their answer if more information could be given. Most common reason for being negative towards participation is that the customers do not understand the consequences that follows. Being a part of the system's balance is generally perceived to be positive. Quotes such as "*If I can be engaged I want to be engaged*" and "*controlling my indoor temperature one degree, why not?*" have been expressed.

During interviews, many customers asked questions about how, in detail, the controlling of household heating equipment would work. How many times per day, week or year their indoor temperature would change due to DSR, if they need to buy something in order to participate, why the island mode will only be under operation for 10 weeks per year, were also questions we received. One customer asked: "*Will I know when my house is being controlled?*". These were questions we could not answer since not all practical conditions were set by E.ON at the point when interviews were made. Instead, we referred to upcoming E.ON information meetings and material.

Economical perspective

This question had two point of views. Firstly, it was of desire to understand if customers are willing to invest in new household equipment, hence, if they are willing to pay, for participating in DSR. Secondly, it was of desire to understand how much the customer value their DSR participation, basically what compensation they demand in order to participate in DSR. However, a direct question regarding economic conditions was decided not to be asked during interviews. This was due to the conflict that arises when the interviewed customer is not only a participant in a survey, but in fact already a part of the pilot project, to whom an agreement will be offered in only a few months' time. Telling the customer that there will be a possible reduction of energy costs, might give the customer false hope and later disappointment if the reduction is not as sufficient as the customer hoped for. Also, telling the customer that they might have to pay extra in order to participate, might scare customers away. It was also noticed, when one interview lead into economical discussions, that asking about the two perspectives had a risk of confusing the customer. When a customer stated, "*I can't pay for extra costs*", and thereafter asking how much they demand for their offered service, did not make sense. However, many customers did mention they are unwilling to increase costs with DSR participation. One household explained she would like to participate, but it will have to be with the already installed equipment; "*High investment costs are not a priority we can make*". Another customer directly came to the point and said "*This project is great if we can decrease our electricity costs a little*". "*I would be happy for lower energy costs*" has also been noted during an interview. This implies, participation is motivated if no extra costs apply.

Driving forces to participate in DSR

When finding which incentives E.ON should offer to customers for DSP, a customer's motivations and driving forces to participate actively in the project were searched for. The questions asked were, as explained in section 5.2.5, Hypothetical Factors, based on hypothetical key factors in the LES project; environment (what do you think about environmental issues?), new technology (are you interested in using new technology?), energy systems (what are your thoughts on future energy systems?), local energy (how important is it for you, that the energy you use is produced locally?) as well as costs (not asked directly). Concluding all answers and impressions from customers, three main driving forces to participate were found; environmental concern, economy and local engagement. Almost every customer mentioned his/her enthusiasm to actively contribute to a better environment and to the utilization of renewable energy in Sweden; "*It feels good that we can be a part of something that is good for the future"*. Secondly, many customers expressed their concern about increased costs or interest in decreasing costs. Finally, many customers also indicated a positive reaction to the fact that Simris will benefit from nationwide attention as a small town on the countryside.

5.4.2. Mail and Online Survey

Out of 138 surveys sent to Simris households, 62 answers were received and analysed. Only two answers were received via the online survey, the remaining answered via traditional mail. All surveys were analysed even though 16 of the written survey respondents were also interview respondents. Therefore, the total reach of the overall research is 66/149 customers (44.3%).

Demography and households

The survey targeted 21 customers not permanently resident in Simris, hence 38% use their house as a vacation house (between 0 and 26 weeks per year), see Figure 14. This might imply lower DSP for the project since permanent customers are easier to target and communicate with all tear around. Most households were couples or single households as shown in Figure 15. Only eight households were families with children under 15 years of age, Figure 16. The average age of the responding customers were high, 68% of the households had at least one resident representing the age group of 60+. Here, the survey reinforces the findings from interviews, as well as known statistics from Statistiska Centralbyrån. More men than women have answered the survey as seen in Figure 17, which might get us to speculate if this is because men have higher knowledge or tend to take decisions regarding energy systems in households.

More than half of the households who answered the survey have an electricity agreement with variable price today. This gets us speculate if customers are risk prone, see Figure 18.

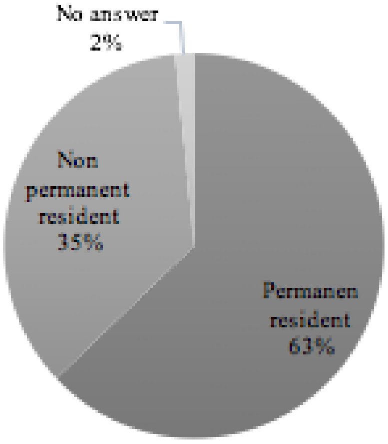
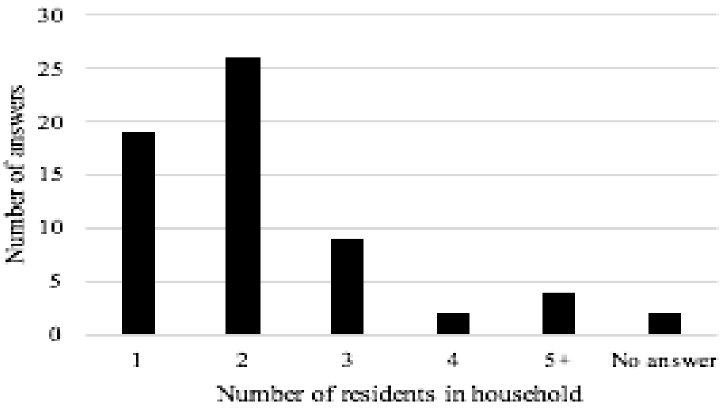


Figure 14 - Are you permanent residents in Simris?

Figure 15 - How many residents live in your Simris household?



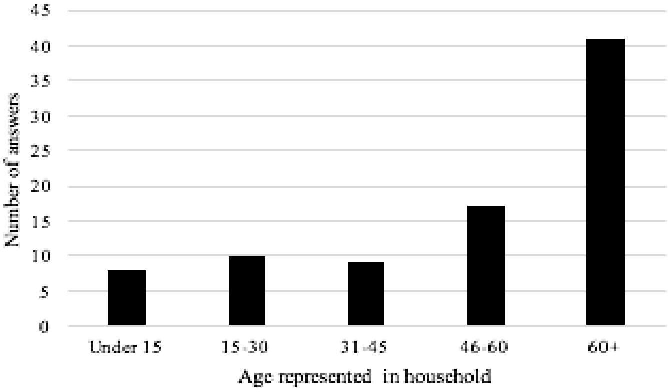


Figure 16 - Which groups of ages are represented in your household?

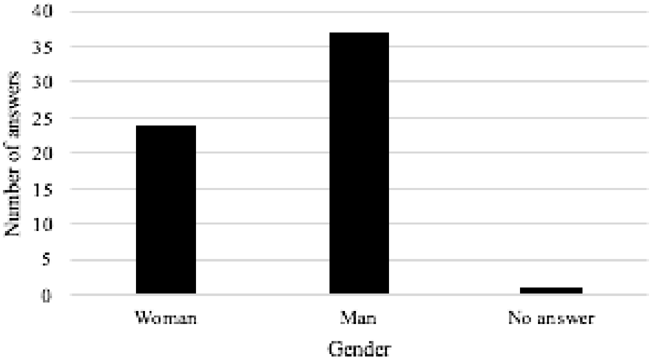


Figure 17 - Gender of the respondent

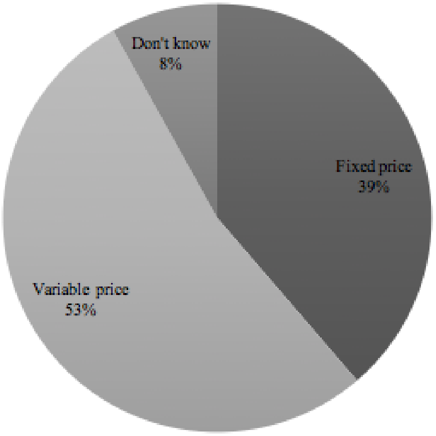


Figure 18 - Which kind of electricity agreement do you have today?

Attitude towards the project

According to the survey answers, most customers had heard about the project before answering the survey, and in most cases, knowledge about the project was gained from the first letter sent out by E.ON, statistics shown in Figure 19. Note that the interview findings showed that more than half heard about the project through other channels than the first letter. Positive attitude towards the project exists among the households who answered, most common answer is to have a *very positive* attitude towards the project and being interested in it, shown in Figure 20. Here, the survey answers correlate well with interview answers and give a similar picture of project attitude. Out of the survey answers, 16 have responded they are either neutral or have a negative attitude towards the project. Reason for not being positive, are mainly the short time the project will run, and higher enthusiasm towards other energy resources than wind and solar. Two examples of these comments are: "*I believe in nuclear power for future development, we have the world's most safe nuclear power plants according to statistics*" and "*Shame it is only 10 weeks*".

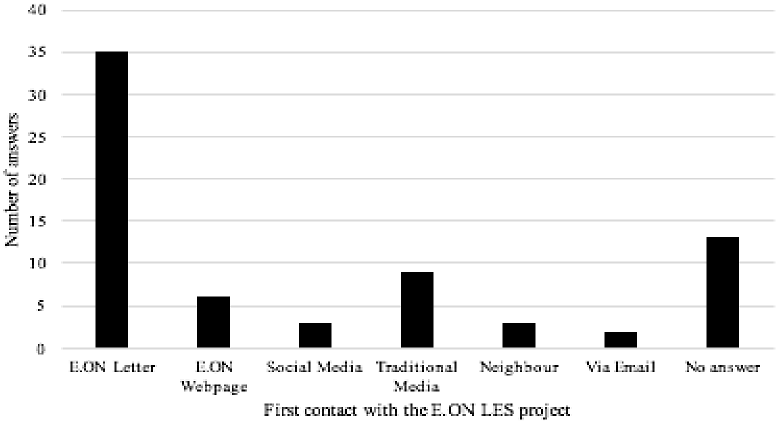


Figure 19 - How did you first hear about the E.ON LES project?

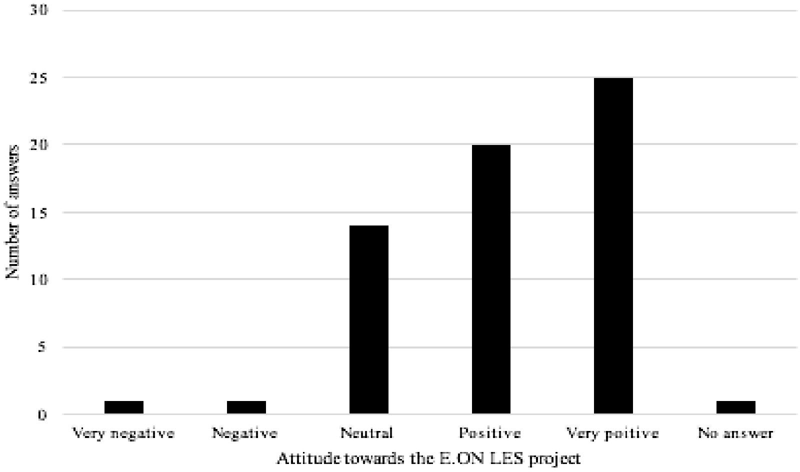


Figure 20 - What is your general attitude towards the E.ON LES project?

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Attitude towards technology, energy and environment

The survey questions regarding the hypothetical factors investigated, were asked in the form of a scale of five alternatives. The middle alternative was a neutral option, where the customer could express neutral attitude towards the renewable energy, local energy, environmental products and new technological products. Two higher alternatives let the customer express positive attitude towards the factors, and two lower alternatives let the customer express a negative attitude.

The survey answers showed that both environmental friendly products and environmental friendly energy is *important* or *very important* to the inhabitants of Simris, see Figure 21 and 24. The reason for being interested in the project is mostly due to its close connection with positive climate contributions and increase of renewable energy sources. Again, interview findings and survey findings show similar result. Survey answers also show that attitude towards the wind turbine and solar park has slightly increased over the years since they were built and this proves that change of attitude is possible, see Figure 22 and 23.

Most answers stated it is important to use energy that comes from renewable energy sources. But just as findings from interviews showed, it is not important to consume energy produced in the local area of Simris, see Figure 25. This might contribute to a conflict in communication between customer and company; "*When Swedish energy system is so well functioning, why disconnect from it?".* There might be a risk that customers do not understand the purpose of the project, or why an LES is needed from their point of view. This might impact customers' attitude towards the project, making them sceptical to its meaning. The purpose of the project should be communicated clearly to Simris households.

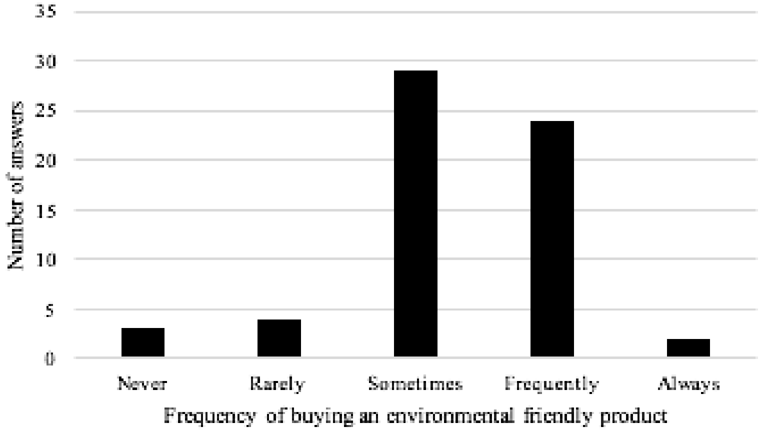

Figure 21 - How often do you choose to buy an environmental friendly product before a traditional product even though it is more expensive?

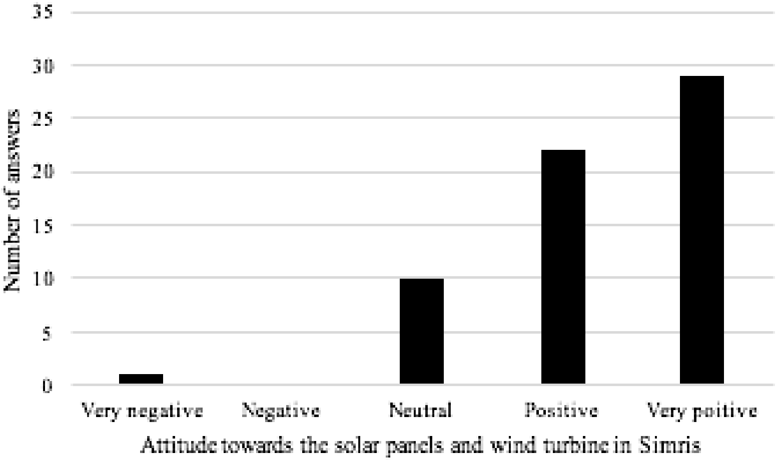

Figure 22 - What is your attitude to the PV power station and wind turbine in Simris?

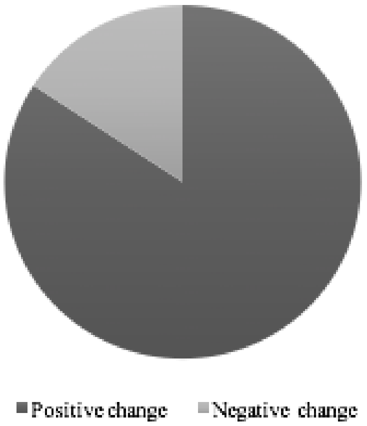

Figure 23 - Change in attitude of PV power station and wind turbine in Simris.

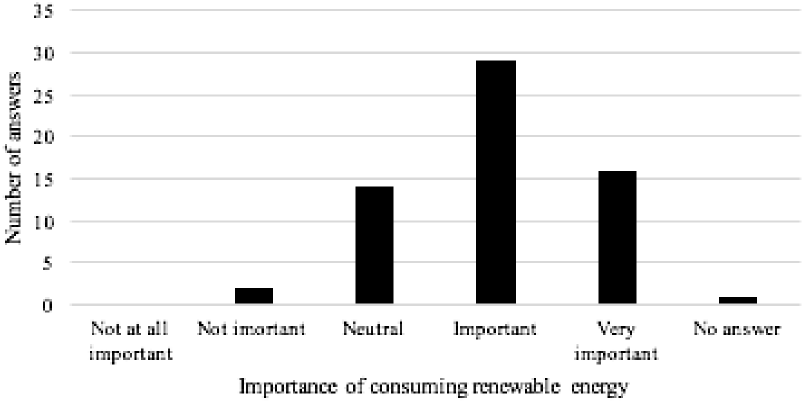

Figure 24 - How important is it for you that the energy you use comes from renewable sources?

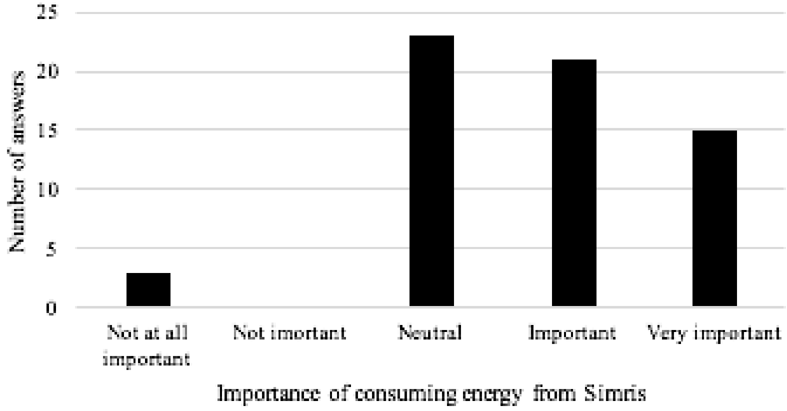

Figure 25 - How important is it for you that the energy you use comes from Simris?

Household technology

In order to map household technical conditions, there were some questions in the survey about the existing heating technology in the household. Summarised from survey answers in Figure 26, only 16 households currently had an air/water heat pump and 31 had a separate hot water boiler. In total, 40 out of the 62 mapped households, had equipment that could be used in DSR today. However, since detailed information such as model and age of system is lacking, a further investigation still needs to be done of these 40 potential DSR technologies.

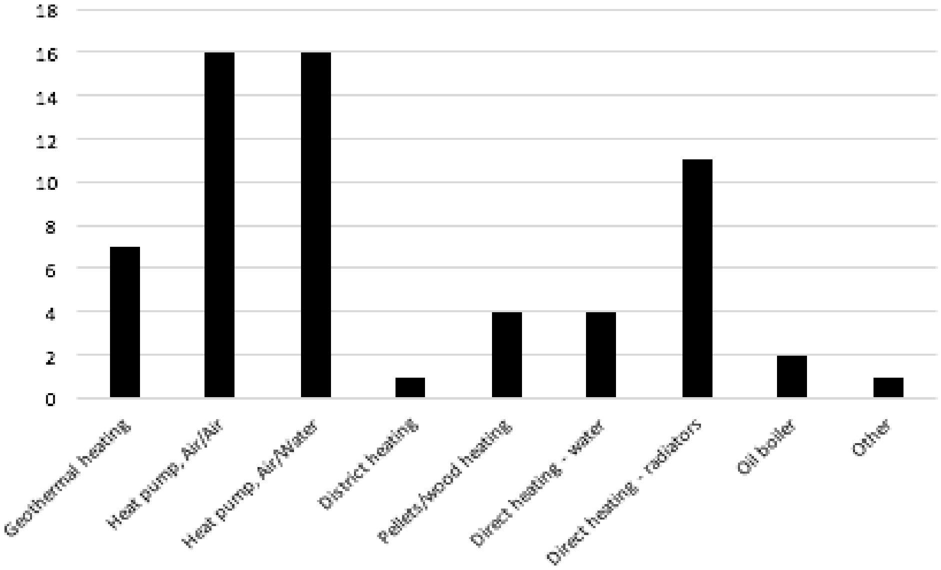

Figure 26 - Which heating system do you have in your Simris household?

A direct question about interest in investing in new household equipment was also asked in the survey, see responses in Figure 27 and 28. Unfortunately, only 15 respondents would be interested in investing in a new heating system. This shows that an investment incentive for customers might be needed. Further, we can also speculate about the short test period time, only ten weeks per year during three years. There might be a risk that customers do not understand why they need to invest in new heating equipment when the baseline of it is that it will be used ten weeks per year. Maybe the testing period of island mode can be extended or give an incentive strong enough for customers to invest in new heating systems for own use.

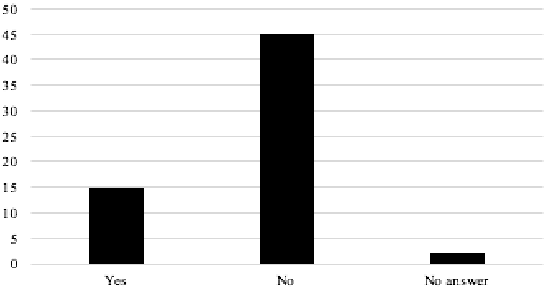

Figure 27 - Would you be interested in investing in new heating technologies?

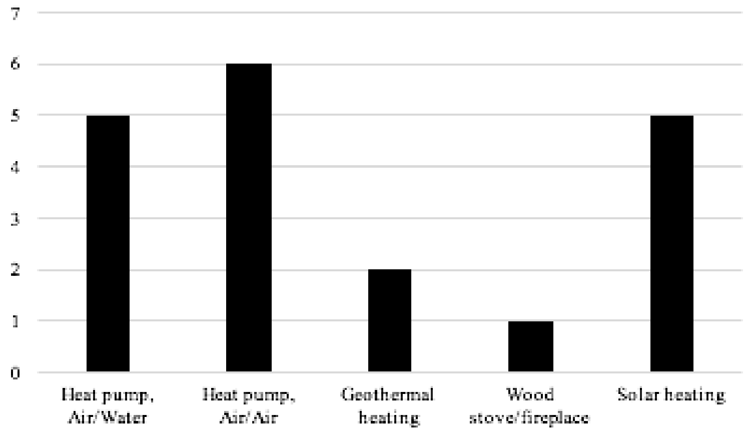

Figure 28 - If you are interested in investing in new heating equipment, what equipment are you interested in changing to?

Interest in participating actively in the project

There is no doubt that there is an interest in participating with household components in DSR; 63% showed an interest in participating in DSR. Most of those who showed interest are permanent residents, which are the ones easier to target and communicate with for DSR control at any time of the year. The three most common answers for why the customers are interested in participating, as shown in Figure 29, were the following:

- Curiosity for the project
- Contribution to better environment
- Seeing opportunities to decrease energy costs

It is important to note that the project and DSR contribution has not been marketed as a way of cutting electricity costs. It has neither been marketed as an environmental friendly project. The main point addressed has been the local perspective of the project, and its possibilities to take advantage of the local conditions and electricity production. Still, cutting costs is what many customers hope to achieve according to the survey answers, as well as to contribute to a better environment. For an LES project, this might mean the view expressed about the project can be adjusted.

Out of the non-interested, which was 34% of survey respondents, around a third chose not to show interest in active DSR participation due to lack of understanding about how their involvement can decrease household electricity costs. The answers are presented in Figure 30. Moreover, another frequent answer was that they know or understand too little, or have too little information, to base their report of interest with. Next to these, most common answers for showing a negative interest were regarding time constraints. Lack of time, no time to engage in energy matters, and usage of the Simris household only as a holiday home were three reasons customers had commented in the survey. It is understood that customers request information in order agree on remote steering of their heating equipment, but more noticeably, lack of information is a reason for not even showing interest in participating and receiving more informative material from the company. Costs, however, is a key factor, and might play an important role in customers' decision making. Both interested and non-interested customers strive for lower electricity costs. Again, which prices or compensation models the customer will be offered have not been communicated by E.ON when the survey was sent out. We find that a financial incentive is of importance, and a key attraction point to communicate to non-interested customers.

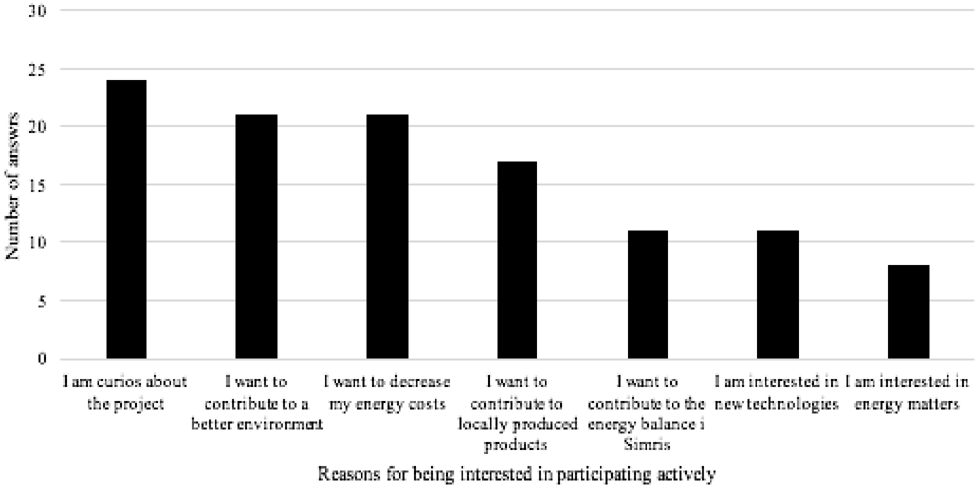

Figure 29 - Why are you interested in participating actively in the E.ON LES project?

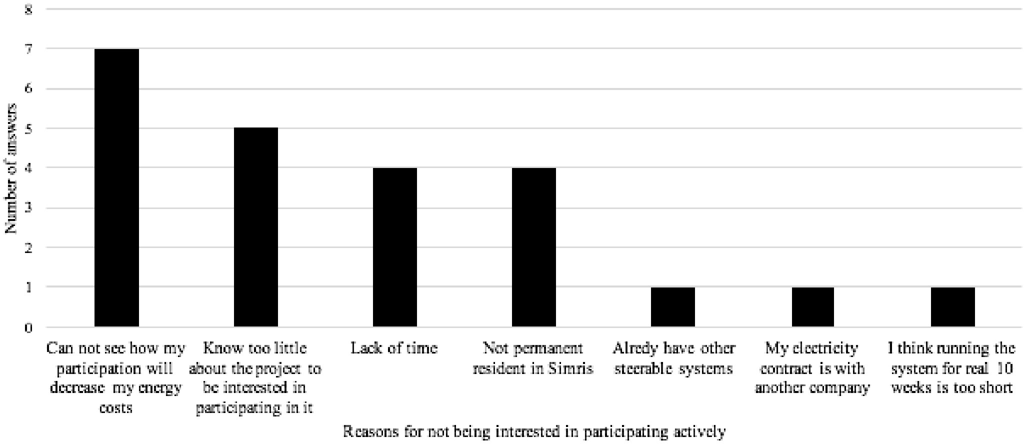

Figure 30 - Why are you not interested in participating actively in the E.ON LES project?

5.5 Conclusion

The interviews and survey answers of this study show that there are various driving forces in Simris area that could incentivise participation in DSR. Both interviews and the survey answers give a clear picture that the question of environment and positive climate contributions creates drive. This topic is mentioned by almost every customer contacted. Next to that, the focus lies on costs, and the fact that any increase in cost related to DSR would discourage a large part of the target group. Decreasing costs is a driving force for engaging in DSR, although the decrease must be noticeable and matter for the household economy. On the other hand, technological driving forces are low, which might be correlated to the high age of the inhabitants in the village. Few customers show interest in high technology application tools or new household heating and control equipment; few discussions rose regarding this topic. Many questions arise though, about how the local electricity system will work in reality, and how and when the project will run. Even though most customers have knowledge about energy production, distribution and own their usage function, there is confusion regarding the role of a DSR household to be found, it is unclear if active participation is a choice or not. Customers request detailed description about what kind of equipment that is needed for DSR participation and in which ways. Many customers also express a request of knowing how many times and for how long time per occasion their equipment will be controlled. Further, a confusion regarding the difference between retail companies and grid owners is a risk factor for DSR participant recruiting. A handful unreachable customers explain their non-interest with the fact that they are not E.ON clients. Other unreachable customers claim they do not have time to look into this matter.

Driving forces and restraining forces among customers to participate in DSR are therefore summarized:

Table 3 - Three main driving forces and restraining forces found among inhabitants to participate in demand side response.

Driving Forces	*Restraining Forces*
Curiosity	Low level of knowledge about DSR
Positive environmental contribution	Increase in costs
Decrease in electricity costs	Time constraints

The driving forces found can, by the energy company, be used to create incentives given to the customer as a way to motivate DSR participation. If we transform the driving forces into incentives, we get three pillars which should all be used to motivate customers to offer their household flexibility resources as a DSR service. We have built an incentive triangle, see Figure 31, to show the three incentives where the financial incentive can be used as a base, but the environmental and engagement incentives are equally sized, to be used as sub-incentives in communication for example, equally important. With the survey results, we believe the non-financial incentives should be remembered to support a money transaction for the DSR service the customer is offering. As presented previously, a financial driving force did not even exist among many customers (else than no increased costs).

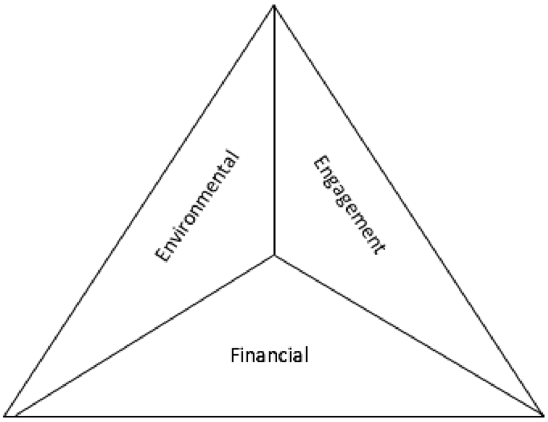

Figure 31 - The incentive triangle built, based on driving forces found in Simris from interview and survey answers.

The financial incentive
Because

- Customers do not want increased electricity costs.
- Customers would like to see decreased costs in exchange for time and engagement.

Use

- As a compensation for potential increased costs that can arise when a customer is participating in DSR.
- As an attraction incentive to get customers who are not interested to participate unless they would gain from it economically.

The environmental incentive
Because

- All asked customers have mentioned a positive attitude to environmental benefits.
- To use electricity from renewable sources is important to more than half of the asked customers.
- Many customers see renewable energy as a future supply resource.
- There is a positive attitude towards the already existing PV power park and wind turbine.

Use

- As an incentive in communication. Use material that proofs how DSR participation contributes to a better environment and climate through LES and RES.
- In a feedback tool. Present to the customers how much CO_2 reductions they are contributing with, or how much solar power is being used, due to their participation.
- As an educational platform where customers get to learn about sustainable resources and how they can use them in addition to DSR.

The engagement incentive
Because

- All asked customers have expressed curiosity for the project. Either to participate, or to express their opinions in a survey or during an interview.
- To be a part of something new, and to engage in matters regarding the village or neighbourhood together with neighbours, is popular.

Use

- As a happening. Make DSR participation something exciting; rewarding programme when reached a certain amount of controlled kWh for example.
- As a feedback and visualisation tool where customers can track own and system consumption.

Looking at the restraining forces found, these can be used to create key success factors when introducing DSR and incentivising the service. Especially, they can be used in communication and during customer recruitment.

Table 4 - Key success factors found for customer approach. Based on the restraining forces found from interviews and survey answers.

Key Success Factors		
Success Factor	Created based on these results	Can be used in this way
Simplicity	→ ● DSR is a new concept for most customers and difficult to understand. ● Low level of knowledge about DSR. ● Many customers have asked for more information about their role in the LES. ● Customers do not understand that they possess a flexibility resource. ● Uninterested customers claim they do not have time to engage in energy matters.	● Approach customers in the simplest way possible to reach out to all customers.
Trust	→ ● DSR is a new concept for most customers and difficult to understand. ● Low level of knowledge about DSR. ● Customers are asking for stable costs (no increases)	● Approach customers in a trustworthy way and only make promises that can be kept. ● Approach the customer in a way so that they fully understand what their role in DSR is.

Considering the customer perspectives found, the question of how to use them in order to create a financial incentive for a DSR service agreement has to be examined. The economic incentive does not seem to be the general driving force in Simris, but since a financial contract is to be developed in the scope of the LES project, a financial incentive still needs to be created in this study.

Firstly, the survey has found that almost no customer is willing to pay extra for participating in DSR. This means, DRS would demotivate customers to participate if it brings higher costs. Therefore, any possible increase of electricity usage with the DSR components during steering must be investigated and if they exist: they must be covered for.

- **For further investigation: Potential unwanted energy consumption for customers**

Secondly, the interviews and survey found that key success factors for recruiting and attracting customers to offer their flexibility resources are simplicity and trust. Therefore, it can be elaborated that a financial incentive should reflect these factors. One of the simplest ways to offer an incentive is to offer a fixed financial incentive. This is also what Broberg et al (2014) chose as baseline agreement offers in their investigation, since it is a clear and easy way for customers to take decisions from. A fixed incentive also brings trust with the customer since it will be a value the customer for sure will receive.

- **For further investigation: Fixed Incentive**

This will be investigated in Chapter 7.

5.6 Discussion

The findings from the interviews and survey answers complement one another well. For most topic areas, the results show same or similar overall picture. The qualitative interview results were reinforced with quantitative survey results.

First contact with the project can be seen as an indication of how well the project is communicated by the company. Naturally, it is beneficial and positive for company reputation if project information is communicated by them on first basis. Positively, survey answers show higher success with dissemination of information from E.ON than interviews. The survey findings add an additional picture that company information letter has been received to a greater extent.

5.7 Critical Review

As in any research, it is possible to critically review the findings and results of this investigation. Interview targets were approached during project information meetings, and volunteers were scheduled with appointments. Consequently, already interested customers may have overrepresented the interview selection group.

Further, the credibility of answers can be discussed since the target group of interviews is not a statistically random or representative selection. The asked interviewees are in fact customers, who are already involved in the local energy system project whether they want it or not. Since the survey target group consists of existing customers, who will be presented with a DSR offer from the company within a year, how survey and interview questions were composed was carefully considered. The notion of active participation might have impact the investigation in the way that customers do not fully understand the meaning of demand side response.

According to Bengt Ringnér, researcher at the Centre for Mathematical Sciences at Lund University, it is difficult to generalize answers from surveys of this kind. With probability theory, you can estimate the amount of answers needed when choosing people or respondents by chance, but in case of target group not chosen by chance, the propensity to respond depends on the factor investigated. Ringnér explains that for 62/149 responses, there is strictly no knowledge about what the other 89 would answer. The distortion effect of the loss depends on how difficult the question is. As a reminder, the aim of the DSR project is to connect household customers who want to be a part of the project, and the customers that do answer in this research are of high value to reach this goal, i.e., the survey has been reached to the desired population but the total desired population has not answered to it.

Moreover, belief in renewable energy and environmental benefits, can be seen as a social trend. There we can speculate that there is a risk that respondents to the written survey and interviewees have talked positively about this factor because of social expectations. Therefore, there might lay uncertainties regarding the strong driving force of positive environmental contribution to participate in DSR found in Simris. However, we cannot assume customers have not answered honestly to our questions, and we will therefore stay with the survey’s overall findings.

Chapter 6

The System Perspective

In this chapter, the system utility benefits that is provided with DSR is investigated through simulations. The design of the simulation model is explained and motivated, and lastly, results are presented and analysed.

6.1 System Utility Investigation Method

To comprehend the behaviour of the power system, and to understand how DSR influences it, a model is created in Matlab that simulates the energy flow through all different components in the LES. The model is designed to measure the system utility provided when customers' DSR equipment is used as flexibility resources, and to investigate when that utility occurs over different time periods.

System utility is in this study defined as the reduced margin costs of the production in the system, that flexibility can contribute with. By mapping the utility together with information of when it occurs, an evaluation can be made on what impact the different DSR components have on the system. In addition, it can map capacity hence financial enhancements they contribute with to the LES, which is a research question of this study.

With simulation results, it is also possible to understand which components are the major cost drivers of various seasons. These cost drivers are the ones setting the electrical price in the system and the size of compensation to the customer. Three seasonal time intervals are created in order to investigate the influence and impact DSR has on system utility. In the end, the model is simulated in three scenarios with various numbers of DSR-components attached.

6.1.1 Model Assumptions

Assumptions regarding the potential of storage capacity and to use as stored energy during overproduction, and capacity to reduce load during underproduction, are made. These assumptions are done in order to create the model, reflecting a realistic LES, and are explained for each component in Table 5.

Table 5 - Table of assumptions made for the different system components.

Assumption of system components for simulation model		
Component	*Overproduction*	*Underproduction*
Heat Pump	HP is activated and capacity increased to use 4 kW (Nibe F2040, n.d.) during a time of one hour, assuming indoor temperature has increased its promised maximum. After, the heat pump is deactivated during a time period of two hours since the indoor climate needs to go back to its reference temperature. Time periods simulated are motivated further in Chapter 7. Power saved when the heat pump is turned off, is 2.24 kW during the winter season and 1.3 kW during spring/autumn and summer seasons (Nibe F2040, n.d.). The instantaneous availability of HP in the LES is estimated to 50%, which means that only half of the heat pumps connected to DSR in the system can be used at once due to technical function of a HP.	HP is deactivated and the capacity decreases with a power of 2.24 or 1.3 kW depending on season (Nibe F2040, n.d.). It is turned off during a period of 2 hours, decreasing the indoor temperature to the promised minimum. The HP is not available again for DSR until a power peak that is high enough occurs and the indoor climate can go back to its reference temperature.
Hot Water Boiler	HWB is activated with a power of 3 kW (Nibe AB, n.d.) during a period of two hours heating the tank water from 40 °C to 75 °C. When the tank water reaches its maximal temperature of 75 °C, the HWB is unavailable for remote control until it has been tapped. It is assumed that the tank is mainly tapped due to shower usage pattern, mainly one large tapping per day. Note, after it has been tapped, the HWB can provide its flexibility when needed at any time during the day, but has to wait for reset (all water is heated again).[1]	We assume that no flexibility is available in the HWB during underproduction, since we assume it will only be charged 2 hours a day once at any time of the day.
Customer Battery Energy Storage System	The maximum energy input is 5 kWh. It is assumed that it is possible to charge the battery, if the power in the LES is mostly generated from wind. In case of a sunny day, it is assumed CBESS is already charged with own PV, leaving little or no storage of power from the LES. CBESS storage is therefore estimated to be available only when electricity production	During underproduction, only the energy input from the LES can be used, however, no extra energy that the customer itself have stored is assumed to be available. This is since the technical challenges to measure what energy in the batter that comes from micro production and what comes from the LES. Therefore, the minimum state of charge is 0 from the LES perspective.

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[1] This assumption is based on the report where Hledik et al (2016) investigate thermal storage opportunities in electric water heating. They present an average electricity usage profile of electrical resistance water heaters in an area of Minnesota, US. This consumption load profile is assumed to keep a minimum water temperature of around 50°C, which is somewhat lower than the Swedish standards as mentioned in Chapter 3. However, the consumption pattern is of relevance to the simulation set-up of this study. Furthermore, the assumption for tank tapping is strengthened with this report’s customer survey saying there are many single and couple households living in Simris; i.e. hot water usage should not be excessive. With these assumptions, steering availability of the HWB is estimated to only 2 hours each day after tank is emptied. The real availability is higher and there is a potential to control the HWB more hours in a day. But to simplify the model, these 2 hours can be used for flexibility once at any time of the day. In addition, the potential to increase the tank water temperature from 60 to 75 °C is not assumed possible even though it might be. The water will only be heated from 40 to 75 °C to simplify the model.

	from the central PV park is below 50 kW, which is 11.3 % of its installed capacity. This is a simplification made because we do not have the data or simulation tool to measure the state of charge, SOC, of the CBESS from micro-production to add in our model and due to time constraints of the study. For further development of the model it should be added.	
Battery Energy Storage System	BESS maximum energy input 333 kWh.	Minimum energy input is 66 kWh, 20% SOC of maximum input. The kept capacity is beneficial during absolute power shortage in the system. The state of charge is however assumed to be 0 kWh when the simulation starts.
Back-Up Generator	BUG can only generate electricity and can therefore not be used to handle negative discrepancy.	The BUG can produce at maximal power of 480 kW.

6.1.2 Priority Order

A priority order was decided for how to use the different components in the simulation. DSR equipment was prioritised, before the system's central equipment, since the goal is to optimise the usage of customers' flexibility, in order to see its maximal potential.

When there is overproduction, the following priority order was chosen:
CBESS was chosen as highest priority since it is the most flexible DSR resource, since the battery can be charged during overproduction, and after being directly used if underproduction occurs. The HWB and HP were chosen as second and third in order since they possess the risk of becoming "locked" during underproduction when they have been used during overproduction (see Table 6 for model assumptions). We choose to activate the HP before the HWB because the low availability of HWBs from our earlier assumptions (see Table 5). BESS is after the HWB in the order, and the last choice is to reduce/waste production in the system, since the producer loses revenues.

When there is underproduction, the following priority order was chosen:
The HP was chosen to be activated first, if not "locked", since it has the highest potential to decrease in capacity. Secondly, CBESS is used, and thirdly the BESS. After the BESS is used, and if we still have a negative discrepancy, the BUG will be activated to supply the system with electricity. If not even BUG can handle the discrepancy, electricity must be bought from the overlying grid in worst case. The BUG is chosen before buying from the grid in the priority order since it is of desire for the LES to work self-sustaining, disconnected from the overlying grid. However, in this demonstration project, it will still be possible to use the overlying grid due reduce the risk of outages. The components priority order for over- and underproduction is presented in Table 6.

Table 6 - Table of chosen priority order for the simulation tool.

Overproduction	Underproduction
1. CBESS	1. Heat pump
2. Heat pump	2. CBESS
3. Hot water boiler	3. BESS
4. BESS	4. BUG
5. Production control	5. Buy from grid

6.1.3 Data

The model is based on production data from the local WT and PV power station. This data is compared with consumption data from Simris households, checking the discrepancy of the system. Both production and consumption data are hourly measurements from year 2016 extracted from E.ON data sources. Available measured data existed from the years 2014 to 2017. However, we chose to use one year of data in the simulation, the latest available data to reflect the latest system conditions. The production characteristics of the WT and PV power station is described in Chapter 4, together with consumption data.

6.1.4 Model Code Structure

Matlab is used as software tool to write the model and to run the simulation. The structure of the simulation is shown in Figure 32, where the hourly discrepancy together with the priority order decides which component will be activated next.

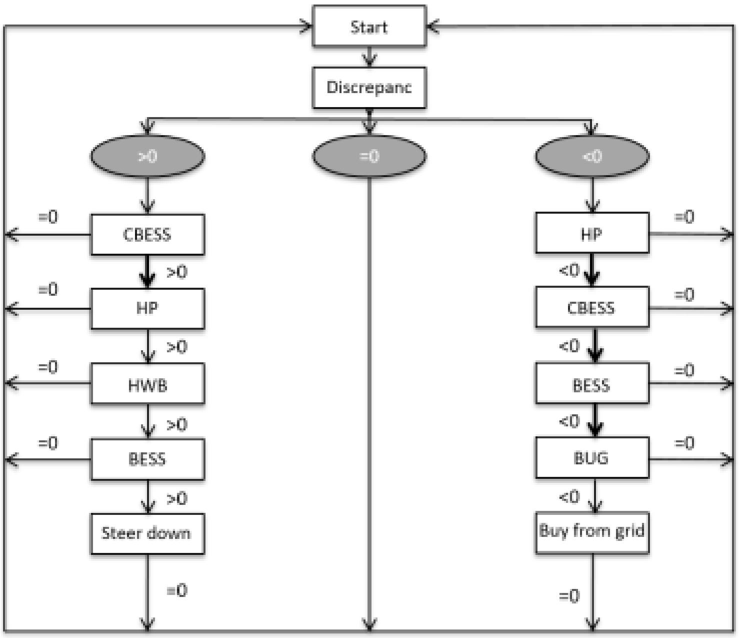


Figure 32 - Schematic picture of simulation construction.

6.1.5 Time Intervals Simulated

The electricity consumption in Sweden is almost twice as high during the cold winter months compared with warm summer months (Svenska Kraftnät, 2016). Energy consumption is high during winter, but production from PV solar power is low. In the summer, it is the other way around, and in the spring and autumn it follows a dynamic pattern (Svenska Kraftnät, 2016: Stridh, 2017). Electricity production from wind power is however slightly higher during winter on average (Lindmark, 2017). These findings support the production and consumption characteristics in the LES studied, presented in Chapter 4. Due to these findings, it is motivated simulate the model in seasonal intervals. These intervals have been found through a basic system analysis where historical discrepancy between supply and demand in the LES was plotted. The data plotted is real hourly measurements from 2014, 2015 and 2016, calculated into a mean value for every day into a yearly average. This yearly average discrepancy curve was found to have similarities with a Swedish average daily mean temperature curve, extracted from Sweden's Meteorological and Hydrological Institute (SMHI) using the same years of data. The system balance follows a seasonal pattern in which the model is therefore simulated, see Figure 33. The three seasons will use its months' average electricity spot-prices (Table 7) together with used fuel cost of the BUG at a load of 75%.

Table 7 - Prices to buy and sell electricity used in the simulation in the different seasons and the fuel cost to run the BUG at a load of 75%, to calculate the cost to use the system components (Appendix B).

	Buy electricity (SEK/kWh)	Sell electricity (SEK/kWh)	BUG (SEK/kWh)
Winter	0.31	0.48	2.78
Spring/Autumn	0.30	0.47	2.78
Summer	0.28	0.45	2.78

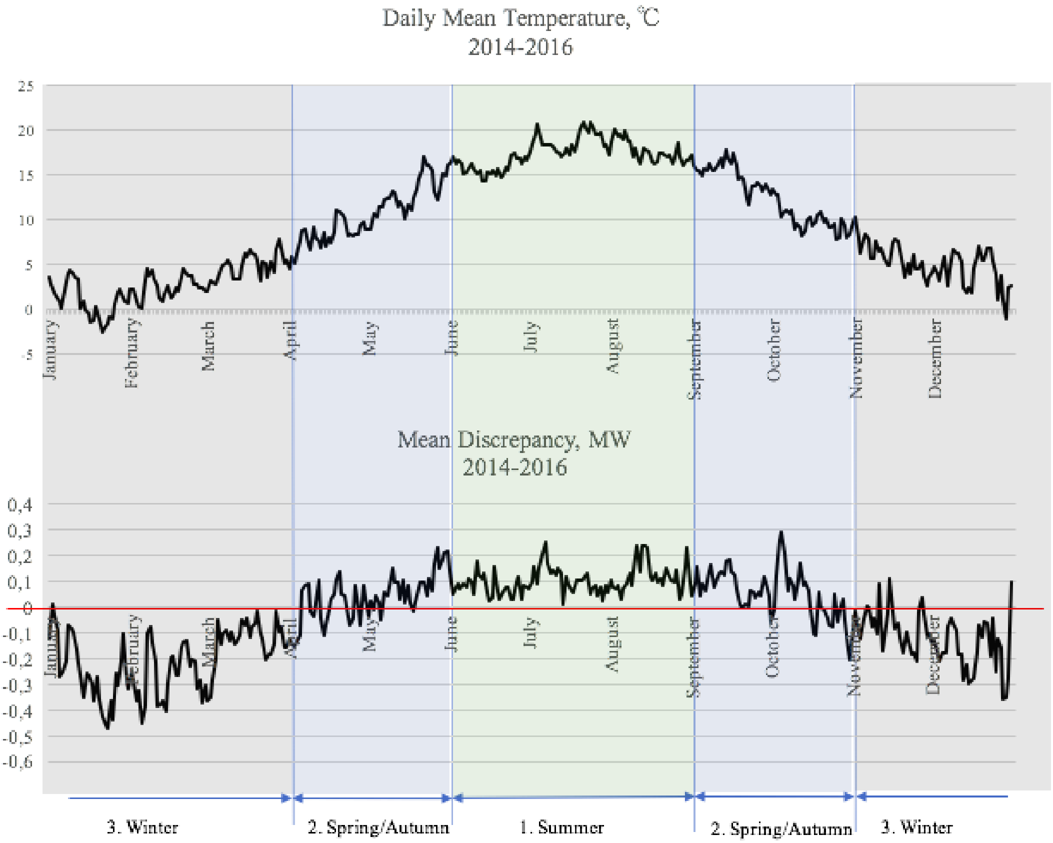


Figure 33 - View of average daily mean discrepancy in LES combined over the years 2014 to 2016 in relation to daily average temperature measurements in Lund over the same years (SMHI).

6.1.6 Scenarios

We have created three scenarios in order to investigate the impact and enhancements of DSR in the system, and how the numbers of controlled components change the power situation for different hours. All three scenarios were simulated using the same assumptions, priority order and seasonal intervals. Numbers of components simulated in the scenarios are however different, and are presented in Table 8.

Scenario 1 has no available flexibility provided from the customers, compared with the two other scenarios. The number of units in Scenario 2 is based on E.ON's internal goal of 30 active customer (in addition, the findings from our customer research show that 40 customers already have any of the controllable equipment today). Scenario 3, is a high estimation with almost every connection point attached to DSR.

Table 8 - Number of system components in Scenario 1, 2 and 3.

Unit	Scenario 1 (Nr of units)	Scenario 2 (Nr of units)	Scenario 3 (Nr of units)
HP	0	15	50
HWB	0	15	50
PV + CBESS	0	5	30
BESS	1	1	1
BUG	1	1	1

6.2 Simulation Results

In this section, the results of the three simulated seasons are presented. The power use of the BUG, BESS and main grid is financially examined with added margin costs. Customers' provided flexibility is also presented for each component in all three scenarios.

6.2.1 Winter Season

Production and consumption

The total production during this season from the PV power park and WT is 733 MWh and the load in the town is 1 365 MWh. This difference in supply and demand makes a large negative total electricity discrepancy between production and consumption in the LES.

Local Energy system simulation

BUG is activated most hours to handle negative system imbalance. There are also periods of time when the BUG does not provide enough supply together with the WT and PV power station to meet electricity demand in the system. When BUG fails to handle the imbalance of system, the overlying grid must be used. The BESS is used few hours and has not enough capacity to handle the negative discrepancy, and few overbalanced hours occurs. The simulation shows that there are few times during winter season when there is a need to control (i.e. waste) production. Figure 34 presents the power use from the system components during the winter in Scenario 1, 2 and 3 where the BUG usage is presented with a blue line, the BESS usage is presented with a yellow line, and the usage of the overlying grid is presented with a red line.

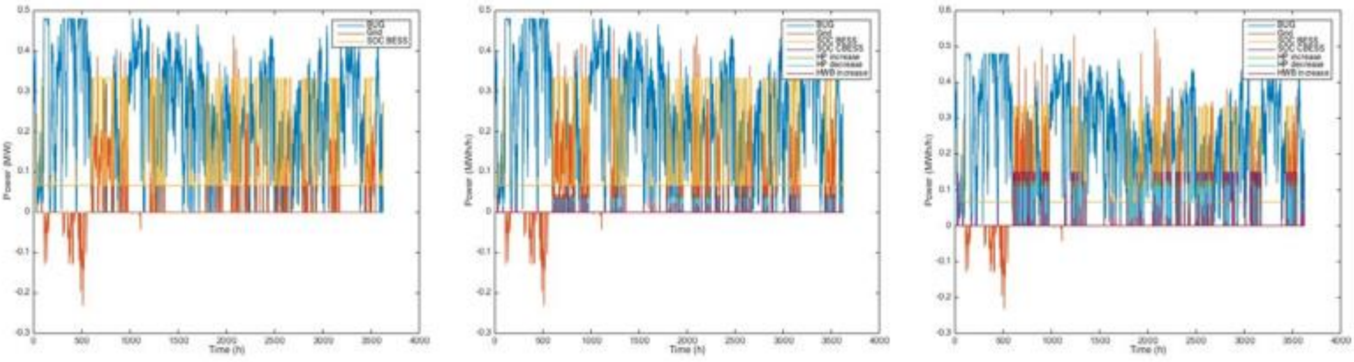


Figure 34 - Power MWh/h use from the system components during the winter in Scenario 1, 2 and 3.

The simulation results show that BUG needs to produce around 700 MWh, and the provided flexibility in Scenario 2 and 3 is 6 MWH and 17 MWh. The amount of electricity that the LES cannot provide by itself to meet demand is around 11 MWh and does not change in any of the scenarios. Production that is needed to be controlled is around 80 MWh and changes only in Scenario 3 with a provided flexibility of 1 MWh. The fuel cost to run the BUG is almost 2 MSEK in Scenario 1 and this cost is slightly lower in Scenario 2 and 3 with cost saving around 16 000 and 46 000 SEK. The lost revenues of controlling production is almost 40 000 SEK and is the same in all scenarios meaning that there is no flexibility preventing control of production in the winter. DSR has not managed to make the micro-grid nonedependence of the overlying grid. The cost of buying from the grid is calculated to 3 000 SEK. Table 9 presents the result of energy use and costs of the BUG, electricity production curtailed and the lost revenues, and the amount of electricity needed to be bought from the overlying grid, and the cost of it.

Table 9 - Simulation results of energy use and cost of BUG, buy from grid and lost revenues of controlled production.

Winter									
	BUG			Buy from grid			Control of production		
Scenario	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
MWh	*704*	*698*	*687*	*11*	*11*	*11*	*83*	*83*	*82*
Difference	-	*6*	*17*	-	*0*	*0*	-	*0*	*1*
SEK	*1 956 223*	*1 939 882*	*1 909 521*	*3 581*	*3 581*	*3 581*	*39 779*	*39 779*	*39 399*
Difference	-	*16 351*	*46 712*	-	*o*	*0*	-	*0*	*380*

6.2.2 Spring/Autumn Season

Production and consumption

The total production during this season from the PV power station and WT is 645 MWh and the load in the village is 447 MWh. The season total positive energy discrepancy between production and consumption is low.

Local Energy System simulation

During spring/autumn, the peaks of overbalanced power that the system cannot handle are high, but occurs rarely. Even though the BESS is used frequently, its capacity is low and the state of charge (SOC) is 100 % most of the time, and the system must curtail its production. The BUG needs to be activated at times, but the main issue during the season is the positive discrepancy. There is however no negative discrepancy that the system cannot handle, together with the BUG, during this season. Figure 35 presents the power usage from the system components during the spring/autumn in Scenario

1, 2 and 3 where the BUG usage is presented with a blue line, the BESS usage is presented with a yellow line, and the usage of the overlying grid is presented with a red line.

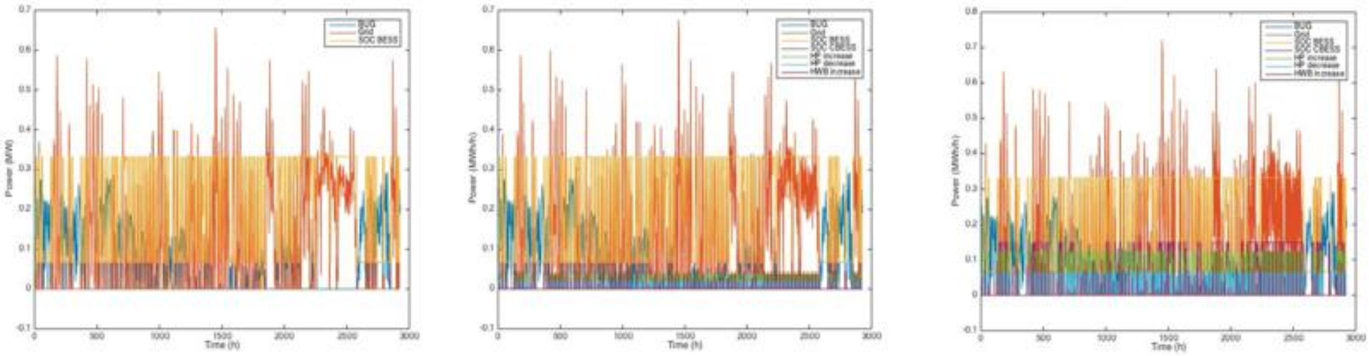


Figure 35 - Power MWh/h use from the system components during the spring/autumn in Scenario 1, 2 and 3.

The BUG needs to be activated for around 100 MWh. There is a small difference in energy production between all scenarios, and the flexibility provides up to 6 and 14 MWh in Scenario 2 and 3. The amount of production curtailed is around 300 MWh, with a provided flexibility of 8 and 21 MWh in Scenario 2 and 3. The results show that it is never needed to buy electricity from the overlying grid. The BUG cost is around 300 000 SEK, twice as much as lost revenues due to production curtailment which is around 150 000 SEK. The flexibility in Scenario 2 and 3 reduces fuel cost of BUG with around 15 000- and 39 000 SEK. Lost revenues by controlling production can be reduced with a total of 4 000 and 10 000 SEK for Scenario 2 and 3. Table 10 presents the result of energy use and costs of the BUG, electricity production curtailed and the lost revenues, and the amount of electricity needed to be bought from the overlying grid, and the cost of it.

Table 10 - Simulation results of energy use and cost of BUG, buy from grid and lost revenues of controlled production.

Spring/Autumn									
	BUG			Buy from grid			Control of production		
Scenario	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
MWh	109	104	95	0	0	0	306	299	285
Difference	-	6	14	-	0	0	-	8	21
SEK	306 611	288 185	264 647	0	0	0	144 052	140 424	134 055
Difference	-	15 426	38 964	-	0	0	-	3 628	9 997

6.2.3 Summer Season

Production and consumption

The total production during this season from the PV power station and WT is 433 MWh and the load in the town is 173 MWh. The total positive energy discrepancy between production and consumption in the LES is small.

Local Energy System simulation

During summer, peaks caused from overbalance of power are high and occurs often. SOC is 100% most of the time and the power production must be controlled much to balance the LES. The BUG is used but the amount of negative discrepancy is low, and it is not needed use the overlying grid. This is since the BUG has more than enough capacity to handle the negative imbalance in this season. Figure 36 presents the power use from the system components during the summer in Scenario 1, 2 and 3 where the BUG usage is presented with a blue line, the BESS usage is presented with a yellow line, and the usage of the overlying grid is presented with a red line.

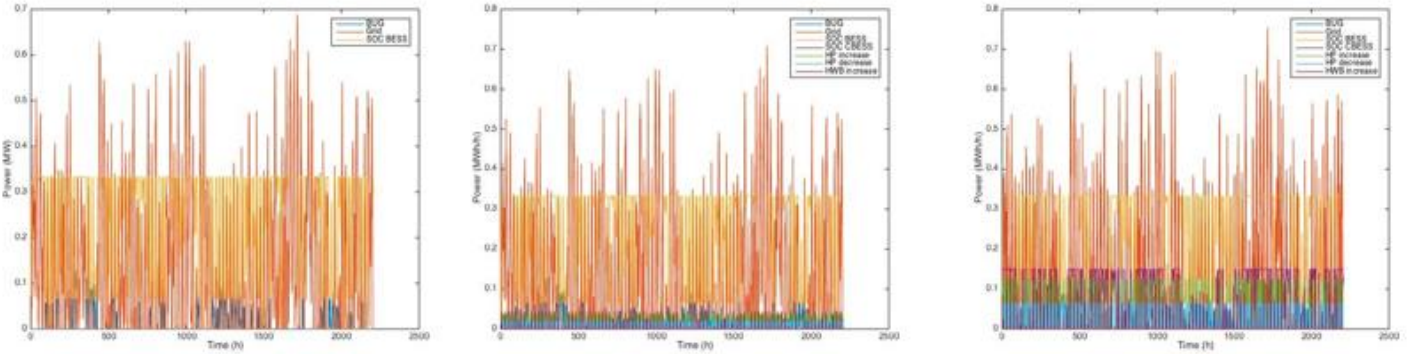


Figure 36 - Power MWh/h use from the system components during the summer in Scenario 1, 2 and 3.

The BUG is needed to produce around 14 MWh and the flexibility provided from Scenario 2 and 3 are 3 and 6 MWh for this component. The overlying grid is never needed to be used to cover a negative discrepancy between production and consumption. It is however required to curtail around 270 MWh to balance the LES. Here, the provided flexibility is 2 and 14 MWh for Scenario 2 and 3. The fuel cost of running the BUG is around 40 000 SEK, and the flexibility in Scenario 2 and 3 reduces the fuel costs with approximately 7 000 and 17 000 SEK. The lost revenues of controlling production are around 120 000 SEK and can be reduced with approximately 2 000 and 6 000 SEK for Scenario 2 and 3. Table 11 presents the result of energy usage and costs of the BUG, electricity production curtailed and the lost revenues, and the amount of electricity needed to be bought from the overlying grid, and the cost of it.

Table 11 - Simulation results of energy use and cost of BUG, buy from grid and lost revenues of controlled production.

Summer									
	BUG			Buy from grid			Control of production		
Scenario	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
MWh	14	11	8	0	0	0	272	268	258
Difference	-	3	6	-	0	0	-	4	14
SEK	38 981	31 779	21 511	0	0	0	121 021	119 261	114 769

Difference	-	7 202	17 469	-	0	0	-	1 760	6 252

6.3 Conclusion

Since the reserve capacity with high fuel costs must be used frequently, it is not motivated to disconnect from the overlying grid during winter. Analysing the system enhancements provided by DSR flexibility, it can be concluded that it has little impact and costs are barely reduced, even in a high customer participation scenario. During the winter season, the highest cost of electricity is the cost per kWh of using the BUG. Hence, this is the price the system is willing to pay for sustaining system balance during winter. The flexibility given would, from a system perspective, be worth anything below this price.

During Spring/Autumn, the system switches between negative and positive discrepancy leaving a highly dynamic situation, and room for a dynamic use of the flexibility resources. Lost revenues due to control of production is, however, lower than the costs of using the BUG. The price the system is willing to pay for flexibility during spring and autumn varies between the one of BUG operating costs and the fact that the system is willing to waste energy production. The value of the flexibility, that could be given to balance the system from a system perspective, could then be a value between highest operating costs, BUG in this case, and lost revenues to control production in this season.

The summer season must handle a lot of overproduction, positive discrepancy. The value of flexibility in SEK is however lower in the summer than spring/autumn and winter where BUG is a factor when the price is set, from a system perspective. From a technical perspective, it is easier to control the production to meet demand then to use the costumer’s flexibility service with the same goal.

Analysing the results from the simulation and the low utility provided from flexibility it is hard to motive why DSR should even be used. DSR increases the level of complexity for both the system and the costumer with barely any impact. Even though the system is not benefiting much from introducing DSR over time, there is still a market value for every point in time when costs can be reduced through DSR.

- **For further investigation: The market value of flexibility**

This will be investigated further in Chapter 7.

6.4 Discussion

The amount of energy managed by the different components is highly dependent on the chosen priority order and the results of the simulation could therefore be of other scales if other priorities were chosen. The selected order does not optimize the system in an energy or economic way, it was chosen to visualise the customers’ maximal flexibility and how it can contribute to the system. In addition, in a real-life scenario, it might not be possible to use all different components in the various seasons. During summer, it is not likely that the customer would accept a higher temperature in their homes. It can also be technical difficulties to use the HP when the outdoor temperature is high. During summer season, HWB might be the only component that can be used as a decentralised storage capacity by the system since the SOC of CBESS is most certain high because the customers own micro-production. If the production from the WT and PV power station is controlled and curtailed, the penetration of renewable energy sources decreases in Swedish generation mix, making the LES have a negative impact on the environment in that aspect.

Chapter 7

Further Investigations of Perspective Results

This chapter will further investigate three concepts that was found in Chapter 5 and 6. The first one is to find out how to compensate the customer for potentially unwanted energy consumption in DSR participation, the second is to investigate a fixed compensation and which factors it could include, the third is to offer a part of the market value in the system, as an incentive for the flexibility given by the customer to the system.

7.1 Perspective Results

In the two previous chapters, two perspectives of DSR incentives were investigated; the customer's and the system's. During these investigations, insights were gained and it was found that three factors had to be investigated further. These were:

- **For further investigation: Potential unwanted energy consumption for customers**
- **For further investigation: Fixed Incentive**
- **For further investigation: The market value of flexibility**

In the coming sections of this chapters, the bullet points above will be further investigated.

7.2 Potentially Unwanted Energy Consumption

As explained in this case study; in the case of when there is overproduction, it is of aim to increase electricity usage through DSR, instead of curtailing the power production. This electricity is meant to be added, through heating systems turned into heat in the customer's house. In this way, it is possible to benefit from thermal inertia that occurs in a house, basically it can be said that we are storing energy in a house in the form of heat. However, this extra energy, is energy that the customer did not want from the beginning. When energy is added in a customer's home, it is logged on the customer's metering system and later, the customer must pay for it.

It is concluded in the customer survey that customers do not want their energy costs to increase if they are to participate actively in the LES project. Following in this chapter, we will investigate if, and in that case how, a customer might suffer from increased costs when remote DSR is adding electricity, into heat during overproduction.

7.2.1 Heat Pump

HP capacity increase over a period intend to contribute to a thermal storage effect where heat is added in a building at one point, available to use at a later point in time. Basically, shifting heat storage in time to conform to LES situations. Thinking of this, the customer could hypothetically benefit from the extra heat at a later point in time, which leaves no unwanted energy consumption.

However, this was investigated further. When increasing the indoor temperature at the same time as the outdoor temperature stays stable, heat losses, will in theory increase, leaving the customer with a small increase of extra energy consumption. How a HP should be controlled via DSR, and the theory behind unwanted energy for customer have been investigated together with the Thomas Ranstorp, CEO Ivago AB, specialist in automation, energy systems and IT, meeting 2017-05-16. All simplified investigations below have been developed together with, and under guidance of, Ranstorp.

The span of temperature change promised to the customer is to ±1°C, for comfort reasons. A simplified theoretical concept will be used in this study, if or when the 1°C indoor temperature increase is reached, the HP is to be deactivated to return to normal temperature.

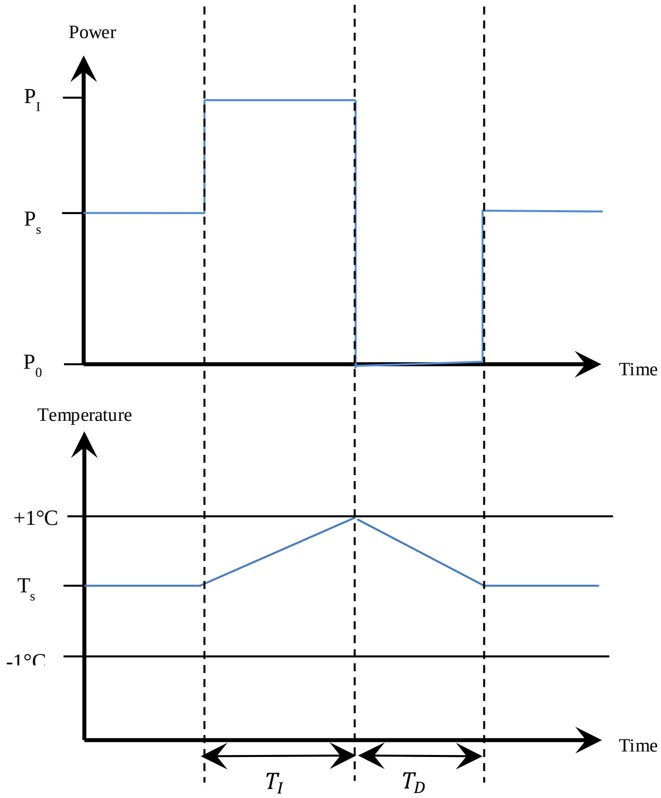


Figure 37 - Simplified theoretical concept investigated of remote steering of a heat pump.

Top graph of Figure 37 shows, in the first section, average power used to maintain desired indoor temperature given a specific outdoor temperature is called P_S, the stable power. During a certain time, when there is overbalance in the system and electricity is sought to be used instead of wasted, a signal will activate HP in DSR. When a HP is activated in remote controlling, its power usage increases to a certain kW, which is called P_I. The time when the HP is activated and using its max power is called T_I, time when the HP power usage is increased.

When the electric power usage for when a HP is increased, added heat to the house increases, resulting in indoor temperature increase, which is shown in the bottom graph. When +1°C is reached the heat pump must be deactivated for DSR. P_S and P_I show a mean line of HP electricity usage. Note that temperature changes are in practice not linear as in Figure 37, this is a simplified graph of controlling a HP.

In order to understand which extra costs this increased power brings for the customer, what happens inside the house must be investigated. Using Figure 38, the following simplified steps can be identified:

1. HP electricity usage is increased, transforming it to heat effectively given by COP.
2. Heat is transferred into the house heating system, which means into water.
3. Energy is stored in the house heating system, which can benefit the building later when HP is deactivated.
4. Heat conductivity from house heating system increases $P_{inertia}$ (from stable indoor temperature, hence 0W) depend on all surfaces and masses in the house and on the initial temperature of each of these surfaces.
5. New energy balance: $P_{inertia} = P_{in,heat} - P_{out,heat}$
6. Gradually, when heat is added to the house and energy is stored in indoor masses, which mainly depend on mass values and thermal conductivity, the indoor temperature start increasing.
7. After a certain time, one degree increase can be reached, and $P_{out,heat}$ increases.
8. The small amount of energy that is not stored for later use, but is increasing $P_{out,heat}$, is the amount considered as unwanted energy.

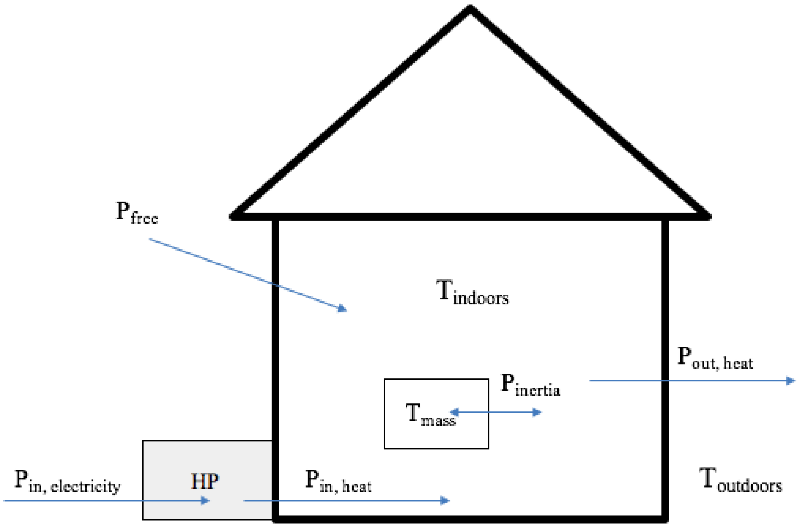


Figure 38 - Simplified heat flow of a house created together with Tomas Ranstorp, CEO Invago AB, Meeting 2017-05-16, Email 2017-05-17.

In order to calculate the amount of unwanted energy and which costs it brings for the customer, the above discussion has been further simplified and $P_{inertia}$ is ignored, since it would demand detailed simulations with a lot of input from each single building. This study has therefore developed a simple model on how this extra energy can assumed, and thereafter priced.

Using $P_{in,electricity}$ from Equation 1, Section 3.6.1, we use Equation 10 below to analyse how much extra electricity has been used when increasing from T_1 to T_2.

$$Increased\ HP\ electrical\ power\ usage = P_{electricity,T1} - P_{electricity,T2}\ (W) \qquad (10)$$

Thereafter, the share of the increased electricity usage, in relation to the power usage when controlled with remote DSR, is calculated in Equation 11:

$$Share\ of\ increased\ losses = \frac{Increased\ HP\ electrical\ power\ usage}{P_{electricity,T2}}\ (\%) \qquad (11)$$

A simple price model is built where the cost of electricity, increases in relation to the increased losses, with the same share:

$$Price\ of\ increased\ heat\ losses = \\ (1 + share\ of\ increased\ losses) * Price_{electricity} - Price_{electricity}\ (SEK/kWh)\ (12)$$

Results using the model in an extracted scenario

To investigate an average value of how much the extra share of heat losses can cost for the customer, calculations has been made for a specific scenario. This scenario includes a reference house, which aims for resembling an average house in Simris, and reference air/water heat pump. See Appendix C for chosen parameters. In the model explained above, the share of increased heat losses would apply to the existing electricity price at the time when the customer is being controlled. However, a chosen static electricity price is chosen to simplify scenario calculations, see Appendix B.

The electricity capacity needed to keep 20°C and 20 + 1°C respectively is shown in Figure 39. The value of 20°C is chosen as indoor reference temperature since it is recommended by the Swedish national board of health and welfare as minimum, and in addition since it is easy to calculate with.

As displayed, a small increase of electricity usage is needed when keeping a higher indoor temperature. Operating capacity is highly dependent on the outdoor temperature.

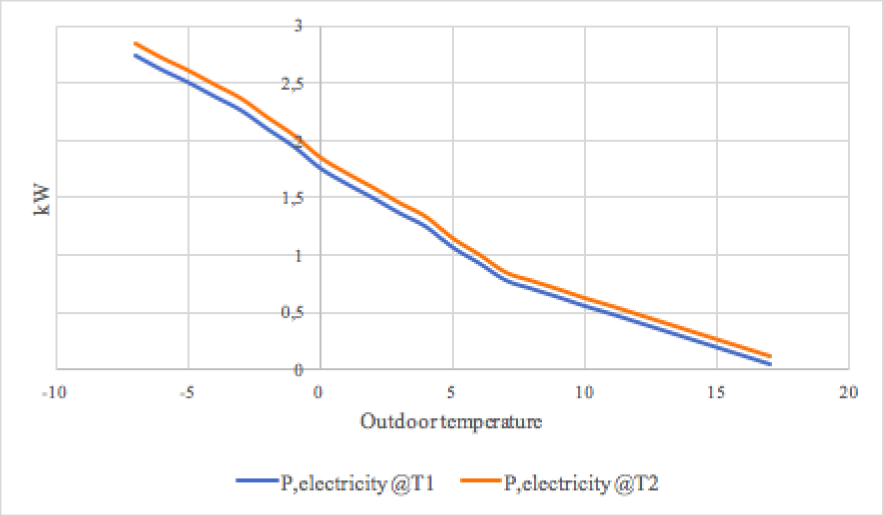


Figure 39 – Electrical power usage in kW of an air/water heat pump for keeping indoor temperature T1 = 20°C and T2 = 21°C in relation to outdoor temperature.

Plotting the above electricity usage difference for the reference temperature T1 = 20°C and reference +1°C, is shown that it decreases with increased outdoor temperature. Meaning, increasing indoor temperature 1°C during high outdoor temperatures requires less extra electricity due to low ΔT , and low heat losses initially. In proportion to the initial usage however, the share of the increased electrical power usage increases, since initial heat losses are low. In percentage, heat losses increase with a steeper curve during higher outdoor temperatures, hence lower ΔT.

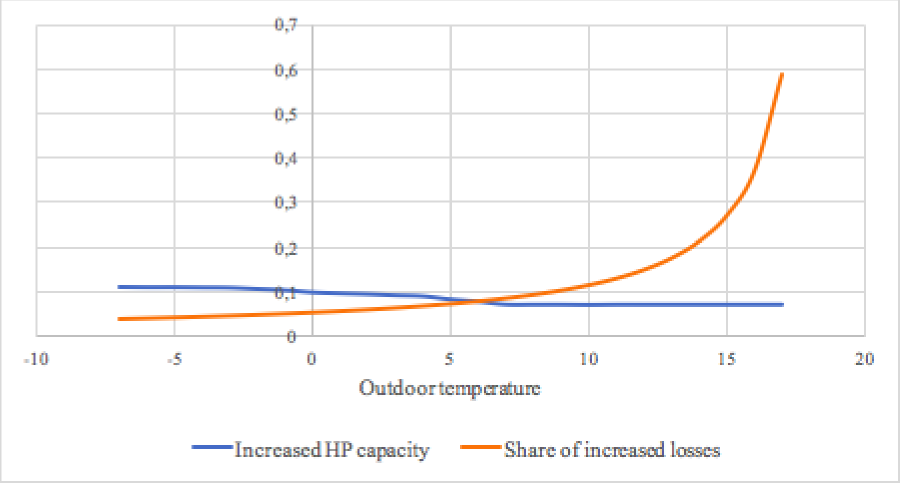


Figure 40 - Difference of capacity usage for indoor reference temperature and reference temperature +1°C, hence the increased HP usage capacity (blue), plotted together with the share of increased losses (orange).

Even though increased electricity usage decreases with outdoor temperature, the share of it increases since heat losses are initially lower at high outdoor temperatures.

Interpreting the increased share of dwelling heat losses, as a percentage of which electricity usage is increased, electricity costs would increase with the same share. Consequently, increased heat losses in relation to the added heat energy, gives increased costs with increased outdoor temperature.

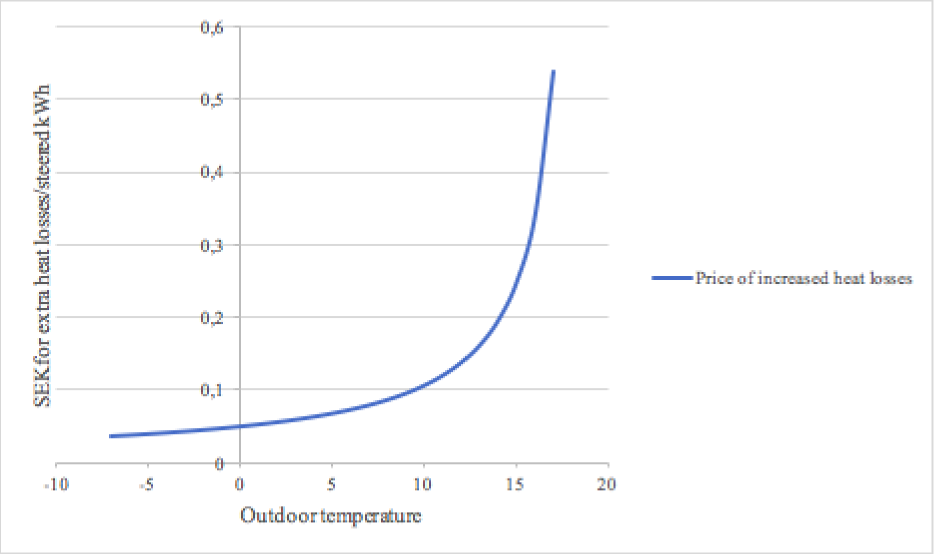


Figure 41 - Price curve, based on a chosen spot price, of increased heat losses in relation to outdoor temperature.

In percentage, a customer suffers from higher unwanted heat losses during higher outdoor temperatures. A compensation model based on the price of the unwanted heat losses, is issued accordingly to Figure 41.

Contrary, if HP is deactivated for LES underbalance reasons, the price curve acts conversely. Due to decreased heat losses, the customer will experience reduced expenses in relation to the electric power decreased, see Figure 42.

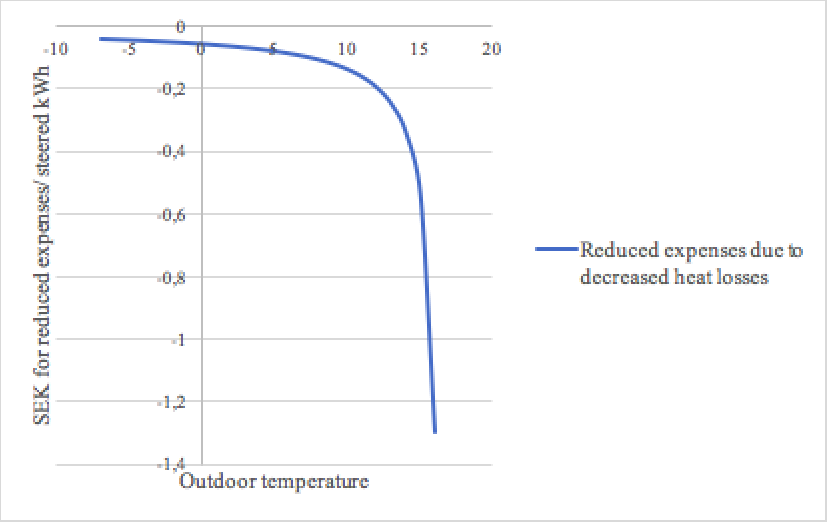


Figure 42 - Reduced expenses curve, based on spot price, of decreased heat losses in relation to outdoor temperature.

Matching activation and deactivation of HP, additional heat losses, and gained energy they almost equalize, see Figure 43.

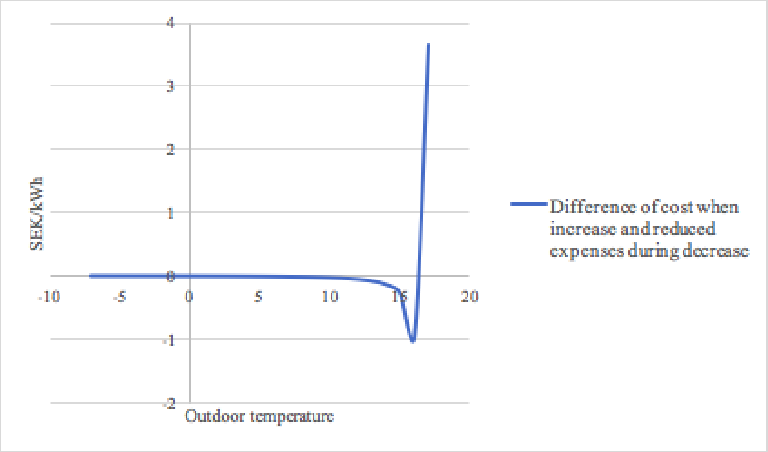


Figure 43 - Difference of extra electricity costs due to extra heat losses during overbalance steering, and reduced expenses due to reduced heat losses during underbalanced steering, in relation to outdoor temperature. Note that the system shifts at 17°C.

Analysis and Conclusion

Implementing DSR through a HP by increasing its electrical power usage, would imply unwanted energy in the form of increased heat losses from the dwelling. These are however, not high and very dependent on how long time the HP is controlled and building fabric. The model built is very simplified, using the worst-case scenario of increasing indoor temperature to + 1°C and a real simulation of a house would be needed to gain exact values.

Our analysis above, as shown in Figure 43, explains that the amount of unwanted heat losses a customer suffers from during increased power control through DSR, could be offset by the amount of gained heat losses a customer experiences during decreased power control. However, this theory requires a system where a customer is being activated during overbalance the same amount of kWh as being deactivated during underproduction. It also requires the spot price to remain the same over these periods as well as the steering occurring at times when the outdoor temperature remains stable.

Based on our analysis, we think that of one conclusion is that the company should not activate customers' climate scale using the HP at outdoor temperatures above 10°C, as the customer cannot benefit from it and costs for covering heat losses increases exponentially.

To be able to calculate the actual cost of the increased heat losses, during the time when HP's electric power usage is increased, it requires time registration and disaggregation of electricity metering as well as a reference to the actual spot price the time being.

7.2.2 Hot Water Boiler

When a HWB is remotely steered and the water in the tank increases at a time when the customer does not wish to use domestic hot water, the energy added can be seen as unwanted from a customer perspective. The amount of added energy that is unwanted, depends on how much extra energy heat losses this will bring, which depends on the time during which the tank water is tapped by the customer,

Heat losses and the efficiency of the HWB depend on thickness, insulation material and temperature differences between the water and the tank's ambient air. Also, if the maximum water temperature is set to be higher than normal due to increased storage capacity, a way to calculate unwanted energy consumption is by comparing the heat losses occurring at the increased tank water temperatures, with the “old” temperature. A simple model of investigating the extra amount of heat losses from a tank that a customer might experience is made through multiplying the temperature difference with time controlled by DSR. Figure 44 simplified describes the behaviour of a HWB. It is assumed to run on maximal power when adding heat to the water, until it has reached its desired temperature. Then, the HWB is completely turned off waiting for next time to heat the water.

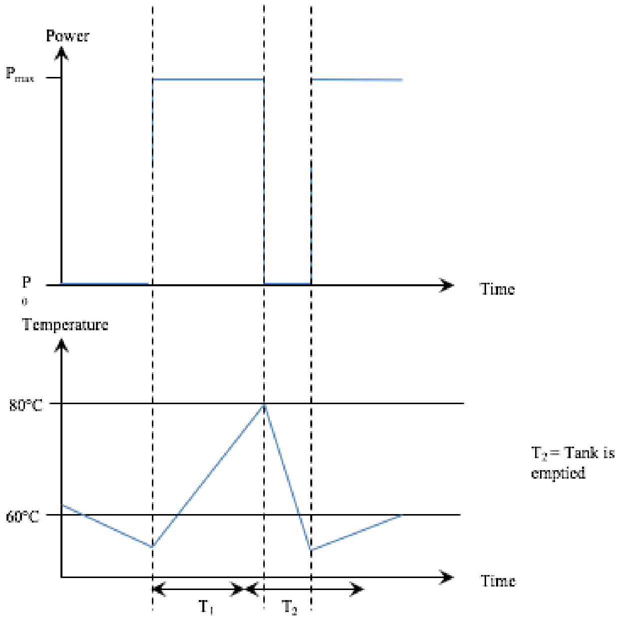


Figure 44 - Simplified theoretical concept investigated of remote steering of a hot water boiler.

The top graph shows average electrical power used to maintain desired tank water temperature. The electricity power input to the tank varies between maximum and off-mode, regulating temperature when needed. Note that temperature changes are in practice not linear as in the figure above.

The parameters calculating the amount of unwanted energy consumption of a HWB is presented in Appendix C.

Results using a reference HWB

The result of unwanted energy and cost for the customer will be calculated in two ways. First an own method will be presented, comparing heat losses with the HWB maximum water temperature, setting at 75 and 65 ℃. The second method is based on an earlier study, comparing the results of their experiment with ours, using the same method but our parameters.

The own method is comparing the heat losses of the HWB during the time it takes for the water temperature to drop from 65 to 60 ℃ when the maximal water temperature is set to 75 instead of 65 ℃ (Nibe AB, n.d.).

The energy needed to increase the water temperature from 20 to 75 ℃ was calculated with intervals of 1 ℃, using Equation 7 in Chapter 3. The amount of energy needed for each temperature interval, is presented in Appendix C. The total needed energy from 20 to 75 is calculated to be 1.90 kWh.

$$E = V_{tank} * \rho_{water} * \beta_{water} * (T_{end} - T_{start})\ (W) \qquad (7)$$

Heat losses from HWB to the ambient surroundings for each temperature interval between 20 and 75 °C was calculated with Equation 8, in Chapter 3. The result of heat losses from the HWB to the ambient surroundings, for each temperature interval is presented in Appendix C. The difference in heat losses at a certain temperature compared with the heat loss at 65 °C, with intervals of 1 °C from 75 to 61°C is presented in Table 12.

The time it takes for the water temperature to decrease from 65 to 60 °C due to heat losses, is calculated to be 17.3 hours using Equation 9, in Chapter 3. With the same equation, the time it takes to decrease from 75 to 65 °C with intervals of 1 °C was created and is presented in Table 12.

Table 12 - Ten intervals from 75-65 °C with the heat loss difference and time of the interval.

Interval	**Heat loss difference (kW)**	**Time of interval (h)**
75-74	0.0109	2.7105
74-73	0.0098	2.7607
73-72	0.0087	2.8127
72- 1	0.0076	2.8668
71-70	0.0065	2.9231
70-69	0.0055	2.9815
69-68	0.0044	3.0424
68-67	0.0033	3.1057
67-66	0.0022	3.1718
66-65	0.0011	3.2408

The difference in energy heat loss starting at a water temperature of 75 instead of 65 °C is calculated with intervals and heat loss differences presented in Table 12. The time it takes for the water temperature to drop from 65°C to 60°C is calculated to 17.3 hours, and during the same time, the water temperature would drop from 75°C to 68 °C. The difference in energy heat losses, starting at 75°C instead of 65 °C, is calculated to be 0.05 kWh. With a COP of 3, the auxiliary energy would be 0.02 kWh. The unwanted cost of this, with an electricity price of 0.92 SEK/kWh, see Appendix C, is 0.04 SEK. Dividing the unwanted cost to use the HWB with the amount of energy payed by the customer to heat up the water from 20 to 75 °C, which is 1.9 kWh, the unwanted cost would be 0.02 SEK/kWh.

Unwanted energy with DSR has been studied before by De Montfort and Leeds Metropolitan Universities, using a HP with domestic hot water storage which leads us to the second method. In the study, it was assumed that the tank is heated up and untapped during 10 hours, with a worst case temperature difference 40°C and a heat loss at 2.5 W/°C giving a needed input of 100 W heat and an electrical input of 50 W with a COP of 2. The result of the study gave 0.5 kWh of unwanted energy (Boait and Stafford, 2011).

With the same assumptions used by Boaits and Staffords, but changing the domestic hot water storage parameters in Appendix C, and using the results from Table 12, the result of unwanted energy is calculated to 0.2 kWh in our study.

Analysis and conclusion

The amount of unwanted energy, and the cost it brings for the customer, activating HWB in DSR is situational. The customers' behaviour is a big factor, how much hot water they use and how often it is used. Each household has a unique behaviour that needs to be learned in order to optimise the system. A compensation of 0.02 SEK/kwh is a low cost for the energy company to be allowed steering customers HWB, but our model and this value can be used as a guideline. The compensation would be different for each unique HWB since they use different electric power in kW, have different tank sizes and heat losses. The reference HWB used for the method in this study is good isolated. Older ones, normally has higher heat losses which would bring a higher compensation for that unit, compared with the one investigated. If the variable costs of controlling is in fact this low, it should be tested further with experimental methods as well as in the project. However, HWB's have a great potential to use as a device in DSR due to its high capacities and small heat losses, hence unwanted costs.

7.2.3 Customer Battery

Unwanted energy is not an issue for customers having own batteries connected to their micro-production of electricity from PV-cells. An issue is however the battery efficiency, meaning that input of energy is not the same as the output, due to energy losses. Another problem with a battery is that it might have a negative value to the customer due to buying and selling prices of electricity. Depending on how the battery is used in the LES, it might not be that the one who pays for the energy to be stored, is also the one using that energy. It is to be investigated further if cost coverage is needed for these issues and how high the compensation should be.

How to use the battery with DSR

The battery can be used in several ways with DSR to benefit the LES. One way to use the battery is by using it as an addition to central BESS. This means that when there is overproduction the energy can be stored in the costumers battery and later on that stored energy can be used elsewhere to balance the system when there is underproduction. In this way, can cause the one who pays for the energy initially will not be the one using it. A second way is that the stored energy in the costumer battery provided from the system and own micro-production can only be used by the same customer.

Value for private customer of having a battery

A worst-case scenario is investigated to understand which value there is for a private customer to own a battery, using the same spot price for selling and buying electricity. The price of buying electricity is set to 0.92 SEK/kWh (Appendix B) without any profit margin and to sell from own micro-production is 1.17 SEK/kWh (Appendix B). The price of buying electricity is less then selling for a micro-producer. This means that there is no value to store own produced energy in a battery for self-usage. It is more beneficial to sell as much produced energy as possible and then buy electricity from the grid when your production can't match the demand of your household. For each kWh that you store instead of selling it you can lose 0.25 SEK/kwh which is the difference between the price of buying and selling electricity. Adding to this is that the efficiency of the battery is only 95 % (Fronius, 2017). With the assumed price to buy electricity the efficiency of the battery would make the costumer lose 0.05 SEK/kWh to use the battery. This loss needs to be covered and compensated to the customer if it the LES that charge the battery and uses it. These costs exist only when the consumption in the house is less than the production since it is only then the LES can use the battery for storage else it would be charged from the customer's own energy production.

Analysis and Conclusion

The negative value for the customer to have a battery connected to their micro-production is based on the selected spot price for this study. In this study, the spot price is assumed to be the same when selling overproduced electricity and when buying electricity from the grid. This is most certain not the case, since the spot price changes hourly which causes a difference in the price to buy and sell electricity for the customer. It is likely to assume that the spot price is higher when you need to buy from the grid since a higher demand usually creates a higher price. This can make the negative value of having a battery to be equalized. The negative value is to be remembered the worst-case scenario for a customer. It is not sure that the owner of the battery will have the right to acquire a tax reduction of 0.6 SEK/kwh. Without the tax reduction, the result would be positive of having a battery. Battery wear out is not mentioned in this study since the battery is assumed to be given for free to the customer and E.ON has pay for it. It will not be necessary to compensate for something E.ON bought and gave out for free. Since the value of having a battery can be positive due to missing tax reductions and changing spot price and a possible investment discount the customer should not be compensated for the battery in this regard. The loss of efficiency should however be covered when the battery is stored with electricity from the LES leading a cost coverage of 0.05.

How the battery will be used in the system needs to be investigated further to understand technical possibilities and boundaries. This is today unclear hence this study does not have to right material or tools to further research this question. Therefore, simple calculations and reasoning on how it could work have been done, concluding that further investigations must be done within this area of the project.

7.3 Fixed Incentive

The customer survey concluded in Chapter 5 that a fixed incentive must be investigated further. A fixed incentive is both simple and brings trust (the two success factors found) since customers can easily understand the value they will be given for their service, and are guaranteed a certain compensation.

7.3.1 Fixed incentive definition

Depending on if or how a fixed incentive is combined with a variable market value incentive, it can compensate for or include different factors. But, based on this study's literature review and own customer survey, finding both driving and restraining forces for DSR, we have chosen to use a fixed incentive to cover for three factors:

- Intrusion compensation
- Decreased comfort level compensation
- Attraction for participation

The first is intrusion. What is it worth for customers to even let a company remotely control your household heating equipment? Broberg et al. (2014) discussed the intrusion aspect, regarding the unwillingness to let a company map your energy usage. It is important to remember that HP and HWB controlling might affect indoor household temperature. This might be perceived as comfort deterioration by some customers, which also must be compensated for. For example, Sernhed (2004) presented a study of remotely controlled customers, where some of them noticed a decrease in temperature during steering periods.

The fixed compensation also should be on a level for the customer to gain attention and attraction to the offer. The fixed compensation is the only set value that is guaranteed to the customer in its exact amount. It will be the first compensation the customer is faced with and is assumed to be the most understandable and concrete part of the offer with the customer.

7.3.2 Customer knowledge

In general, the most important factor regarding DP expressed is that no costs are wished to increase. However, some customers expressed a demand for noticeable decrease in energy costs in order to feel attracted, and some expressed they are willing to pay more for contributing to a better environment by participating. When discussing attraction compensation, it also should be mentioned that only 44% of the targeted households answered to either the written survey, or participated during interviews. Could the other 56% that did not show an interest at all be attracted by a fixed compensation?

Further, other drivers than financial are expressed. The environmental driving force is high. This speaks against a high financial compensation, where a climate positive proactive scheme could attract several households to participate in DSR. Likewise, the engagement incentive is high in Simris. Inhabitants are curious and highly interested in doing something and engaging in matters worth engaging in.

7.3.3 Analysis

There are facts found, shortly presented above and in Chapter 3, Theoretical Background, that speak for and against a high fixed compensation value. A summary of these facts, weighing the different alternatives, are explained in Table 13.

+ −

Table 13 - Factors weighted for a high or low fixed compensation.

Factors which ways for a high compensation	**Factors which ways for a low compensation**
High sensitivity for changing indoor climate at night time (See for example Broberg et al (2014) in Chapter 3).	Low sensitivity for changing indoor climate at day time (See for example Broberg et al (2014) in Chapter 3).
Smart Grid Gotland did not manage to attract more than 14% of the target participants (See Chapter 3, Theoretical Background).	Both Fortum project and EcoGrid Bornholm managed to attract and connect the number of participants desired to DSR (See Chapter 3, Theoretical Background).
Low number of answers to the customer survey in this study, 40% of entire Simris area.	Findings from this study's customer survey claim that the most important factor is that the cost of electricity due to heating does not increase.
Findings from this study's customer survey state that the decrease of energy costs must be significant to engage and give time into a project.	Findings from this study's customer survey state that, 63% of respondents are interested in participating without knowing any compensation at all will be given.
Reduced comfort level if controlled during summer and winter.	Indoor temperature is only to be changed +-1 degrees, which generally does not compromise on comfort level.
Intruding household in a way never experienced by the customer before.	No findings from this study's customer survey state that intrusion is a problem. Most customers have positive attitude towards E.ON.
	The LES project will only run in island mode hence connect customers 10 weeks per year.

Basing the fixed compensation values on the study made by Umeå University, Broberg et al (2014), a fixed compensation that stretches from 0 to 2 500 SEK is proposed. The reference value, 650 SEK, is also based on this research which is the value demanded for indoor heat changes during night time.

The most important factor for customers, proven by both this study's investigation and other projects' investigations, is that no extra costs will rise with DSR participation. The zero-compensation case would therefore be recommended to be complemented with an investment support or give away. DSR equipment is costly and installation of these could "scare away" many possible customers. Further, the heating equipment needed can also be of interest to discount, in order to not lose customers who cannot increase expenses.

Analysis and Conclusion
Since the LES project cannot ensure no controlling at night time, a value higher than 650 SEK should be discussed. Continuing, what the fixed compensation is supposed to cover should be looked at.

- The intrusion aspect is confirmed to be of low importance. Only the survey from Broberg et al (2014) mentions any problem regarding leaving information and inviting a company into your household. The analysis is that a compensation for intrusion can be none or close to zero. However, taking future perspectives into account, data logged over time and customers realizing it, can have an impact on this value.

- The comfort aspect is of higher importance. Broberg et al (2014) talks about this matter in their choice experiment. Changed indoor temperature and when it occurs, have an influence on customer compensation demand. Customers are demotivated to agree on remote indoor heat controlling when it is done at critical times when they are in the house. Here, it also has to be taken into consideration that the load of HWB and HP steering generate different levels of perceived comfort change. Assumingly, indoor temperature (HP) comfort is more sensitive than tap water temperature (HWB). In this case, a fixed compensation model could depend on installed equipment and its effect on human comfort change.

  The matter of contributing positively to the environment can be discussed within the comfort aspect. Many customers are driven by the environmental driving forces, both in Simris, Gotland and on Bornholm, in which they see a satisfaction in doing something good for the environment, sacrificing comfort.

- The attraction aspect is also of high importance. Not half of Simris inhabitants have even responded to the survey questionnaire, nor contacted E.ON for any questions. At Gotland, only 14% of the aimed target group participated in DSR tests. Further, non-interested customers have expressed that they would like to see a significant decrease in costs in order to consider participation. A fixed compensation could possibly replace a decrease. The question can be asked, *what is a significant value?* It can be perceived as one that matters, one that could possibly cover other household costs such as one or half of an electricity invoice, a technical component etc.

Taking the above into consideration, this study suggests a value between 650 SEK and 2 500 SEK in compensation per year for household intrusion and comfort change, weigh towards a lower value. Together with the attraction aspect, a higher value should be added to attract initially non-interested customers, customers finding no other incentive.

7.4 Flexibility Incentive

Even though DSR showed not to have a large impact over time through the simulations made in Chapter 6, there is still a value during the point in time when DSR is activated. DSR does still give economic value, as shown in the simulation, when it is used instead of the alternative. Based on these simulation investigations, we have chosen to see the system as a trading market, where the flexibility provided by the customer has a market value based on the utility it has on the system in the specific point in time when it is being used. For example, at one specific point in time the BUG needs to be used. The system is then prepared to pay the margin cost for BUG, at that specific point. Any kWh produced with a margin cost lower than the one of BUG, would be of value for the system.

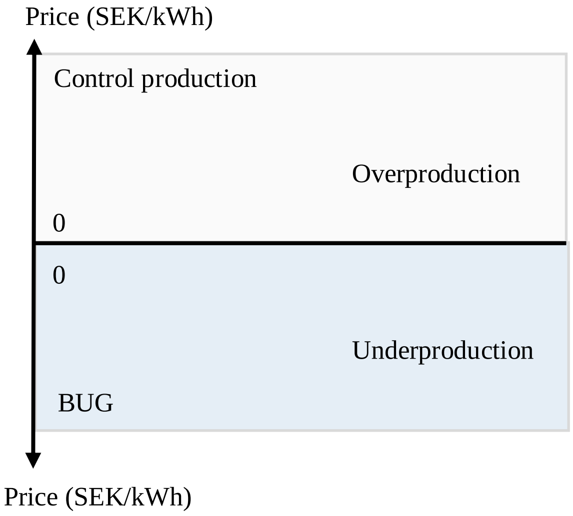


Figure 45 - Market value span depending on system health, and the highest operating margin cost.

We have chosen to see this value as dynamic, depending on if there is under- or overproduction in the system, since these situations are driven by different costs. The result of the simulations made it clear that the market value of the flexibility should be different in all seasons, varying between the cost per kWh of the BUG, and lost revenues due to controlled (wasted) production from the WT and PV power station. Figure 45 presents how we have chosen to create the variation of the market value depending on system health.

Winter
During the winter the LES would benefit every kWh not needed to use the BUG, meaning that the market value of flexibility should be anything below the price to use the BUG. This is what the system operator would benefit from flexibility.

Spring/Autumn
The system suffers from both under- and overproduction during the spring/autumn. This means that the market value can maximum be set by the cost per kWh to use the BUG when there is a negative discrepancy and the lost revenues per kWh when there is a positive discrepancy.

Summer
The market value of flexibility should be set after the lost revenues per kWh to control the production of the WT and solar PV power station since there is a high amount of overproduction in the summer.

Chapter 8

Economic Incentive Model

This chapter will explain three building blocks identified in this study. These building blocks will be used to create model proposals, different constructions of financial incentive models that can be recommended to E.ON.

8.1 Building Blocks of Incentive Model

With the results from the customer and system perspective research, three insights were investigated in Chapter 7. In this chapter, they will be used to function as building blocks of a financial model. These will be elaborated, creating different proposals of incentive models. The three building blocks are:

- Fixed, yearly incentive for intrusion, comfort and attraction.
- Cost coverage compensation covering all increased costs customers may experience.
- Flexibility incentive to give the customer a fair remuneration of their flexibility.

The created building blocks are described below:

Fixed incentive
A fixed remuneration proposed as a building block to give the costumer a yearly remuneration for the intrusion, allowing the energy company to control their equipment, the potentially comfort change they may experience and to create attraction making them want to become an active part of the project. The building block is presented in Figure 46, based on intrusion, comfort and attraction.

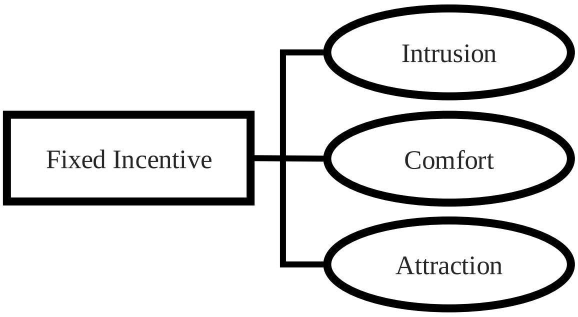


Figure 46 - Fixed Incentive building block

Cost coverage

The Cost Coverage building block was created to compensate the potential increased energy cost per kWh that the costumer may experience by allowing an external aggregator control their decentralised energy storage. This study has investigated three equipment to be used in DSR. The increased cost the costumer may suffer from is different for all equipment and so is the proposed compensation. Figure 47 presents the structure of the building block which contains coverage for costumers HP, HWB and CBESS.

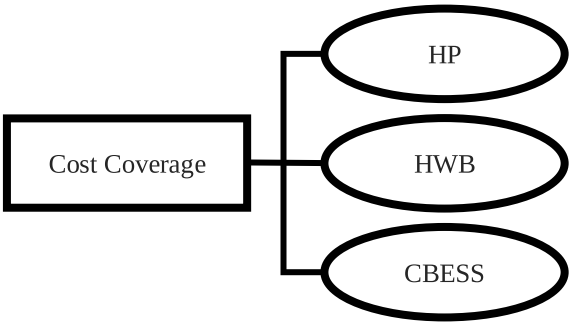


Figure 47 - Cost Coverage compensation building block

Flexibility incentive

The service of flexibility that customer is providing through DSR has a market value for the energy company, which the customer should take part of and to be remunerated for. This building block is developed to give to the customer a fair reimburses of that value per kWh. The remuneration, which is set after the market value, depends on the system's health, therefore the current cost driver, but also on the utility provided from the costumer's flexibility. When the system suffers from underproduction, the market value is based on the BUG operation costs. When it suffers from overproduction, it is based on the lost revenues from controlling the production. The structure of this building block and what the market value of flexibility is based on is presented in Figure 48 showing the cost driver of the system and the utility from flexibility.

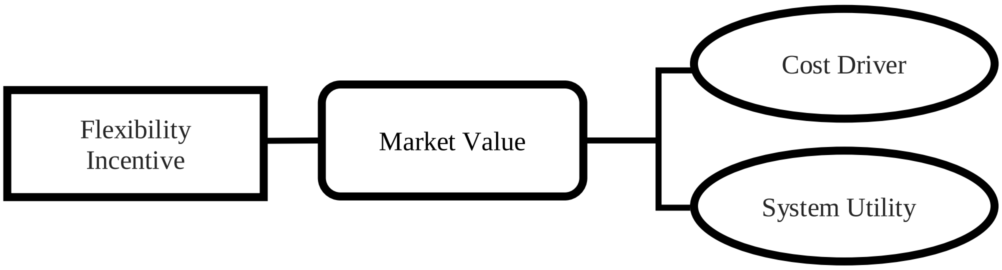


Figure 48 - Flexibility Incentive building block

8.2 Economic Incentive Model Propositions

Four incentive models based on the three presented building blocks have been developed as proposals to E.ON Elnät AB. The aim is to attract customers to offer their flexibility resources in DSR, and suggest value-combinations for the service of flexibility that can be remunerated. We have therefore used the question "*How would a customer like to be presented to DSR, with an economic incentive*?" when creating the models. These models are presented separately in each following section, describing and motivating its structures.

Model 1

A model structure designed by E.ON, seen in Figure 49, uses the three building blocks separately making the model very adaptable to the system and customer behavior. How the model is offered is presented in Table 13.

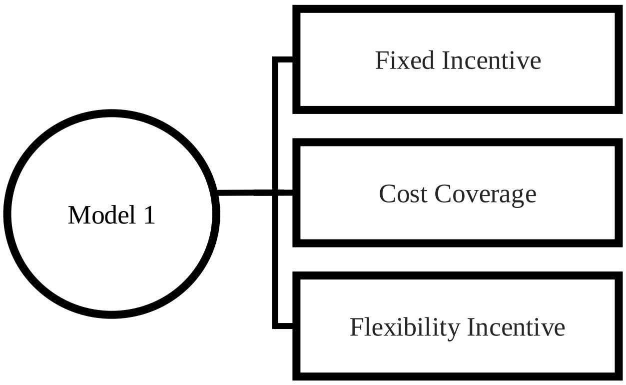


Figure 49 –Structure of Economic Incentive Model 1.

This model was built to give a fair compensation and remuneration to the customer, based on their exact use of energy, with variable coverage for unwanted energy and flexibility incentive. In addition, it creates an attractiveness with a fixed incentive. Since this study's customer survey found, for example, that some customers did not fully understand the difference between network owner and electricity retailer, the model's level of complexity can therefore be too high and hard to implement. It can also be difficult to implement for the company. To measure the extra costs that a customer experience for every kWh controlled, demands new measuring technologies and data logs that can be disaggregated. It also demands a complete log of the system production, at the exact time when a customer is controlled, to be able to calculate which cost drivers are present at this time.

Table 14 – Economic Incentive Model 1.

Model 1
Fixed (SEK/year)
Variable
Cost Coverage Heat Pump (SEK/kWh)
Cost Coverage Hot Water Boiler (SEK/kWh)
Cost coverage Customer BESS (SEK/kWh)
Value of flexibility overproduction (SEK/kWh)

Advantages

- Fair and exact remuneration for every kWh the customer is being controlled.
- Creates attraction with a fixed remuneration.
- Customers can be motivated during both initial agreement of participation (fixed), but also every time the household is being controlled, knowing that they are compensated (cost coverage) and payed for (flexibility incentive) during every intrusion.

Disadvantages

- Can be complicated to communicate to customers since it is based on several variable remunerations.
- Technical challenges to implement for an energy company because it can .be hard to measure the amount of unwanted energy.

Model 2

Model 2 is dependent on the system's different behaviours during various seasons. It is built to introduce a model that is taking the different cost drivers for different seasons into account, and to present them in three seasonal intervals, winter, spring/autumn and summer instead of instantaneous values that changes every for simplicity. The goal is to use a mean seasonal value for cost coverage and the flexibility incentive. The fixed incentive is proposed to be a yearly value, but could be changed over seasons due to the fact that comfort might be perceived differently by the customer over different seasons. The structure of the model is presented in Figure 50 containing a fixed and seasonal incentive value and how it is offered is presented in Table 15.

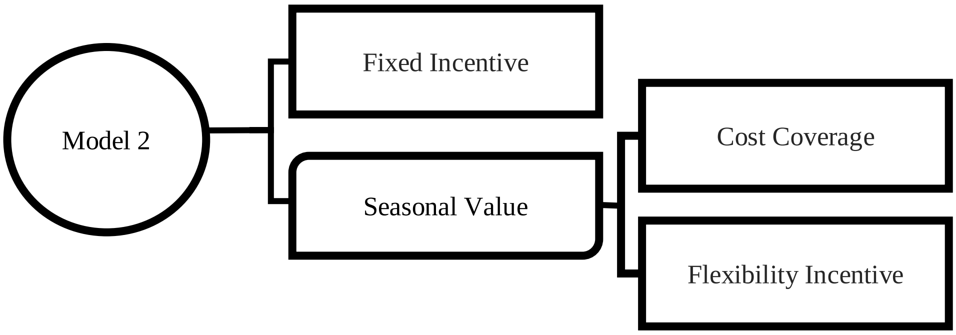


Figure 50 – Structure of Economic Incentive Model 2.

For winter seasons, we propose a remuneration between the highest cost coverage and the market value of flexibility when the BUG is activated.

During spring/autumn, the value of flexibility switches between the cost of using the BUG and the value of lost revenues to control production. Therefore, we propose that the remuneration can vary between the highest cost coverage and a weighted value of the cost to run the BUG and to control production based on the amount of energy they produce and control.

$$Weighted\ value = \frac{(Cost\ per\ kWh\ to\ use\ BUG) * Energy_{BUG} + (lost\ revenues\ per\ kWh\ due\ to\ controlled\ prodcution) * EnergyEnergy_{Control}}{Energy_{tot}} \quad (13)$$

The proposed seasonal remuneration in the summer, the highest cost coverage and the lost revenues per kWh to control production.

Table 15 - Economic Incentive Model 2.

Model 2
Fixed (SEK/Year)
Season
Winter (SEK/kWh)
Spring/Autumn (SEK/kWh)
Summer (SEK/kWh)

Advantages:

- Easy for customers to understand because the few variable remunerations.
- Customers can be motivated during both initial agreement of participation (fixed), but also every time the household is being controlled, knowing that they are compensated (cost coverage) and payed for (flexibility incentive) during every intrusion.
- Fair to set prices after season, both for customers and the system.
- Fairly easy for the company to implement.

Disadvantages:

- Still, technical challenges apply when the company must log every kWh steered at each customer's household, and disaggregate the metering.
- The variable compensation will be of an average value over seasons, and not the exact market and cost coverage compensation value. This can be unfair to both the system and the customer.

Model 3

The main driving force for DSP is to contribute positively to the environment, and perhaps a financial incentive is not needed at all. It is however understood, that customers do not wish to experience increased costs. Therefore, this model proposes a minimum financial compensation by only covering their increased cost that arises when their equipment is controlled during activation. The remuneration is proposed to for the HP, HWB and CBESS. The structure of the model is presented in Figure 51, including only the cost coverage block. How it can be offered is presented in Table 16.

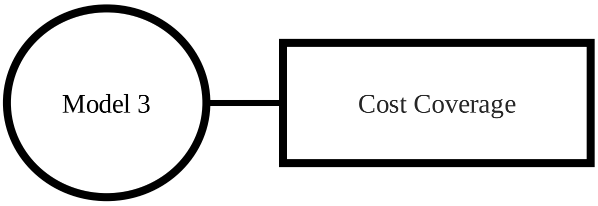


Figure 51 – Structure of Economic Incentive Model 3.

Table 16 – Economic Incentive Model 3.

Model 3
HP (SEK/kWh)
HWB (SEK/kWh)
CBESS (SEK/kWh)

Advantages:

- Minimum required remunerate for participation according to customer research.
- Semi-complex for the customer. Easy to understand but with some complex details.

Disadvantages:

- Does not remunerate for intrusion or comfort.
- No attraction incentive for non-interested customers.
- Semi-complex for the customer to understand.
- Can be a disadvantage that the customer is not rewarded for its participation, only compensated for losses.
- Technical boundaries (today) to measure exact steered kWh.

Model 4

Another proposition is to incentivise participation with only one fixed yearly compensation, including all building blocks seen in Figure 52 and presented in Table 17. The idea is to simplify a financial remuneration with proposing one value ensuring the customer both cost coverage, and revenues participating in DSR. This is the simplest service agreement, and presumably the easiest one for a customer to understand. To understand can have a value which attract costumer alone.

This value could be estimated through the following model:

$$\begin{aligned} &\mathit{Fixed\ Remuneration} \\ &= \frac{\mathit{Estimated\ kWh(\ activated - deactivated)}}{\mathit{Equipment}} * \mathit{Highest\ Cost\ Coverage\ value} \\ &+ \frac{\mathit{Estimated\ kWh\ activated}}{\mathit{Equipment}} * \mathit{Flexibility\ value\ of\ production\ curtailment} \\ &+ \frac{\mathit{Estimated\ kWh\ deactivated}}{\mathit{Equipmet}} * \mathit{Flexibility\ value\ of\ BUG\ running\ costs} \\ &+ \mathit{Fixed\ incentive} \end{aligned} \tag{14}$$

Estimated kWh steered for the Simris case study can be found from Table 9, 10 and 11 in this study.

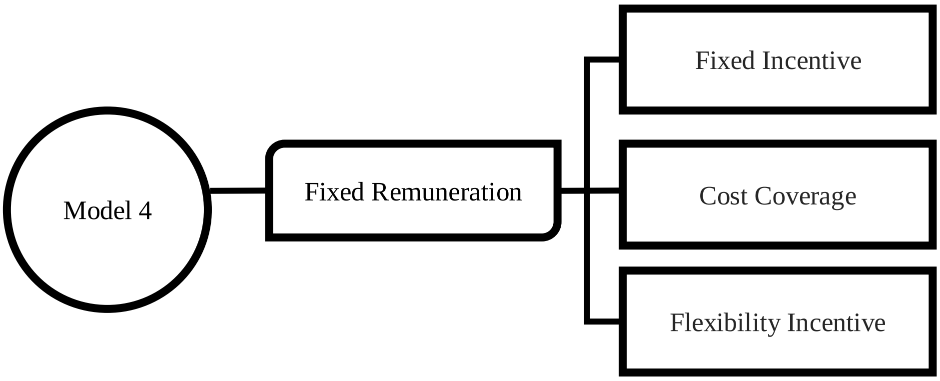


Figure 52 – Structure of Economic Incentive Model 4.

Table 17 - Economic Incentive Model 4.

Model 4
Fixed (SEK/year)

Advantages:

- Easy and simple for customers to understand, which increases the attraction and maybe level of engagement
- A complete fixed incentive lowers the threshold for customers that does not have time, energy or interest in learning about DSR participation
- Easy for E.ON to both create and offer
- E.ON save money and effort on agreement creation and preservation

Disadvantages:

- The valued offered must be thoroughly considered and motivated in order to combine all blocks in an accurate way
- Can be seen as non-fair from a customer perspective, if all customers are compensated with same value but not steered in the same way
- Will not give the customer the exact compensation value
- Risk of overcompensation
- Costumer have a chance to feel unmotivated when being steered since they have already been given the remuneration.

Chapter 9

Conclusion & Contribution

In this chapter, this master thesis will be concluded and we will answer to its purpose and research questions. This chapter will also discuss this study's contribution to the field of demand side response and incentivising it, on a greater scale, with Simris as base case.

9.1 Conclusion

The purpose of our study has been the base of our research and has reflected the content of the study throughout the process:

The purpose of this study is to investigate how to incentivise customer participation in demand side response in a local energy system in Simris and to develop an economic model for how customers' participation in demand side response activities should be valued and compensated to provide sufficient incentives for participation, and a fair compensation for customers cost arising in the participation.

Using an incentive-based DSR program to incentivise customers to participate in DSR, where customers receive payment or rate discounts through an economic model has worked well for other DSR pilot projects. None of the investigated projects' economic incentive models worked perfectly for the DSR introduction in the E.ON local energy system project, and therefore, an own model was developed to attract the inhabitants, designed to suit their needs.

To fulfil the purpose of the study creating an economic model, we needed to understand how customers can be incentivised to participate in demand side response, and combine it with how much value demand side response can have for the local power system. Therefore, two perspectives were investigated. First, the customers' perspective through a customer survey, and second, the LES's perspective with simulations of the energy flow through the system components.

The overall conclusion of this study is that there is a conflict in the market between the energy corporates and private household customers.

We learned, through our customer survey, that the main driving force of the inhabitants to participate actively in the project was their will to contribute positively to the environment and climate. In addition, we learned that increased costs are demotivating. Communication between customers and energy companies should be simply and trustful, and an economic model should have a simple design making it easy for customers to understand.

Continuing, the major issue found is that energy companies tend to strive for, although very fair compensations and intelligent incentives, relatively complex solutions from a customer's perspective.

As found earlier in the study, understanding has a value itself for the customer. However, there should be a minimum level of complexity so that an economic model to fulfil its purpose. Therefore, we listened to both perspectives and created a fairly complex model in a simple package.

To finalise this study, we must answer our research questions and summarise our findings leading to these answers. First, we will answer research question number one, RQ1, but in order to do so we first need to answer its sub-questions, RQ1:1 and RQ1:2.

RQ1:1: Which driving and restraining forces exist among customers in Simris to participate in demand side response?

In order to answer this question, we conducted a customer survey where we met the inhabitants of Simris. We wanted to know what they thought of E.ON's local energy system project and investigate if, and in that case why, they would like to contribute participate actively in the project. If the customers were not interested, we wanted to understand why, so that incentives could be created to attract a large number of customers. After 20 interviews and 62 written survey responses, we found an overall picture of the driving forces and restraining forces. The following picture is from the conclusion of Chapter 5, The Customer Perspective.

Table 10 - Three main driving forces and restraining forces found among inhabitants to participate in demand side response.

Driving Forces	*Restraining Forces*
Curiosity	Low level of knowledge about DSR
Positive environmental contribution	Increase in costs
Decrease in electricity costs	Time constraints

These driving forces can also be confirmed by previous studies and other projects investigating demand side response, but it is important to remember that this project is a pilot of a local energy system in Simris, which follow with specific conditions. These specific conditions are that both decrease but also increase of capacity control is of scope, and the system will only run on local resources. These conditions could hypothetically both motivate and demotivate customers' participation. It was found that it mostly motivates customers to participate. In conclusion, customers are driven by and curious about the fact that they can be a part of a development project in the form of a renewable local energy system, especially since it contributes positively to the environment, in the hope of saving some money by participating actively in it.

RQ1:2: How can an economical incentive model look like for demand side response participation in the local energy system project?

Customers are willing to participate, but not on a complex level. Therefore, an economic incentive model should look like a simple one, when presented to the customer. We gathered the findings from our customer survey, concluding that a simple way of financially incentivising DSR is to do it with a fixed remuneration. Further, we found that customers do not want to see increased electricity costs by participating in DSR, and through our system utility simulations, we could see that the system brings different costs during different seasons. Therefore, an economical incentive model can be based on the three building blocks; fixed remuneration, cost coverage and flexibility incentive, as presented in Chapter 7. The value of it, the total remuneration, can reflect the three building blocks, and according to our customer research, it does not need to be high. However, if the project wants to attract non-interested customers, a higher value can be considered.

RQ1: How can demand side response be introduced to household customers?

Combining the answers of RQ1:1 and RQ2:2, we can now answer to this question. Demand side response can be introduced to household customers as a service that the customer offers to the company. The company can further introduce the possible service that the customer is able to provide through incentives, covering a financial remuneration, a product and communication regarding the service's positive effect on the environment and ways to engage in something new and exciting.

The financial remuneration can be in the form of an economic incentive model based on three, or any of the three, building blocks found through customer driving forces and variations and cost drivers of the LES power grid conditions, see Chapter 8.

RQ2: Which enhancements can demand side response contribute with to the self-sustaining local energy system in Simris?

With the results from our simulations, with our assumptions, in three different seasons presented in Chapter 6, it was shown that demand side response can contribute with system capacity, hence financial, reductions. In all scenarios during the three simulated seasons, both the backup generator and the production control can be reduced in MWh when using customers' flexibility resources. Through this, the margin costs for central production can be reduced. Demand side response does help system power discrepancy to smoothen. The effect is however relatively small. The enhancements that demand side response can contribute with are not substantial enough to create a self-sustaining local energy system. There will still be periods when the LES needs help from the overlying transmission grid, to supply Simris inhabitants with electricity.

9.2 Contribution

The focus of this study has been to investigate how an energy company can incentivise customer participation in demand side response in a local energy system in Skåne, Sweden. This is not the first time this has been done. Many projects have and are operating all over the world shifting electricity consumption in different ways. Most commonly, the reason for shifting load is to reduce high consumption peaks, for production and grid benefits. In literature, different studies can be found of how customers value load shifting, change in comfort, remote controlling of heating equipment and positive contribution to environment and climate.

In the E.ON LES project, the goal is to sustain a local system, hence the way of controlling customer consumption, DSR, is therefore not of same scope as it is for most other projects. Here, we want to add energy in customers' households, not only decrease, in order to make use of as much electricity as produced as possible. The factors regarding a local energy system, combined with demand side response, and how to get customers to participate in it, was difficult to find in literature. Our study can contribute with an investigation of customer incentives where there is possibility of increasing electricity consumption in new local, economic conditions.

The concept of using demand side response to help a local energy system self-sustain, increasing or decreasing consumption due to signals or overbalance or underbalance can be useful in other settings. In Sweden, we have a well working electricity system where national overbalance or underbalance is solved through import of export, but in some smaller societies where import or export is not an option, a local energy system with DSR can be of interest. For example, on an island or in remote areas located far away from the grid, the LES + DSR concept might be an interesting option to investigate. Further, in systems that has high penetration of intermittent renewable energy resources, but with limited export possibilities such as on Gotland, Sweden, or in Denmark, DSR with both increase or decrease control could be interesting. Here, maybe our study and guidelines for an economic incentive model can be beneficial.

Chapter 10

Recommendations

In this chapter, the recommendations for the LES project and for future work will be stated. The recommendations are formulated from our point of view, from our knowledge gained during this work. The recommendations for the LES project will be focused on pleasing the customers' perspective, taking their standpoint. The recommendations for future work regards thresholds we have found during our study that the LES could benefit from in future developments.

10.1 The LES Project

- The LES project is a research and development project including many new dimensions and interesting factors that can catch attention. In the best of worlds, DSR flexibility could be offered voluntarily and an internal market could be created to keep the LES stable itself, at all times reflecting supply and demand. However, Simris demographics show high average age, with the risk of low stamina, but still high driving forces to engage in something exciting. Customers are eager to actively participate, but not to a high complex level. It is proven through our customer survey, that the financial driving force might not be one of the strongest. We think that it is therefore of interest to catch Simris inhabitants environmental and engagement driving forces, instead of detailed trading schemes.

- Since our customer survey show some confusion regarding the role of an active LES participant and what it implies, we recommend creating and use an extensive recruitment and communication plan, including customer education. We think that, from a customer point of view, knowledge and understanding has a value itself. We also think that it from the beginning should be communicated to customers what will happen in a transparent and trustworthy way to increase understanding for the company from the customer's perspective.

- Even though it is not the strongest driving force, we think that a financial incentive is needed for recruiting customers to offer their heating household equipment as flexibility resources. However, it does not have to be of high values for 30 customers to participate actively in the LES project. Among all 62 customers answering to our customer survey, the environmental and engaging driving forces are strong and could be used as important sub-incentives.

- We recommend to financially incentivise DSR participation to customers as simple as possible. We think that both the amount of customer participants, E.ON staff and the other tasks in the project would benefit from an easy built and understandable financial DSR model. We think that covering for potential increased costs, comfort change, intrusion and to add an attraction value would be sufficient for the customer to understand and to satisfy the financial driving force.

- We recommend incentivising customer participation in DSR with Model 4, because it will be easy for customers to understand, easy for the company to implement and does not require disaggregation of measurements. Even though motivation might not be high during controlling periods in the household, since no variable compensation is given, it can attract a high number of participants with its simplicity.

- Since the backup generator has high marginal costs, and is proven to be needed to operate many hours during winter season in island mode, it might be of interest to look over the fuel costs and other alternative sources for emergency electricity source in scares times.

10.2 Future Work in the LES Project

- In order to understand how to incentivise customers to contribute with their household heating equipment, it would be of value to have all setting clear when both creating and communicating the incentive to customers. We recommend setting the system conditions to connect specific consequences and risks with customer involvement and DSR, when deciding on an incentive model.

- When we made our simulations, we used an historical times series of hourly data, and could directly see the implications of household equipment controlling for the next hour. This is harder to anticipate in a real-time scenario. Therefore, we recommend using a load and production forecasting tool with a higher granularity than hourly, to optimise the LES, DSR and system priority order.

- We think that logging and measuring of the energy controlled in a customer households by the company in DSR, would simplify a compensation model for potential increased costs. It would also be of value for both the customer and company when implementing DSR and communication its benefits. Hence, to provide customers with this information is of value since they request information of when and how long to their equipment is controlled. If this is not possible, we recommend simulating a household and thermal inertia for exact results.

10.3 In General

- In the case of an LES with added DSR flexibility, we would recommend running under dynamic conditions, to decrease risks for curtailment or outages.

- For future LES systems, we recommend to further investigate the complexity of the system, and how the market price changes depending on the instantaneous conditions of the system.

References

Albadi, M.H & El-Saadany, E.F. 2008. *A summary of demand response in electricity markets. Electric Power Systems Research*. University of Waterloo:Department of Electrical and Computer Engineering.

Björklund, M., Paulsson, U. 2012. *Seminarieboken - att skriva, presentera och opponera*. Edition 2:1. Lund: Studentlitteratur AB.

Boait, P., Staffort, A. 2011. *Electrical load characteristics of domestic heat pumps and scope for Demand Side Management.* De Montfort University & Leeds Metropolitan University. Cired.

Boverket. 2000. *Har du legionellabakterier i dina vattenledningar?*. Klippan: Ljungbergs Tryckeri AB.

Broberg, T., Brännlund, R., Kazukauskas, A., Persson, L., Vesterberg, M. 2014. *En elmarknad i förändring - Är kundernas flexibilitet till salu eller ens verklig?* Handelshögskolan, Umeå Universitet. Centrum för Miljö- och Naturresursekonomi. Energimarknadsinspektionen.

Brodén, D. 2013. *Analysis of Demand Response Solutions for Congestion Management in Distributed Networks.* Stockholm: KTH Electrical Engineering.

Cheng, W. 2015. *Demand Response in China.* http://en.cnesa.org/latest-news/2015/6/24/demand-response-in-china (Retrieved 2017-05-27).

Custom Thermoelectric. 2013. *Heat transfer equations.* http://www.customthermoelectric.com/heatequations.html (Retrieved 2017-02-26).

Council of European Energy Regulators. 2014. *CEER status Review on European Regulatory Approaches Enabling Smart Grid solutions ("Smart Regulations").*

De Leeuw, E. D., & Dillman, D. A. 2008. *International handbook of survey methodology*. Taylor & Francis.

Denzin, N.K. 2006. *Sociological Methods: A Sourcebook.* 5th edition. Routledge, Aldine Transaction.

Dincer, I., Rosen, M.A. 2007. *EXERGY: Energy, Environment and Sustainable Development*. Elsevier.

Energimyndigheten. 2015. *Elnätet.* http://www.energikunskap.se/sv/FAKTABASEN/Vad-ar-energi/Energibarare/Elektricitet/Elnatet/ (Retrieved 2017-05-16)

E.ON. Non dated (a). *Presentation of the Memos*. Essen.

E.ON. Non dated (b). *Functional Specification*. Malmö

E.ON Non dated (c). Kundlista. Malmö

E.ON. 2017a. *Information of the spin-off of Uniper.* http://www.eon.com/en/investors/spin-off-of-uniper-group.html (Retrieved 2017-02-26).

E.ON. 2017b. *Interview with Johannes Teyssen.* http://www.eon.com/en/about-us/profile.html (Retrieved 2017-02-26).

E.ON. 2017c. *Organisation E.ON RU Sweden.* Presentation. Malmö

E.ON Elnät. 2017. *Local Energy Systems.* https://www.eon.se/en_US/samhaelle---utveckling/local-energy-systems/the-future-is-local.html (Retrieved 2017-05-16)

E.ON UK. 2017. *What is decentralized energy?* https://www.eonenergy.com/for-your-business/large-energy-users/manage-energy/energy-efficiency/decentralised-energy-experts/What-is-decentralised-energy (Retrieved 2017-05-20)

E.ON System Drawings. Non dated. Map SRS connection point, E.ON grid structure in Simris.

Ericsson, K., Göransson, L., Johnson, F., Klingmann, J., Nilsson, LJ., Palm, E., Samuelsson, O., Svensson, J., Söder, L., Normark, B. & Åhman, M. 2015. *Den elbaserade ekonomin 2050*. Delba2015.

European Commission. 2017a. *What is Horizon 2020?.* https://ec.europa.eu/programmes/horizon2020/en/what-horizon-2020 (Retrieved 2017-02-26).

European Commission. 2017b. *Press Invitation - Interflex Kick-Off Meeting*. January 26, 2017 - 9.15 AM, Allianz Riviera, Nice.

Fritz, P., Jörgensen, E., Lindskoug, S. 2009. *Att följa elpriset bättre*. Göteborgs Energi. Elforsk Rapport 09:70.

Findahl, Olle. 2010. *Äldre svenskar och internet*. Stiftelsen för Internetinfrastruktur. Danagårds Grafiska 2011. https://www.iis.se/docs/Aldre_svenskar_och_internet_2010.pdf (Retrieved 2017-03-21).

Fortum. 2017a. *Piloten för virtuella kraftverk*. http://www.fortum.com/countries/se/privat/energismart-hemma/virtuelltkraftverk/pages/default.aspx (Retrieved 2017-05-04).

Fortum. 2017b. *Lyckad projektstart för Fortums "virtuella kraftverk" - närmare hundra Stockholmshushåll deltar*. Pressrelease 2017-03-03. http://media.fortum.se/2017/03/03/lyckad-projektstart-for-fortums-virtuella-kraftverk-narmare-hundra-stockholmshushall-deltar/ (Retrieved 2017-05-04).

Free Dictionary. Non Dated. *American Heritage® Dictionary of the English Language, Fifth Edition, 2011*. http://www.thefreedictionary.com/ (Retrieved 2017-05-25).

Fronius. 2017. *Fronius Energy Package.*

http://www.fronius.com/cps/rde/xbcr/SID-7C2726BF-CDE97855/fronius_international/SE_DS_Fronius_Energy_Package_EN_386411_snapshot.pdf (Retrieved 2017-04-04).

GEAB, Vattenfall, ABB, KTH. 2011. *Smart Grid Gotland Pre-Study*. Public version of report, August 26, 2011. Smart Grid Gotland partners, Swedish Energy Agency, VINNOVA, Swedish Energy Markets Inspectorate.

Guggenheim, S. 1990. *The Household Economy: Reconsidering the Domestic Mode of Production*. Science, vol. 249, no. 4976.

Gustafsson, A. 2016. *Kommande bidrag för energilagring i hemmet.* Energimyndigheten. http://www.energimyndigheten.se/nyhetsarkiv/2016/kommande-bidrag-for-energilagring-i-hemmet/ (Retrieved 2017-04-24).

Haimi, R. 2013. *Kall lägenhet gör dig sjuk och stressad.* Dagens Nyheter 2013-10-31. http://www.dn.se/sthlm/kall-lagenhet-gor-dig-sjuk-och-stressad/ (Retrieved 2017-05-26).

Hledik, R., Chang, J., Lueken, R. 2016. *The hidden battery - opportunities in electric water heating*. The Brattle Group, Inc.

Gsänger, S., Sawyer, S. and Januario, C.S. 2012. *Renewable Energy Technologies: Cost Analysis Series*. IRENA: International Renewable Energy Agency. Volume 1: Power Sector. Issue 5/5.

Krögerström, L. 2017. *Frivillig styrning ska göra elsystemet flexibelt*. NyTeknik 2017-01-31. http://www.nyteknik.se/energi/frivillig-styrning-ska-gora-elsystemet-flexibelt-6820497 (Retrieved 2017-05-04).

Lantz, Annika. 1993. *Intervjumetodik.* Lund: Studentlitteratur AB.

Larsson, Ö., Ståhl, B. 2012. *Lösningar på lager - Energilagringstekniken och framtidens hållbara energiförsörjning.*VINNOVA Analys VA 2012:02

Lindmark, S. 2017. *Elproduktionen 2016 var stabil och bjöd på få överraskningar. http://www.energimyndigheten.se/nyhetsarkiv/2017/elproduktionen-2016-var-stabil-och-bjod-pa-fa-overraskningar/* (Retrieved 2017-05-29).

Linnarsson, J., Holmén, S., Fritz, P., Springfeldt, PE. 2013. *Förutsättningar och drivkrafter för olika typer av elkunder att justera förbrukningsmönster och minska sin elförbrukning idag och i framtiden.* NEPP, North European Power Perspectives.

Mcensustainableeneergy. 2011. http://mcensustainableenergy.pbworks.com/w/page/20638049/Electricity%20Systems (Retrieved 2017-05-28).

Nejman, J. 2017. *Smart Grid Gotland, ett av världens smartaste elnät.* Energinyheter.se. http://www.energinyheter.se/20170307/17136/smart-grid-gotland-ett-av-varldens-smartaste-elnat (Retrieved 2017-04-29).

Nelson, C.M. 1988. *The Resolution of Conflict in Joint Purchase Decisions By Husbands and Wives: a Review and Empirical Test.* NA - Advances in Consumer Research Volume 15, eds. Micheal J. Houston, Provo, UT : Association for Consumer Research.

Nibe AB. Non dated. *Elektrisk varmvattenberedare COMPACT-SC.*
http://www.nibe.se/nibedocuments/17130/639623-1.pdf
(Retrieved 2017-04-12).

Nibe F2040. Non dated. *Varvtalsstyrd utomhusmodul i kompakt format*. http://www.nibe.se/nibedocuments/19361/639512-4.pdf (Retrieved 2017-03-28).

Niehof, A. 2011. *Conceptualizing the household as an object of study*. International Journal of Consumer Studies, vol 35. Blackwell Publishing Ltd.

Nordpool. 2016. *Elspot prices.*
http://www.nordpoolspot.com/Market-data1/Elspot/Area-Prices/SE/Yearly/?view=table
(Retrieved 2017-03-15).

Nylén, P-O. 2011. *Möjligheter och hinder för laststyrning*. Elforsk:11:70.

Pyrko, J. 2008. *Direkt och indirekt laststyrning i samspel?*. Lund University-LTH: Institutionen för Energivetenskaper.

Pyrko, J., Darby, S. *Conditions of behavioural changes towards efficient energy use – a comparative study between Sweden and the United Kingdom.* Lunds University, Oxford University Centre for the Environment.

Rowles, P. 2010. *Demand Response and Demand Side Management What's the Difference?*
http://www.energyadvantage.com/blog/2010/02/demand-response-demand-side-management-what%E2%80%99s-difference/
(Retrieved 2017-05-27).

Samordningsrådet för smarta elnät. Non Dated. *Aktörerna på elmarknaden*. http://swedishsmartgrid.se/smarta-elnat-i-sverige/aktorer-pa-elmarknaden/ (Retrieved 2017-05-21).

SCB, Statistiska Centralbyrån. 2009. *Tätorter 1960-2005*. MI 38 SM 0703. Serie MI38 - Småorter och tätorter.

SCB, Statistiska Centralbyrån. 2016. *Folkmängd i tätort och småort per kommun 2010.* www.scb.se/MI0812. (Retrieved 2017-05-18).

SCB, Statistiska Centralbyrån. 2017a. *Kommuner med högst och lägst medelålder, 31 december 2016 jämfört med 31 december 2015.* http://www.scb.se/hitta-statistik/statistik-efter-amne/befolkning/befolkningens-sammansattning/befolkningsstatistik/pong/tabell-och-diagram/topplistor-kommuner/kommuner-med-hogst-och-lagst-medelalder-31-december-2016-jamfort-med-31-december-2015/ (Retrieved 2017-03-21).

SCB, Statistiska Centralbyrån. 2017b. *Kommuner i siffror*. http://www.scb.se/hitta-statistik/sverige-i-siffror/kommuner-i-siffror/#?region1=1291&region2=00 (Retrieved 2017-03-21).

Sernhed, K. 2004. *Effekten av effekten. Elanvändning och laststyrning i elvärmda småhus ur kund- och företagsperspektiv*. Licentiatavhandling: Institutionen för Värme- och Kraftteknik. Lund University.

Simris Byalag. 2017. A/B Flygtrafik. http://www.simris.se/historik.asp (Retrieved 2017-05-11).

Smart Grid Gotland. 2017. *Smart Kund Gotland*. www.smartgridgotland.se (Retrieved 2017-04-21).

Stridh, B. 2017. *Hur mycket solel producerades i Sverige 2016?. Hur mycket solel producerades i Sverige 2016?* http://bengtsvillablogg.info/2017/02/08/hur-mycket-solel-producerades-i-sverige-2016/. (Retrieved 2017-05-28).

Svenska Kraftnät, 2016. *Så hanterar vi vinterns utmaningar. http://www.svk.se/drift-av-stamnatet/drift-och-marknad/vinterns-utmaningar/*
(Retrieved 2017-05-28)

Söder, L. 2013. *På väg mot en elförsörjning baserad på enbart förnybar el i Sverige: En studie om kraftsystemets balanserin*g.Version 3.0.

Trong, D.M., Salamon, M., Dogru, I. 2016. *Erfaringer med forbrugerkommunikation i Smart Grid – med eksempler fra EcoGrid på Bornholm*. Østkraft.

Wallnerström, CJ., Grahn, E. 2016. *Leveranssäkerhet i Sveriges elnät 2015 - Statistik och analys av elavbrott*. Eskilstuna: Energimarknadsinspektionen.

Warfvinge, C., Dahlblom, M. 2010. *Projektering av VVS-installationer*. Edition 1:10. Lund: Studentlitteratur AB.

Yin, R.K. 2003. *Case study research: design and methods*. 3rd edition. Thousand Oaks: Sage Publications, Inc.

Attachments

Appendix A. Customer Survey

Interview Guide

Project (E.ON LES) presentation to the customer
Målet med pilotprojektet är att integrera den ökade mängden förnyelsebar energi i just ditt elnät och möjliggöra framtida energisystem. Förnyelsebar energi är sådan som kommer från vind, sol och vatten till exempel, och problemet med dessa är att de inte kan ge energi hela tiden då vi vill, utan är endast när väder och andra omständigheter tillåter. För att ett förnyelsebart energisystem ska fungera, bygger det på att kunderna möter de nya förutsättningarna. Därför är det viktigt att förstår hur kunderna står sig till utvecklingen och hur ni vill att er roll i framtiden ska se ut.

Introduction

1. Arrival
2. Who are we?
3. Why we want to study E.ON's new project: future energy systems and why WE think they are important and interesting
4. Goal with the interview: To understand the customer! Because the system might require their active participation.
5. Which factors we have identified and which kind of questions we will ask.
6. Our role: study E.ONs project and future renewable energy systems.
7. First question: How did you first hear about the project and what did you think then?

Personer i hushållet

1. Vad har ni för yrken?
2. Vad har ni för utbildning?
3. Hur många bor här?
4. Vilka bor här?
5. Hur länge har ni bott här?
6. Har ni planer på att flytta?

Hus och teknik

1. Hur stor är bostaden?
2. Hur gammal är bostaden?
3. Har det renoverats?
4. Vad har gjorts?
5. Har ni internetuppkoppling?
6. Vad har ni för uppvärmningsystem i huset?
7. Om värmepump; Luft eller vattenburet?
8. Hur gammalt är ert uppvärmningssystem?
9. Varför har ni valt detta uppvärmningssystem?
10. Vad har ni för krav på ert uppvärmningsystem?
11. Har ni tankar på att förnya ert uppvärmningsysten? Varför/varför inte?
12. Vad för uppvärmningssystem ska ni förnya till?
13. Har ni solceller/ batteri?
14. Om Ja: Hur gamla är solcellerna/batteriet?
15. Om Nej: Har ni tankar på att köpa och installera solceller/batteri?
16. Vad har ni för typ av varmvattenberedare?
17. Hur gammal är varmvattenberedaren?
18. Har ni tankar på att förnya er varmvattenberedare till en elvarmvattenberedare? Varför/varför inte?

Inställning till projektet

1. Hur hörde ni först om projektet?
2. Vad tänkte ni när ni först fick höra om projektet?
3. Vad tror ni är orsaken till att ni tänkte/kände så?
4. Har din inställning om projektet ändrats vid något tillfälle? (tidigt att fråga)
5. Vad beror det på?
6. Vad är er inställning till projektet idag?
7. Vad tror ni kan ändra er inställning till projektet?
8. Vad vill ni veta mer om projektet?
9. Vad tycker ni är bra respektive dåligt med projektet?
10. Vad är er inställning till den befintliga sol- och vind parken?
11. Hur var er inställning när den byggdes gentemot nu?
12. Är det viktigt för er att energin kommer från förnyelsebara energikällor?
    - i. Hur viktigt är det för er mellan 1 och 10, där 1 är att ni inte alls bryr er vart din energi kommer ifrån och 10 är att det spelar jättestor roll att energin är från förnyelsebara energikällor.
    - ii. Varför är det viktigt/ inte viktigt för er?
    - iii. Har ni engagerat er i frågor om förnyelsebar energi tidigare?
        1. Vad?
        2. Om inte, vad är det för trösklar som gör att ni inte engagerar er?
    - iv. Hart du engagerat dig i frågor om miljö tidigare?
        1. Vad?
        2. Om inte, vad är det för trösklar som gör att ni inte engagerar er?
    - v. Vad brukar ni göra på dagsbasis/veckobasis/årsbasis för miljön?
13. Vad skulle ni helst köpa, en dyr produkt som produceras miljövänligt eller en billigare produkt som producerats mindre miljövänligt? (Förutsätter att det är samma typ av produkt)
14. Är det viktigt för er att en produkt produceras lokalt?
    1. Hur viktigt är det för er mellan 1 och 10? Där 1 är att ni inte bryr er om vart energin produceras alls, och 10 är att ni endast kan tänka er handla lokalt producerad energi.
    2. Brukar ni köpa produkter som är lokalt producerade och vad i sådana fall?
    3. Kan ni tänka dig betala mer för en produkt som är lokalt producerad?
15. Vad skulle ni helst köpa, en dyr produkt som är producerad lokalt eller en billigare produkt som producerats icke lokalt? (Förutsätter att det är samma typ av produkt)
16. Är det viktigt för er att kunna göra något för ert närsamhälle/dina grannar?
    1. Hur viktigt är det för er mellan 1 och 10? Där 1 är inte viktigt alls och 10 är ni tycker grannsamverkan är jätteviktigt för er och ert hushåll.
    2. Vad brukar ni göra på daglig/veckobasis/årsbasis för era grannar?
    3. Om inte, vad är det för trösklar som gör att ni inte har engagerat er?
17. Hur intresserade är ni av teknik?
    1. Vilken är den senaste tekniska produkt ni köpte?
18. Agerar ni aktivt för att sänka dina elkostnader? (Hur stor del av er ekonomi är elkostnader?)
    1. Vad har ni gjort/vad gör ni för att sänka elkostnader?

DSR deltagande

1. Är ni intresserade av att delta aktivt i E.ONs projekt?
2. Vad skulle få er att delta?
3. Är det något ni saknar/inte är nöjda med?
4. Hur vill ni delta:
    1. Hur önskar ni att ert deltagande i projektet ska gå till?
    2. Vill ni ha en aktiv eller mer passiv roll?
        - a. Varför en aktiv/passiv roll?
    3. Hur aktiv/ passiv vill ni vara?
        - . Hur aktiv vill ni vara mellan 1 och 10, där 1 är att ni inte vill göra något själv trots att du är delaktig i projektet och 10 är att ni vill göra något varje dag för projektet.
    4. Hur vill ni vara involverad?
    5. Vad tror ni er roll i projektet är och hur ser du på den?
4. Skulle ni på något sätt vara intresserad av att se vad som händer i det lokala energisystemet?

        1. Hur skulle ni vilja se det?

5. Vad för information är du intresserad av att få i en visualiserande plattform?
    i. Exempel
        1. Balansen i systemet mellan produktion och användning
        2. Produktion från vindkraft
        3. Produktion från solkraft
        4. Produktion från reservgenerator
        5. Egen konsumtion
        6. Totala konsumtionen
        7. Totala produktionen
        8. Annat?
    ii. Vill ni kunna vara aktiva själv på en plattform för att kunna ändra er konsumtion?

Värde på deltagande

1. Hur viktigt är personlig integritet för dig/er?
    i. Hur viktigt är det för dig/er mellan 1 och 10, där 1 är att du/ni inte alls ser problem med att dela personlig information till andra och 10 är att du/ni absolut inte vill dela personlig information till andra.
    ii. Varför är det viktigt/ inte viktigt för dig?
2. Vad känner du/ni inför att någon ska ha möjlighet att reglera vissa t*ekniska komponenter* i ditt/ert hem?
    1. Hur mycket bryr du/ni dig/er om att någon har denna möjlig?
    2. Hur mycket bryr du/ni dig/er mellan 1 och 10, där 1 är att någon gärna får ha möjligheten att reglera vissa tekniska komponenter i ditt hem och 10 är att absolut ingen får ha möjligheten att reglera någon komponent i ditt hem.
    3. Varför bryr du/ni diger eller inte bryr dig?
3. Vem skulle du/ni ge förtroende till att få möjligheten att styra tekniska komponenter i ditt hem?
4. Hur viktigt är det för dig/er att själv kunna reglera komponenter i ditt/ert hem?
    1. Hur viktigt mellan 1 och 10, där 1 är att du/ni inte bryr dig/er om hur och vem som styr ditt hem, så länge du/ni får den komfort du önskar, och 10 är att du inte kan tänka dig att någon reglerar något alls i din hem och i din/er vardag.
5. Hur mycket kan du/ni tänka dig tillåta någon att ha möjlighet att reglera *tekniska komponenter* i ditt hem?
    1. Hur mycket mellan 1 och 10, där 1 är ingen komponent i huset, jag vill ha fullt kontroll över allt i mitt hem helt själv, och 10 är alla komponenter i huset.
    2. Varför känner du/ni så?
    3. Har du varit ansluten till tjänster tidigare som inneburit att någon annan reglerat/haft kontroll över något i ditt hem eller i din vardag? (Exempel här kan vara städfirma, fondförvaltning, larm, hundvakt, barnvakt etc)
    4. Vad ser du/ni för risker/vilka risker ser du med att låta någon reglera en komponent i ditt/ert hem?

Appendix B. Costs and Prices

LES's price to buy electricity from an overlying grid (10-20 kV).

Table 18 - LES's price to buy electricity.

	Value (SEK/kWh)	Source
Average spot price of electricity in 2016 for winter/(spring/autumn)/summer	0.272/0.262/0.245	Nordpool
Power transmission fee	0.040	E.ON
LES's price to buy electricity	0.312/0.0302/0.284	

*Monthly subscription and power fee are not included.

LES's lost revenue per kWh to control production with a low current subscription.

Table 19 - LES's lost revenues per kWh to control production

	Value (SEK/kWh)	Source
Average spot price of electricity in 2016 for winter/(spring/autumn)/summer	0.272/0.262/0.245	Nordpool
Electricity certificate	0.1580/0.1584/0.1501	Svensk Kraftmäkling (SKF)
Remuneration of losses	0.050	E.ON
LES's lost revenues	0.480/0.470/0.445	

*Monthly subscription fee in not included

Customer's price to buy electricity

Table 20 - Customer's average electricity price

	Value (SEK/kWh)	Source
Average spot price of electricity in 2016	0.281	Nordpool
Electricity tax	0.292	Svensk Energi
VAT (25%)	0.144	Energimarknadsbyrån
Power transmission fee	0.198	E.ON
Costumer's price to buy electricity	0.92	

*Monthly subscription fee in not included

Costumer's selling price of electricity as micro-producer

Table 21 - Customer's average selling price of electricity.

	Value (SEK/kWh)	Source
Average spot price of electricity in 2016	0.281	Nordpool
Electricity certificate	0.136	Energimyndigheten
Remuneration if E.ON customer or not	+0.1/-0.4	E.ON
Network utility	0.05	E.ON
Tax reduction	0.6	The Swedish Tax Agency
Costumer's selling price of electricity	1.17/1.04	

*Monthly subscription fee in not included

Cost to produce electricity with the BUG

Table 22 -Technical specification of the BUG.

	Value	**Unit**	**Source**
Fuel usage 100% load	116	l/h	Coramatic, Technical specification
Fuel usage 75% load	91	l/h	Coramatic, Technical specification
Fuel usage 50% load	62	l/h	Coramatic, Technical specification
Max net power	480	kW	Coramatic, Technical specification
Fuel price	11	SEK/l	Staffan Sjölander, E.ON
Tank volume	995	l	Coramatic, Technical Specification

The cost to produce electricity with the BUG at different loads are calculated with Equation X and is presented in Table X.

$$Cost\ to\ produce\ electricity = \frac{Fuel\ usage * Price\ of\ fuel}{Load} \quad \text{(X.X)}$$

Table 23 - Cost to produce electricity with the BUG

Factor	**Value**	**Unit**
Fuel cost 100% load	2.65	SEK/kWh
Fuel cost 75% load	2.78	SEK/kWh
Fuel cost 50% load	2.84	SEK/kWh

Appendix C. HP and HWB Parameters and Calculations

Parameters of a Reference House

Table 11 - Parameters used to calculate heat losses of a reference house

Parameter	Value	Unit	Source
Size	150	m^2	Customer survey
Indoor Reference Temperature	20	°C	E.ON reference
U-value	0.4	W/m^2*C^o	Boverket, National Board of Housing, Building and planning
Thermal Bridges	95	W/C	Sveby
Free energy	4380	kWh	Lars Jensen, Installationsteknik
Air heating capacity	1000	J/kg*°C	Lars Jensen, Installationsteknik
Ventilation air flow	0.35	$l/s/m^2$	Thomas Ranstorp
Ventilation air flow of house	0.0525	m^3/s	Thomas Ranstorp
Ventilation efficiency for reheating	0	-	Lars Jensen, Installationsteknik
Relative operating time for ventilation assembly at constant operation	1	-	Lars Jensen, Installationsteknik
Air flow leakage	0	m^3/s	Lars Jensen, Installationsteknik

Parameters of a HWB and Calculated Tables

Table 12 - Parameters used for HWB calculations

Parameter	Value	Unit	Source
Reference temperature of water	65	°C	(Nibe AB, n.d.)
Maximal set temperature of water	75	°C	(Nibe AB, n.d..)
Ambient temperature of boiler	20	°C	Assumed
Volume of the tank	140	litre	(Nibe AB, n.d.)
Surface area of boiler	3.1155	m^2	Own calculations, assuming the tank is a cube
Insulation of the boiler, Thermal conductivity (Polystyren EPS)	0,035	W/m°K	(Nibe AB, n.d.)

Thickness of insulation	0.1	m	Assumed
Density water	1000		The Engineering Toolbox
Water specific heat capacity	4.18	kJ/Kg*°K	The Engineering Toolbox
Maximal power of boiler	3000	W	(Nibe AB, n.d.)

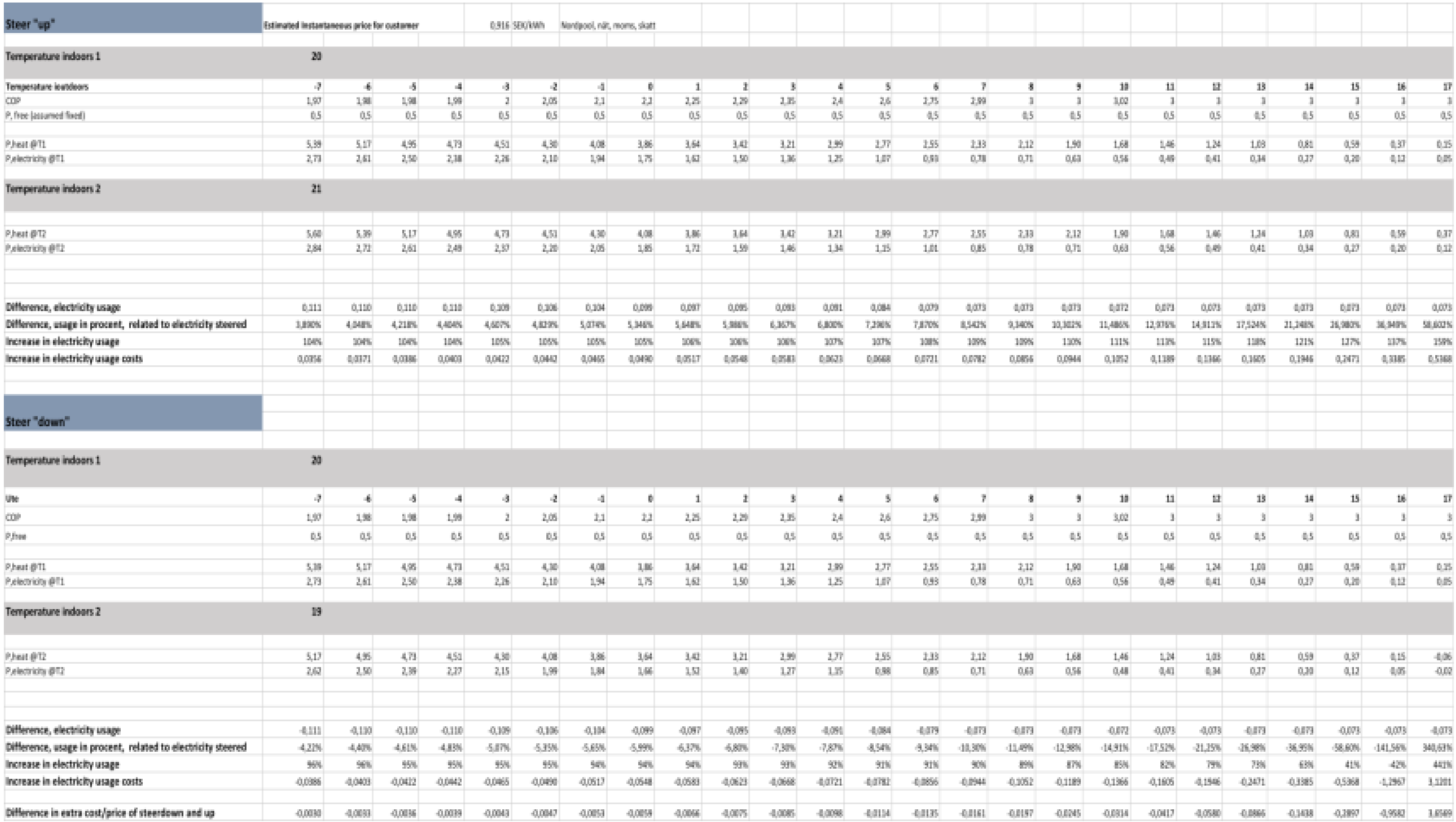
Energy added and heat losses for a specific temperature.

Table 13 - Parameters used for HWB calculations

Temperature	Energy added (kWh)	Heat losses (kW)
75	8,944833333	0,06006
74	8,7822	0,058968
73	8,619566667	0,057876
72	8,456933333	0,056784
71	8,2943	0,055692
70	8,131666667	0,0546
69	7,969033333	0,053508
68	7,8064	0,052416
67	7,643766667	0,051324
66	7,481133333	0,050232
65	7,3185	0,04914
64	7,155866667	0,048048
63	6,993233333	0,046956
62	6,8306	0,045864
61	6,667966667	0,044772
60	6,505333333	0,04368
59	6,3427	0,042588
58	6,180066667	0,041496
57	6,017433333	0,040404
56	5,8548	0,039312
55	5,692166667	0,03822
54	5,529533333	0,037128
53	5,3669	0,036036
52	5,204266667	0,034944
51	5,041633333	0,033852
50	4,879	0,03276
49	4,716366667	0,031668
48	4,553733333	0,030576
47	4,3911	0,029484
46	4,228466667	0,028392

45	4,065833333	0,0273
44	3,9032	0,026208
43	3,740566667	0,025116
42	3,577933333	0,024024
41	3,4153	0,022932
40	3,252666667	0,02184
39	3,090033333	0,020748
38	2,9274	0,019656
37	2,764766667	0,018564
36	2,602133333	0,017472
35	2,4395	0,01638
34	2,276866667	0,015288
33	2,114233333	0,014196
32	1,9516	0,013104
31	1,788966667	0,012012
30	1,626333333	0,01092
29	1,4637	0,009828
28	1,301066667	0,008736
27	1,138433333	0,007644
26	0,9758	0,006552
25	0,813166667	0,00546
24	0,650533333	0,004368
23	0,4879	0,003276
22	0,325266667	0,002184
21	0,162633333	0,001092
20	0	0

Calculations of HP increased energy and cost



Steer "up"	Estimated instantaneous price for customer				0,916	SEK/kWh	Nordpool, nät, moms, skatt																		
Temperature indoors 1	**20**																								
Temperature ioutdoors	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
COP	1,97	1,98	1,98	1,99	2	2,05	2,1	2,2	2,25	2,29	2,35	2,4	2,6	2,75	2,99	3	3	3,02	3	3	3	3	3	3	3
P. free (assumed fixed)	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
P.heat @T1	5,39	5,17	4,95	4,73	4,51	4,30	4,08	3,86	3,64	3,42	3,21	2,99	2,77	2,55	2,33	2,12	1,90	1,68	1,46	1,24	1,03	0,81	0,59	0,37	0,15
P.electricity @T1	2,73	2,61	2,50	2,38	2,26	2,10	1,94	1,75	1,62	1,50	1,36	1,25	1,07	0,93	0,78	0,71	0,63	0,56	0,49	0,41	0,34	0,27	0,20	0,12	0,05
Temperature indoors 2	**21**																								
P.heat @T2	5,60	5,39	5,17	4,95	4,73	4,51	4,30	4,08	3,86	3,64	3,42	3,21	2,99	2,77	2,55	2,33	2,12	1,90	1,68	1,46	1,24	1,03	0,81	0,59	0,37
P.electricity @T2	2,84	2,72	2,61	2,49	2,37	2,20	2,05	1,85	1,72	1,59	1,46	1,34	1,15	1,01	0,85	0,78	0,71	0,63	0,56	0,49	0,41	0,34	0,27	0,20	0,12
Difference, electricity usage	0,111	0,110	0,110	0,110	0,109	0,106	0,104	0,099	0,097	0,095	0,093	0,091	0,084	0,079	0,073	0,073	0,073	0,072	0,073	0,073	0,073	0,073	0,073	0,073	0,073
Difference, usage in procent, related to electricity steered	3,890%	4,048%	4,218%	4,404%	4,607%	4,829%	5,074%	5,346%	5,648%	5,986%	6,367%	6,800%	7,296%	7,870%	8,542%	9,340%	10,302%	11,486%	12,976%	14,913%	17,524%	21,248%	26,980%	36,949%	58,602%
Increase in electricity usage	104%	104%	104%	104%	105%	105%	105%	105%	106%	106%	106%	107%	107%	108%	109%	109%	110%	111%	113%	115%	118%	121%	127%	137%	159%
Increase in electricity usage costs	0,0356	0,0371	0,0386	0,0403	0,0422	0,0442	0,0465	0,0490	0,0517	0,0548	0,0583	0,0623	0,0668	0,0721	0,0782	0,0856	0,0944	0,1052	0,1189	0,1366	0,1605	0,1946	0,2471	0,3385	0,5368
Steer "down"																									
Temperature indoors 1	**20**																								
Ute	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
COP	1,97	1,98	1,98	1,99	2	2,05	2,1	2,2	2,25	2,29	2,35	2,4	2,6	2,75	2,99	3	3	3,02	3	3	3	3	3	3	3
P.free	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
P.heat @T1	5,39	5,17	4,95	4,73	4,51	4,30	4,08	3,86	3,64	3,42	3,21	2,99	2,77	2,55	2,33	2,12	1,90	1,68	1,46	1,24	1,03	0,81	0,59	0,37	0,15
P.electricity @T1	2,73	2,61	2,50	2,38	2,26	2,10	1,94	1,75	1,62	1,50	1,36	1,25	1,07	0,93	0,78	0,71	0,63	0,56	0,49	0,41	0,34	0,27	0,20	0,12	0,05
Temperature indoors 2	**19**																								
P.heat @T2	5,17	4,95	4,73	4,51	4,30	4,08	3,86	3,64	3,42	3,21	2,99	2,77	2,55	2,33	2,12	1,90	1,68	1,46	1,24	1,03	0,81	0,59	0,37	0,15	-0,06
P.electricity @T2	2,62	2,50	2,39	2,27	2,15	1,99	1,84	1,66	1,52	1,40	1,27	1,15	0,98	0,85	0,71	0,63	0,56	0,48	0,41	0,34	0,27	0,20	0,12	0,05	-0,02
Difference, electricity usage	-0,111	-0,110	-0,110	-0,110	-0,109	-0,106	-0,104	-0,099	-0,097	-0,095	-0,093	-0,091	-0,084	-0,079	-0,073	-0,073	-0,073	-0,072	-0,073	-0,073	-0,073	-0,073	-0,073	-0,073	-0,073
Difference, usage in procent, related to electricity steered	-4,22%	-4,40%	-4,61%	-4,83%	-5,07%	-5,35%	-5,65%	-5,99%	-6,37%	-6,80%	-7,30%	-7,87%	-8,54%	-9,34%	-10,30%	-11,49%	-12,98%	-14,91%	-17,52%	-21,25%	-26,98%	-36,95%	-58,60%	-141,56%	340,63%
Increase in electricity usage	96%	96%	95%	95%	95%	95%	94%	94%	94%	93%	93%	92%	91%	91%	90%	89%	87%	85%	82%	79%	73%	63%	41%	-42%	441%
Increase in electricity usage costs	-0,0386	-0,0403	-0,0422	-0,0442	-0,0465	-0,0490	-0,0517	-0,0548	-0,0583	-0,0623	-0,0668	-0,0721	-0,0782	-0,0856	-0,0944	-0,1052	-0,1189	-0,1366	-0,1605	-0,1946	-0,2471	-0,3385	-0,5368	-1,2967	3,1201
Difference in extra cost/price of steerdown and up	-0,0030	-0,0033	-0,0036	-0,0039	-0,0043	-0,0047	-0,0053	-0,0059	-0,0066	-0,0075	-0,0085	-0,0098	-0,0114	-0,0135	-0,0161	-0,0197	-0,0245	-0,0314	-0,0417	-0,0580	-0,0866	-0,1438	-0,2897	-0,9582	3,6569

Figur 53 - Calculations of increased losses in a house when controlling heat pump