TAMPERE UNIVERSITY OF TECHNOLOGY

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DEVELOPMENT OPPORTUNITIES FOR SMART METERING SERVICES IN PRIVATE CUSTOMER INTERFACE

Master of Science Thesis

Examiner: Professor Pertti Järventausta
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ABSTRACT

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The European Union has set ambitious energy efficiency targets, which include for example commonly known "20-20-20"-targets. In order to achieve the targets the European Union has set directives that have led the member countries of the European Union to set a legal framework for the installation of smart meters. Among other things, the smart meters provide opportunities to develop new services that enable more efficient energy usage for the consumers. Informative billing, based on the actual consumption and the internet services that enable the consumer to monitor the hourly consumption data are two examples of these services.

The aim of this thesis was to evaluate development opportunities for smart metering services in the private customer interface. Home Energy Management System, HEMS, is one example of smart metering service. During this work, a small-scale pilot study of HEMS was successfully carried through in a co-operation with a service provider. Pilot included five private households and provided customers with real-time consumption monitoring and enabled market price based steering of reserving electric heating. The customer feedback was collected with interviews and metering data was collected to calculate the potential savings. According to the customers, they did not change their energy consumption behavior significantly during the pilot. The steering of the electric heating enabled savings of 2.4-3.6 €/month when calculated with spot prices. To get a wider perspective about the customer needs for smart metering services a customer survey was carried through. The survey included 187 customers who were using the current internet services provided by the DSO. There is a high interest towards real-time consumption monitoring and HEMS, but the willingness to invest is limited.

The HEMS concept was evaluated based on the feedback from the customer pilot and from the survey. The results can be used when developing future smart metering services by designing the services according to the concrete needs. HEMS system that would enable to control a large number of HEMS-units collectively could enable benefits also for the market actors. Therefore the potential benefits were evaluated also from the supplier and the DSO perspective. The evaluated benefits were small related to the required HEMS-units that would be needed to achieve them. With the piloted cost level of HEMS, the incentive for suppliers or DSOs to offer energy efficiency service like HEMS for the private customers is reduced if there is no possibility to have additional benefits around the service or it is not required by the legislation. This would mean that HEMS is mainly a business opportunity for service providers.

The pilot could be further utilized by providing the pilot customers with dynamic pricing rates. Additionally it could be used to demonstrate direct load steering, and to develop the control methods for a large number of HEMS.

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Euroopan unioni on asettanut kunnianhimoisia energiatehokkuustavoitteita, jotka sisältävät esimerkiksi yleisesti tunnetut "20-20-20"-tavoitteet. Euroopan unioni on asettanut direktiivejä, jotka ovat ohjanneet jäsenvaltiot laatimaan lainsäädännöllisiä vaateita älykkäiden sähkömittareiden asentamisesta. Älykkäät sähkömittarit luovat uusia mahdollisuuksia ja mahdollistavat esimerkiksi kuluttajien energiatehokkuutta edistävien palveluiden kehittämisen. Informatiivinen laskutus, joka perustuu todelliseen kulutukseen sekä internetpalvelut, jotka mahdollistavat kulutuksen tuntipohjaisen seurannan ovat kaksi esimerkkiä tällaisista palveluista.

Tämän työn tavoitteena oli tutkia energianhallintapalveluiden kehitysmahdollisuuksia pienasiakasrajapinnassa. Kodin energianhallintajärjestelmä, HEMS, on yksi esimerkki energianhallintapalveluista. Tämän työn aikana HEMS-ratkaisun pilotointi läpivietiin onnistuneesti yhteistyössä palveluntarjoajayrityksen kanssa. Pilottiin osallistui viisi yksityistä kotitaloutta, joille tarjottiin HEMS-ratkaisun avulla mahdollisuus laitekohtaisten kulutusten reaali-aikaiseen seurantaan ja mahdollistettiin sähkön markkinahintaan perustuva varaavan sähkölämmityksen ohjaus. Asiakashaastatteluiden perusteella asiakkaat eivät olleet merkittävästi muokanneet kulutuskäyttäytymistään pilotin aikana. Sähkölämmityksen ohjaus toi laskennallista säästöä 2,4-3,6 €/kk. Laskenta tehtiin käyttäen pilotin aikaisia sähkön markkinahintoja. Työn aikana tehtiin myös asiakastutkimus 187 verkkoyhtiön internetpalveluita käyttävän asiakkaan osalta. Yleisesti asiakkaiden keskuudessa oli korkea kiinnostus reaaliaikaista kulutuksen seurantaa ja energianhallintapalveluita kohtaan, mutta asiakkaiden halukkuus investoida näihin on rajallinen.

HEMS-konseptia arvioitiin pilotin aikana saadun palautteen, sekä asiakastutkimuksen pohjalta. Tuloksia voidaan hyödyntää tulevien energianhallintapalveluiden kehittämiseen asiakkaiden todellisten tarpeiden pohjalta. HEMS-järjestelmä, joka mahdollistaisi usean HEMS-yksikön hallinnoinnin kootusti, voisi tuoda hyötyjä myös markkinaosapuolille. Hyötyjä tarkasteltiin sähkönmyyjien ja verkkoyhtiön näkökulmasta. Yhteenvetona voi todeta, että saavutettavat hyödyt ovat pieniä verrattuna tarvittavien HEMS-yksiköiden määrään. Pilotoidulla HEMS:n hintatasolla myyjillä tai verkkoyhtiöillä ei ole insentiiviä tarjota energiatehokkuuspalvelua, kuten HEMS, yksityisasiakkaille jos sen ympäriltä ei löydy lisähyötyjä tai sitä ei vaadita lainsäädännön puitteissa. Tämän vuoksi HEMS on pääasiassa palveluntarjoajan liiketoimintaa. Pilottia voisi hyödyntää jatkossa tarjoamalla asiakkaille dynaamista hinnoittelua tai suoran kuormanohjauksen demonstrointiin, sekä HEMS-yksiköiden hallintajärjestelmän kehittämiseen.

PREFACE

The topic for this thesis was provided by Vattenfall Verkko Oy. Part of the work was done under the new owners and the name of company changed to LNI Verkko Oy, which currently operates the distribution network. The examiner for this thesis was Professor Pertti Järventausta from Tampere University of Technology. Supervisors from Vattenfall Verkko Oy were M.Sc. Matti Halkilahti and M.Sc. Ville Sihvola.

First I want to thank Matti and Ville for providing me this interesting topic. I also want to thank for the guidance and valuable advice during the work. I would also want to thank Pertti for examining this thesis. In addition, I want to thank the employees of There Corporation for the rewarding co-operation during this work. Finally, I want to express my sincere gratitude for my family for the support during my studies and this work.

Tampere, January 19th, 2012

Joni Aalto

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ABBREVIATIONS AND NOTATION

DR	Demand Response
DSO	Distribution system operator
EEP	Energy Efficiency Plan
ESCO	Energy Service Company
ETS	Emission Trading System
HEMS	Home energy management system
LUT	Lappeenranta University of Technology
MCB	Miniature Circuit Breaker
NordREG	Nordic Regulators
OTC	Over the Counter
SES	Smart energy switch
SP	Service provider
TUT	Tampere University of Technology

1 INTRODUCTION

European Union has set ambitious energy efficiency targets, which include for example commonly known “20-20-20”-targets. In order to achieve the targets the EU has set directives that have led the member countries of the European Union set legal framework for the installation of smart meters. Large-scale smart meter rollouts are already ongoing in some of the European countries which have decided about a mandatory rollout. There are DSOs who have the full rollout practically carried through and others which have a majority of meters replaced. Among other things, the smart meters provide opportunities to develop new services that enable more efficient energy usage for the consumers.

LNI Verkko Oy is responsible of electricity network services for over 400 000 consumers in Finland. Company maintains and renews the electricity network while also builds new network connections together with contractors. LNI Verkko Oy operates and maintains the network 24 hours a day. Customers’ electricity consumption is metered and the data delivered to the electricity suppliers. The company also develops future networks and network services by utilizing new technologies. Previously, LNI Verkko Oy was a part of Vattenfall AB and the name of the company was Vattenfall Verkko Oy. As a great majority of this thesis work was made under the name Vattenfall Verkko Oy, this is used later in this work.

DSOs operate as local monopolies. Electricity distribution business is regulated by the legislation and energy market authorities. The responsibilities and limitations for the operation are therefore set by the authorities. The major source of incomes for the DSOs are the distribution fees collected from the customers. The pricing of the electricity distribution is controlled over a time periods that are called regulation periods. A new regulation period started at the beginning of 2012. The central legislation concerning the electricity distribution in addition to the principles of regulation is presented in Chapter 1. Also the principles of the pricing of the electricity distribution are introduced.

The energy policy of the European Union affects also the energy companies. As mentioned above the energy policy has led to smart meter rollouts in member countries. These actions are needed to achieve the ambitious targets that have been set. Recently the work has been started to implement a new directive to secure the achievement of the target for the 2020. This could mean new obligations to the energy companies to promote the efficient energy usage of the consumers. Chapter 2 highlights the most important parts of the energy policy of the European Union. Increasing energy efficiency can have significant impacts on the electricity demand that will affect also the electricity distribution business. These issues are also introduced in Chapter 2.

Nordic countries have a common wholesale electricity market. This means that the market actors operating in the Nord Pool can buy and sell electricity regardless of the national boundaries. Currently, the end-users are limited to purchase electricity from the national electricity suppliers. In order to increase the competition in the market and promote the more efficient functionality of the Nordic electricity markets the work has been started to implement a common Nordic end-user market. Nordic electricity markets and the issues that need to be solved before the implementation of common Nordic end-user markets are introduced in Chapter 4.

Smart meters enable the development of more dynamic electricity contracts and distribution tariffs for all end-users. The price of electric energy can be even directly bound to the market price of the electricity, which illustrates the overall market situation. On the other hand, the distribution tariffs could be based more on the demand power of the customer in the future. The demand response means the adjustment of energy consumption according to the steering signals. These signals can be price-signals that enable the consumer to benefit by using the electricity during the cheapest time periods according to the current electricity contract and distribution tariff. Steering signals can be also load steering signals from the market actors. For example suppliers and DSOs could benefit from the load steering of the customers if it would be done on a large-scale basis. Furthermore, a more dynamic pricing of electricity can arouse a need for new smart metering services that help to optimize the electricity usage. These services can also include demand response functionalities. These issues are also introduced in Chapter 4.

Home energy management system, HEMS, is an example of smart metering service. Basically, it is a system that enables the user to control and optimize the electricity consumption in a cost-effective way. HEMS include additional home automation that enables the steering of electricity consumption and the monitoring of device-specific electricity consumption. In the future, HEMS can also provide a load steering possibilities for market actors. According to recent research, there could be approximately 20 % of private households utilizing HEMS in the Nordic countries by the end of 2019. (Parkkinen & Järventausta 2011).

The major objective for this work is to evaluate development possibilities for future smart metering services in the private customer interface. So far, the smart meters have enabled more informative billing and the development of internet services that enable the hourly based consumption monitoring for the consumers. Practically the focus of this work is on the HEMS-concept. During the work, a HEMS was piloted in co-operation with a service provider company There Corporation. HEMS enabled the device specific consumption monitoring in real-time and the market price based steering of electric heating. The goal was to identify potential technical obstacles in addition to the needs and benefits of the private customers. The feedback was collected during the pilot study by interviewing the pilot customers. The pilot process is discussed in Chapter 5. In order to provide a wider perspective on the needs of the consumers concerning the smart metering services a customer survey was also conducted. The objective was to study the overall stance related to smart metering services among the customers using the current internet services provided by the Vattenfall Verkko Oy.

Chapter 6 provides a general evaluation of the HEMS-concept. The customer point of view is evaluated based on the customer feedback and the metering data collected during the pilot. HEMS is a tool for the consumers to optimize the electricity consumption. On the other hand, it can also provide possibilities for the market actors. A large number of HEMS could be collectively controlled by the market actor in order to perform for example load steering. Therefore in addition to the benefits for the consumers there are different types of potential benefits and possibilities for the market actors. The potential benefits and opportunities that are presented in this work are mostly based on the latest results of the research concerning the development of the electricity market. Some of these possibilities are evaluated and illustrative calculations made in order to estimate the potential monetary benefits. As the electricity markets are potentially facing significant changes in the future it is not clear who can offer the future smart metering services and how different market actors could co-operate around them. In Chapter 6, some points of view for the future operation models are discussed. To sum up, this work studies the issues that need to be considered when further developing the future smart metering services and the business model around HEMS.

2 THE ELECTRICITY DISTRIBUTION BUSINESS

The electricity market includes electricity production, transmission, distribution and exchange. In the 1990s many countries started to dismantle the so called vertical integration of power-supply. Vertical integration means that the same company controls the energy production, transmission and distribution. Due to this, the operations of such companies were potentially inefficient and not transparent to the consumer, which means that consumers were not able to be sure if the costs were allocated equitable. (Elovaara & Haarla 2011) Finland was among the first nations to open its electricity market for competition, including electricity production and electricity exchange. This took place in 1995. In practice, all the consumers were able to choose their electricity supplier freely 1998. (Energy Market Authority 2011a)

The companies which provide network services are categorized based on the network in which they operate. The companies operating the distribution networks are called distribution system operators (later DSO). The biggest energy companies needed to separate the electricity supply from electricity distribution into different companies from 2007 onward. (Elovaara & Haarla 2011)

Electricity production and electricity exchange are so called free businesses and do not require a concession. Electricity distribution has remained as a so called natural monopoly in its operating area. Furthermore, electricity distribution business requires a network license. The reason for the monopoly status is that it would be economically unprofitable to build parallel distribution networks. The framework for electricity distribution business comes from legislation and it is regulated by national regulators. Regulation is needed because the DSOs do not have strong natural incentives for efficient operations and reasonable pricing of the distribution services. In Finland this regulator is Energy Market Authority, which also provides network licenses for electricity distribution business and approves the distribution areas for the DSOs.

In this chapter the reader is provided with a description of the electricity distribution business in Finland. The most significant operations of a DSO are introduced as well as the business environment, including the main legislation and the general description of the regulation. In addition the principles of the pricing of the electricity distribution are introduced. These topics need to be covered in order to understand the future development of electricity market and the potential changes in the business environment of the DSOs.

2.1 DSO operations

The main operations of a DSO include business planning and the implementation of a business plan, network planning, building of networks or having them built together with contractors, network operation, condition management, energy metering, balance settlement and customer service. It is possible to group these operations in multiple ways. Lakervi & Partanen (2007) group operations based on the functionality and on the other hand based on core and auxiliary operations. The DSO itself runs the core operations, but auxiliary operations can be outsourced and used as a service. This grouping of the functionalities is being illustrated in the following figure.

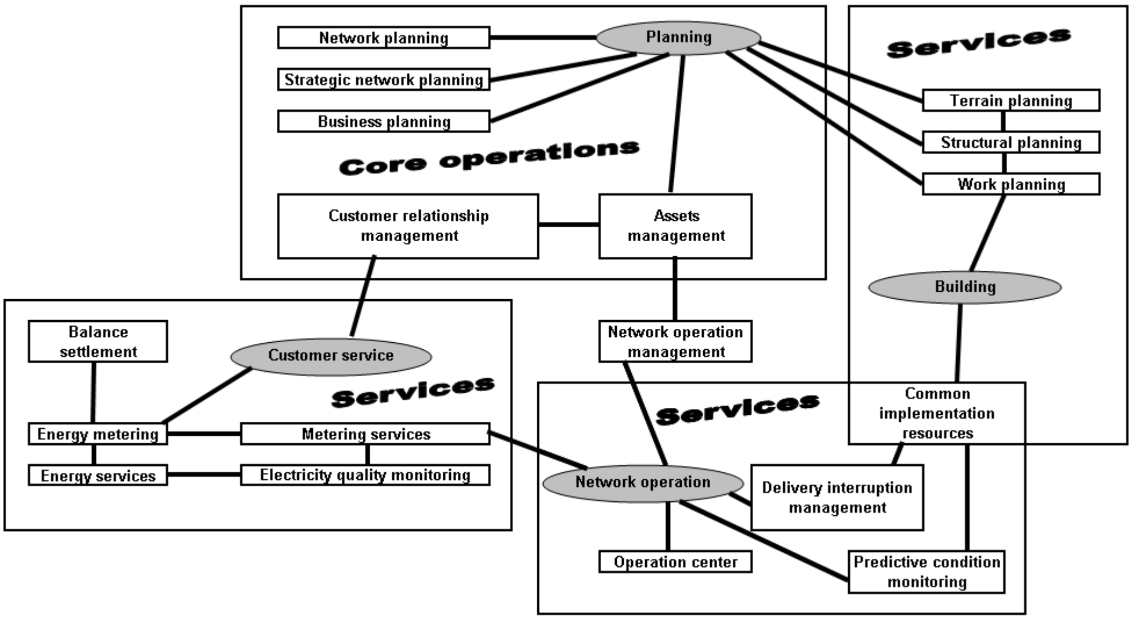

Figure 2.1. *The core and auxiliary operations of a DSO. (Lakervi & Partanen 2007)*

Some of the operations are typical to many companies, but there are some which are characteristic only for DSOs. DSOs operate and maintain the distribution networks 24 hours a day. This ensures the rapid response in case of electricity delivery interruption. DSOs meter the consumption of the consumers in the operating area and deliver the readings for electricity suppliers. DSOs must also provide a balance settlement in their distribution area which means that all the electricity trades in the operating area must be settled. Balance settlement is discussed more in detail in the chapter 4.

Outsourcing of operations has been a growing trend in electricity distribution business. The core functions of a DSO are assets management, including business planning and implementation of a business plan, network development planning, having the networks built and usually customer service. Most common operations that have been outsourced include operations such as network construction and the balance settlement. (Lakervi & Partanen 2007)

Outsourcing of the operations enables DSO to concentrate on core operations and the development of those operations. As listed earlier, electricity distribution requires multiple operations and consequently it is ineffective that a big number of DSOs use their limited resources to develop the same operations. Instead, service providers can use their special knowledge centrally on developing certain operations and further offer these as services to DSOs. Aminoff et al. (2009) summarize this well by stating that "operational efficiency without compromising the quality of service has become one of the main guidelines for DSOs".

A big number of information systems are characteristic for a DSO. DSO environment includes systems such as network information system and customer relationship management system. Almost all the information related to electricity distribution operations and business is being handled with a specific information system. It is also common that the information stored in a certain system is needed in operations with another information system. DSOs have traditionally been in the frontline of utilizing the new possibilities enabled by information systems to their own purposes. DSOs have also utilized new communication technology for example with SCADA-remote operating system. (Aminoff et al. 2009)

2.2 The business environment of the electricity distribution business

Great majority of the DSOs are Limited Liability Companies (Ltd.) and the rest are commercial enterprises owned by communes. The ownership of the Ltd-based DSOs varies a lot. Usually DSOs which operate only in a certain city or commune are also owned by this same city or commune. There are also many DSOs which operate on larger area. These DSOs can be owned by many different cities or communes located in the operating area. The largest, nationally widespread DSOs are usually owned by the parent company.

The overall business objective of a DSO is highly depended on the ownership basis. In some cases the goal is to produce the greatest possible outcome while sometimes the aim is to deliver electricity to the consumers with reasonable distribution tariffs. Lakervi & Partanen (2007) conclude that an effective and well-organized network operation enables possibility to pursue both of these goals simultaneously.

There are also many other stakeholders in the electricity distribution business. Customers are an essential part of the electricity distribution business as well as in many other business sectors. According to Partanen et al. (2010) customer's most fundamental needs and expectations are reasonable and non-discriminatory pricing of the electricity distribution, sufficient quality of electricity and customer service and moreover, environmental friendliness. In addition, network operations should not cause disturbance to a customer.

Pricing of the electricity distribution services is being regulated by the Energy Market Authority. Further, non-discriminatory pricing is being secured by the Electricity Market Act (1995/386). Electricity Market Act (1995/386) states that the electricity distribution tariffs cannot vary according to the customer's location in the DSO's operating area. Moreover, the customer's choice for electricity supplier is not allowed to affect the distribution price.

The society expects that DSOs build and maintain sufficient electricity distribution infrastructure that does not prevent the general development of the society. (Partanen et al. 2010) This is easy to understand when considering the present Information Society. Almost everything is continuously more depended on the availability of secured energy supply. Also the demands for the quality of electricity are getting stricter as there are more vulnerable electrical devices. Economically it is expected that DSOs produce tax-incomes and profits to the certain economic area. Due to the monopoly-nature of electricity distribution business the profits are relatively stable and secured.

2.3 Legislation

According to the Finnish Energy Industries there are three main goals in the Finland's current energy policy: well-functioning energy markets, securing of the energy supply and limiting the emissions according to the international commitments. Ministry of Employment and Economy has the overall responsibility to regulate energy industry. This Ministry is responsible for operating conditions of enterprises, securing the consumers position in the markets and taking care of the public enterprise property. Electricity distribution is under the supervising of Energy Market Authority, Finnish Competition Authority, Consumer Agency and Finnish Safety and Chemicals Agency. (Finnish Energy Industries 2011a)

Energy Market Authority monitors the observance of Electricity Market Act and the obligations that are assigned to the DSOs by the Act. It also works for improving the overall functionality of the electricity market and regulates the electricity distribution business by setting a limit for the maximum profit of a DSO. The DSOs have the obligation to develop the distribution networks and to connect the new consumption points to the network if they are technically eligible. In addition the DSOs have the transmission obligation which means that they need to provide electricity distribution services within the limitations of the network capacity. (Sähkömarkkinalaki)

The Finnish Competition Authority works under The Ministry of Employment and Economy and aims for improvement of economical efficiency for example by following the price of electricity. Consumer Agency aims to secure consumers' economical and legal position. Furthermore, it also implements the Finnish Consumer Policy from the energy consumption point of view. Finnish Safety and Chemicals Agency monitors the implementation of Electrical Safety Act. The role of the European Union has strengthened during the recent years, especially among electricity markets, delivery reliability and environmental related issues. (Finnish Energy Industries 2011b)

2.3.1 Regulation

The electricity distribution business is a monopoly and therefore companies do not have significant natural incentives for reasonable pricing of electricity and cost effectiveness of operations. Usually these incentives come from the regular competition. Regulation is needed and usually there is a certain regulator responsible for these operations. As mentioned earlier, in Finland this regulator is Energy Market Authority. The most important targets of regulation are evenhanded dealing with customers, reasonable pricing and cost effective operations. It must also be made sure that the costs of regulation itself will not rise economically too high. (Partanen et al. 2010)

There are a few regulation models that can be used in electricity distribution business. Regulatory of returns is a common model to be used among monopoly business. In this case a limit is set for a return of capital. This model urges to invest, because it raises the allowed returns. These investments do not necessary affect positively on the quality of distribution so separate quality control is needed. Model does not also encourage cost effectiveness and separate incentive for this is also needed. This model has been criticized of encouraging the companies to strategic behavior in order to maximize the incomes. (Viljainen 2005; Partanen et al. 2010)

In price cap regulation model the authority sets a price cap for companies or a cap for turnover. These types of models have built-in incentives for cost efficiency while it affects positively on the profits. In this case it must be monitored that the investments are still high enough to secure the quality of electricity distribution. (Viljainen 2005)

Yardstick regulation is based on comparing companies to those companies that are found to be effective. It can be said that the allowed revenues of regulated companies are made dependent on the performance of other companies. Usually comparing is done between real companies, but fictional ones can also be used. In practice, these single regulation models are rarely used alone. Usually the regulation model is a combination of these. (Viljainen 2005)

Regulation of the electricity distribution business is characterized by efficiency improvement targets. Most commonly these targets aim at reduction of the operational costs, but these can also be used to urge for quality improvement of electricity or more effective investments. These targets aim to developed companies in a way that is consistent with targets set for distribution business by society. These efficiency improvement targets can be common to the whole branch or they can be more company-specific. (Partanen et al. 2010)

In Finland electricity distribution has been regulated under the Electricity Market Act (386/1995) since 1995. Until the end of 2004 the regulation was made only afterwards. The goal was a reasonable pricing of electricity distribution and cost-effectiveness of a monopoly. After a control period the calculated profit of a company was compared to the reasonable profit calculated based on capital committed to distribution business. If the authority proved that pricing of the electricity has not been reasonable, it urged company to make the pricing more reasonable in the future. The performance measurement was introduced in 2001. The aim was to encourage cost-effective operation by setting a target level for operational costs. The applying of results was a problem because companies knew only after a control period what was the level of the operational costs they should have reached. (Partanen et al. 2010)

Regulation system was renewed in 2005 so that it would fill the requirements of directive 2003/54/EC of the European Parliament and of the Council concerning common rules for the internal market in electricity. The directive demanded that regulation should be made partly beforehand. Control period was set to be four years instead of one, first being three years. Reasonableness of pricing was regulated in periods not based on a statistics of a one certain year. After the period company got a decision if the pricing was reasonable. If not, company needed to lower prices in next control period. Conversely, company was enabled to raise price level in next control period if the profit was under the reasonable profit level. (Energy Market Authority 2011b)

During the first control period in 2005-2007 authority defined limits for reasonable operating costs, depreciation write-offs and capital profits. Also the general efficiency improvement target was set. DSOs should limit the operation costs 1.3 % each year compared to the average annual operation costs in 2000-2003. (Energy Market Authority 2004)

Second control period in 2008-2011 did not significantly differ from the previous one. There were basically two major additions. The company-specific efficiency improvement target and the quality incentive were set. According to the Electricity Market Act (386/1995) DSOs need to pay standard compensation to customers in a case of a long interruption in electricity distribution. This is a one type of quality incentive. Likewise in the first control period, the evaluation of the reasonableness of the prices was based on comparing the calculated profits and the defined level of reasonable capital profits. (Partanen et al. 2010)

The general efficiency improvement target was 2.06 % annually and the company-specific target was set by using so called DEA and SFA efficiency evaluation models. Both targets aim at controllable operation costs and they are taken into account when the realized outcome is being defined. Standard compensations paid to customers were included to controllable operation costs and are therefore under the efficiency improvement target. (Partanen et al. 2010)

The basic starting point in the DEA and SFA models is to define the most effective output-input-rate. The output-input-rates of different companies are compared to this rate. In Finland input-factors are controllable operating costs, straight-line depreciations and the sum of interruption costs. Output-factors are distributed energy, the total length of networks at different voltage levels and the customer number. (Partanen et al. 2010)

Honkapuro et al. (2010a) evaluated the effects of regulation model used in 2008-2011. Basically regulation model was effective. It enabled investments and encouraged towards secured electricity distribution. Furthermore, it also urged for improvement of cost-effectiveness. These are regarded as the most important issues in the regulation of the electricity distribution business. Honkapuro et al. (2010a) also points out the importance of the fact that the DSOs had also developed networks and business activities according their own incentives and targets.

The difference between the operation costs and the investments is one incentive to this kind of activity in the model used 2008-2011. This incentive occurs in situations when there is possibility to make maintenance or replacement investment. Replacement investment is more profitable on the DSO point of view according to regulation, because investments raise DSO's capital and therefore the level of reasonable return of the capital. In addition, the maintenance costs are included to the operation costs, which are under the efficiency improvement target. Still, Honkapuro et al. (2010a) states that these are typical characteristics for this type of regulation models and would be hard to eliminate.

Honkapuro et al. (2010a) also points out that model encourages for improvement of reliability of delivery. This has led to the growing trend of cabling, also in the countryside. Because of the long-term nature of the investments in the electricity distribution sector, also the nature of regulation needs to be predictable in long term. Even if it is not possible to use long term regulation models, it is possible to promote the targeted situation in the future and retain the short term development possibilities of the regulation model.

2.3.1.1 Regulation model 2012-2015

The third control period started 1.1.2012 and will end 31.12.2015. The Energy Market Authority has used the experiences from the previous two control periods to develop regulation furthermore. The basic core of the regulation model will remain, but improvements have been made and couple of new incentives introduced. The basic principles of the regulation model are introduced in the figure 2.2. The most important changes from previous control period are also introduced in this chapter. (Energy Market Authority 2011c)

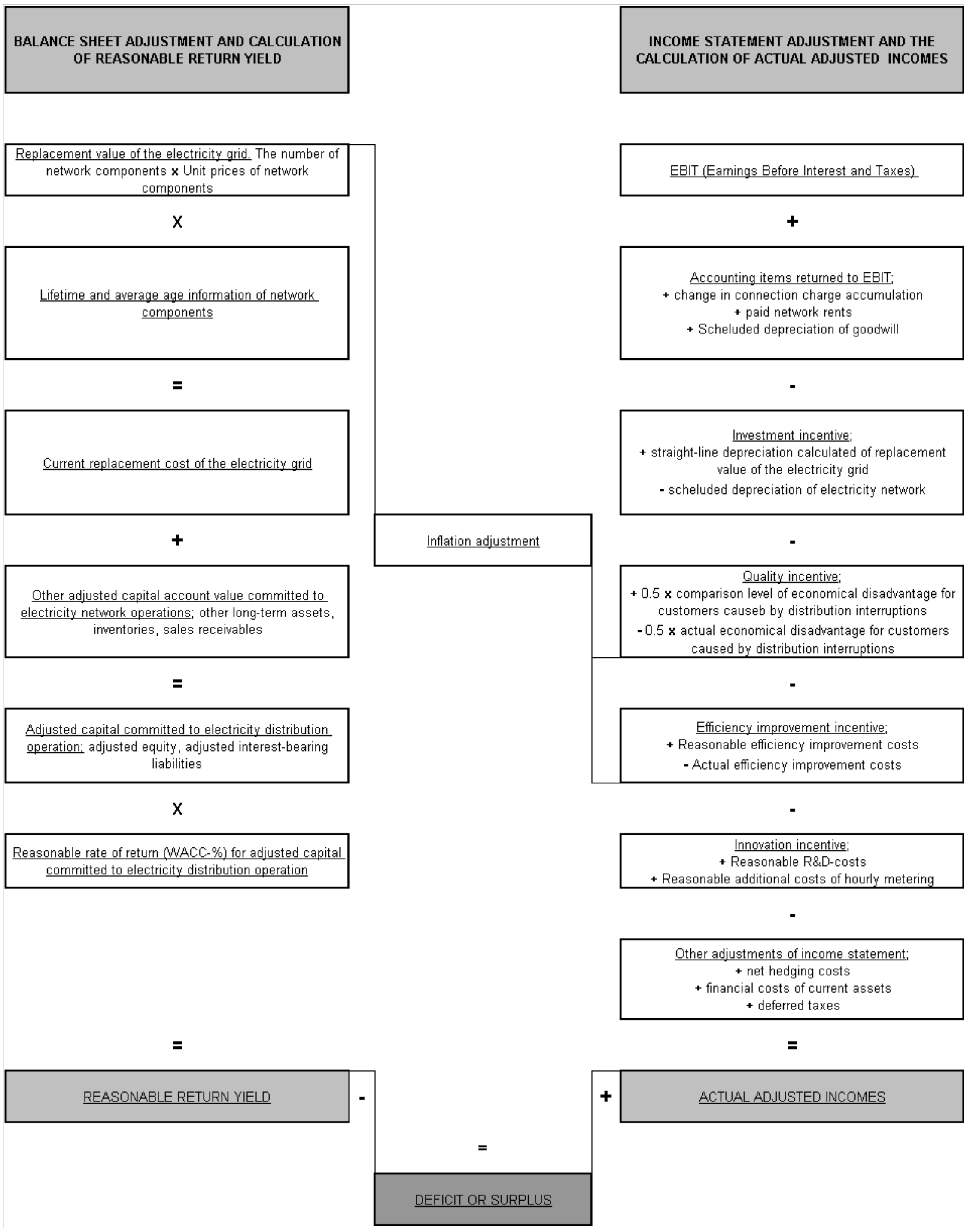

Figure 2.2. *The basic scheme of the regulation of electricity distribution business in 2012-2015. (Energy Market Authority 2011c)*

The basic idea of the regulation of reasonable pricing of the electricity distribution is to determine the level of reasonable return yield and compare this to the actual adjusted incomes of a DSO. If the actual adjusted incomes are greater than reasonable level, DSO is obliged to lower the electricity distribution prices. The amount of deficit or surplus from the second control period that has not been compensated through distribution prices will be added to the amount of deficit or surplus from the third period. (Energy Market Authority 2011c)

The reasonable return yield is calculated by determining the different types of capital and giving them a reasonable rate of return. The starting point for calculating the actual adjusted incomes of DSO is EBIT (Earnings Before Interest and Taxes). By making adjustments and calculating the effects of the incentives the amount of actual adjusted incomes can be determined. (Energy Market Authority 2011c)

The investment incentive was added in the third control period. The goal is to make sure that DSOs have enough incentives to develop networks and invest enough on it. Also innovation incentive was introduced. This incentive encourages DSOs to develop innovative technical and operational solutions for network operations. (Energy Market Authority 2011c)

There are two parts in the innovation incentive. First part is research and development costs and second part is the costs of remote reading of consumption points with maximum of 63 A main fuses. DSO is able to subtract reasonable R&D-costs from the EBIT that is a starting point for calculation of actual adjusted incomes. Energy Market Author determines the level of reasonable R&D-costs. The challenges of the DSO's R&D are related to smart grids and the developing of other new network technology in the near future. It has been estimated that this could raise the R&D-costs of DSOs before the new functionalities are up and running. Energy Market Authority has determined the incentive level of annual costs of hourly metering of consumption points with main fuses maximum of 63 A. This level is five euros for every consumption points. So to sum up, the reasonable R&D-costs and the sum of reasonable hourly metering costs based on incentive level are reduced from the EBIT. (Energy Market Authority 2011c)

The importance of quality incentive was increased. The total quality incentive share of the actual adjusted incomes can now be 20 % instead of 10 % of the DSOs reasonable return yield. The basic idea of this incentive is to minimize the total amount of economical costs of distribution interruptions for DSOs and customers. The most effective way to measure this is to consider the economical costs of electricity distribution interruptions for customers. (Energy Market Authority 2011c)

During the third control period Energy Market Authority continues working to improve the regulation of the electricity distribution business. Energy Market Authority divides the main goals of the regulation into six segments. The pricing of the network services needs to be reasonable. To maintain this, the return yield of the DSOs needs to be regulated. The transmission and distribution of electricity needs to be undisturbed. This will secure the high quality of network services. DSOs need to invest enough on the networks to develop the grid. Furthermore, business activities need to be efficient and the costs reasonable while the viability of electricity distribution business must also be secured. That is why business operations need to be sustainable. Finally, electricity distribution business must be continuously developed through new services and other innovate solutions. (Nurmi 2011)

2.4 The pricing of the electricity distribution

The pricing of the electricity distribution is strongly affected by the Electricity Market Act and the implementation of this law is being regulated by the Energy Market Authority. According to the Electricity Market Act (386/1995) the pricing of the electricity distribution must be based on spot pricing. This means, the DSOs need to make sure that a customer is able to use the whole electricity network, excluding external links, after taking care of the appropriate fees. The Electricity Market Act (386/1995) also states that the pricing of the electricity distribution cannot vary according to the customer's geographical location in the DSO's coherent distribution area.

The pricing of the electricity distribution can be based on different pricing principles. In practice, the electricity distribution pricing is based on following principles. Pricing system is planned in a way that fulfills the requirements for spot pricing demanded by Electricity Market Act. Moreover, the pricing is based on the matching principle. As a result, customers which are connected to the medium-voltage network do not have to pay the costs of the low-voltage network. The pricing system must also be simple enough and therefore easy to understand. (Partanen 2010)

Electricity distribution tariffs consist of fixed cost, distribution costs and power costs. The most common tariffs include basic fee (€/time period) which is depended on the size of the main fuses and one or two (day/night-time, winter/other time of the year) distribution fees (c/kWh). Power based tariff is usually offered to the largest customers. This means that in addition to basic fee and distribution fee there is also a fee based on customer's power demand (€/kW,time period).

The defining of the tariff structure usually includes following tasks. Electricity distribution business is divided into different cost pools. The most significant cost pools are metering and billing, network components and devices, capital costs, operational costs, financing costs, main grid fees, purchasing of electricity losses and administrative costs. Next, the unit costs of different cost pools must be calculated. (Partanen 2010)

For example the unit price of the operational costs is defined as follows. The operational costs are determined part by part in the whole distribution network. Naturally, these costs can greatly vary according to network area. The unit price is calculated by dividing the total costs by annual supplied energy. For example if the operational costs of the distribution transformers and low-voltage networks are 300 k€/a and the annual energy supply is 200 GWh, the unit cost would be 0.15 c/kWh. Next, the costs of different cost pools are allocated to the different parts of the tariffs (basic fee, distribution fee, demand fee). Finally, the tariffs must be evaluated and specified before determining the conclusive tariffs. (Partanen 2010)

There is no legislation or directive on how the DSO's should allocate the costs to different parts of tariffs. Every DSO can do this as they want, if they just justify the chosen structure. The most important question is that which costs are assigned to basic fee and which are collected through distribution fee. Basically the costs that are not related to the amount of energy supply should be included into basic fee and the energy depended parts into distribution price. However, majority of the costs are fixed costs, excluding main grid fees and electricity losses. The basic ideology of the allocation of different cost components is being introduced in the figure below. (Partanen 2010)

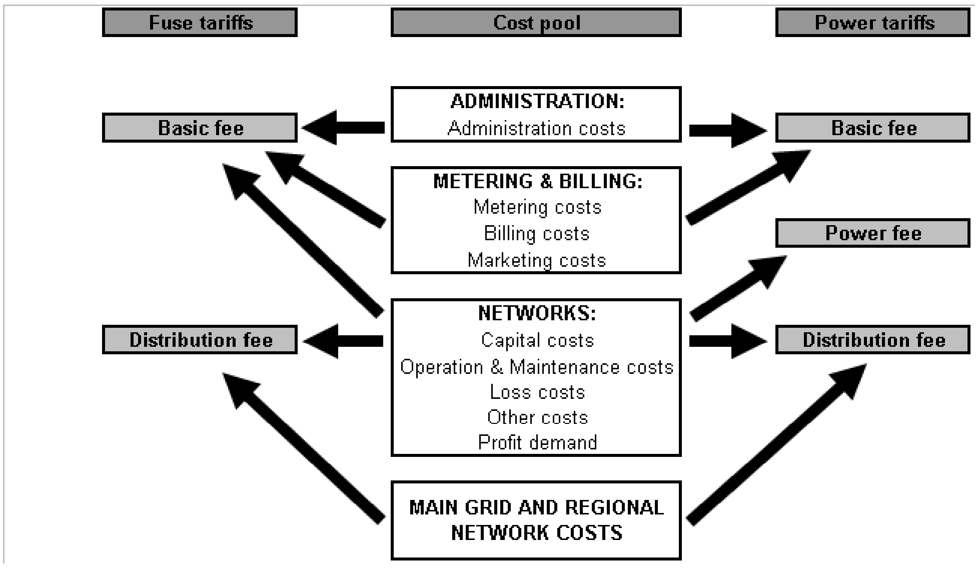

Figure 2.3. *Cost pools of electricity distribution and the cost allocation to the different tariff components. (Partanen 2010)*

In the time-of-use tariffs the cost allocation is also a question of which costs are allocated into day-time tariff and which into night-time/other-time-of-year- tariff. Usually the distribution fee of the night-time is lower and this is based on the ideology that during the night-time there is more available network capacity. This means that consumption during the night-time does not raise the level of peak power demand and therefore it does not cause a need to invest on the grid. (Partanen 2010)

However, with the different tariff structures it is possible to give incentives to customers for adjusting the electricity consumption in a way that would be beneficial for the DSOs. Basically this means that the tariff structure has effects on the overall electricity consumption and on how the total consumption is divided to different time of the day. The basic idea of the tariff structure's effects from the DSO point of view is being illustrated in the figure 2.4.

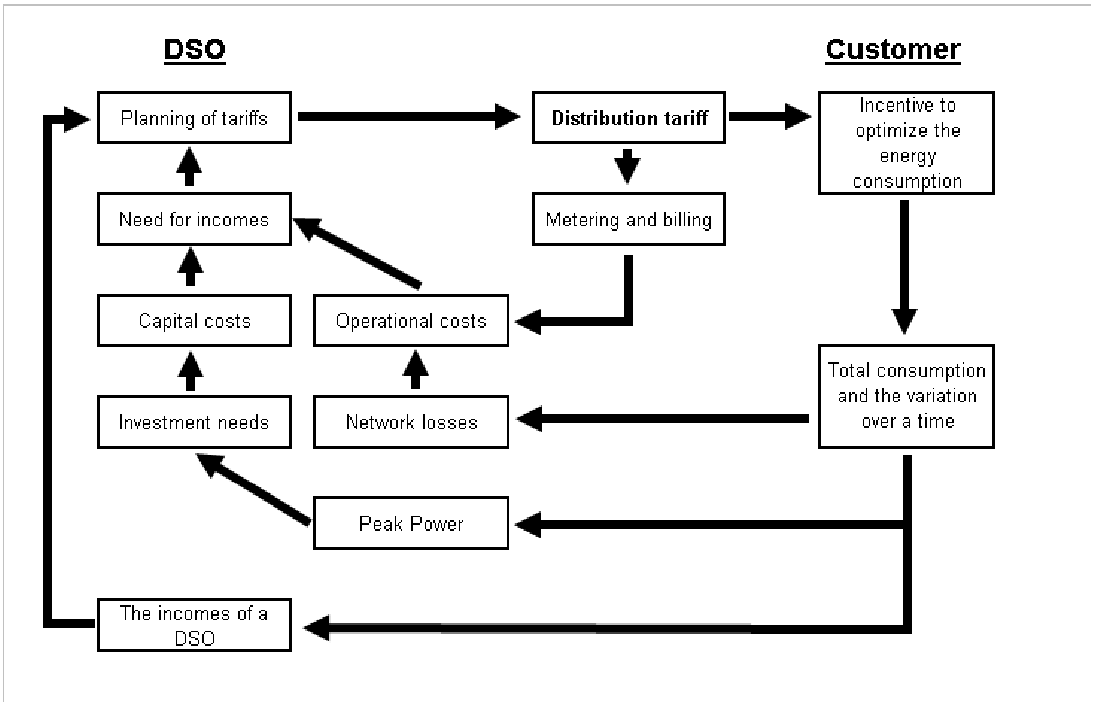

Figure 2.4. *The effects of the tariff structure from the DSO point of view. (LUT 2011)*

There is currently some research about how the electricity distribution tariffs should be developed in the future. This is due to changes in the electricity distribution business environment such as ambitious energy efficiency targets and the rising interest towards demand response. Future network tariffs are discussed more in detail in the chapter 4.5.

3 ENERGY EFFICIENCY

Efficient use of energy, or more familiar, energy efficiency can be achieved by minimizing the needed energy for services and different products. From the technical point of view energy efficiency means using less energy inputs while maintaining the level of economic activity or service. Energy saving is also often used term, but it is broader concept, including also the reduction of energy production through behavior change. (Energy Efficiency Plan 2011) According to the Energy Efficiency Plan (2011) energy efficiency is the most cost effective way to reduce greenhouse-emissions such CO2-emissions and secure the future energy supply.

In this chapter the core of the EU's energy policy, which also affects the energy sector, is introduced. Furthermore, the effects of the energy efficiency to electricity distribution business are presented. The head of the European Union is committed to accomplish the ambitious targets that have been set regarding more efficient energy end-use and the reduction of greenhouse gas emissions. Hence, national targets and incentives have been set and more is likely to come. The companies in the energy sector, including DSO's are in a close relationship with the consumers so these decisions affect also them. Energy companies are already demanded to provide consumers with more precise feedback of their energy consumption and therefore help the consumers to regulate their consumption behavior.

3.1 Political background

The necessity of a common European energy policy is justified by the need to react according the new challenges in energy sector concerning climate change, reliability of energy delivery and competitiveness of the European Union. (Finnish Energy Industries 2011a) At present, the growing demand for energy and the availability of new energy is challenging European Union's energy policy. Also the threat of climate change needs to be taken into account. (Finnish Energy Industries 2011a)

The energy policy of the European Union has three main goals. These goals are sustainable development, maintaining the competitiveness of industry and ensuring the energy supply. (Finnish Energy Industries 2011a) By sustainable development it is possible to satisfy the needs of a modern society without affecting negatively on the future generations. Ensuring the energy supply is vital nowadays. By ensuring sufficient energy supply the energy prices will not raise unreasonably and therefore the competitiveness of the European economy will benefit from this.

These goals are planned to be achieved with a more effective use of energy and by introducing new technology and energy services while also making better use of renewable energy sources.(Finnish Energy Industries 2011a) These actions require co-operation from many different sector. New cost-effective solutions for energy sector needs to be developed and therefore enhance the new technology to come economically lucrative. Likewise, politicians must do their share by setting up legislational framework for the implementation of energy efficiency activities. For example, the reduction of CO2-emission can be done by making better use of renewable energy sources. Moreover, this is an example of an action of sustainable development.

3.1.1 The EU climate end energy package

In March 2007 leaders of the European Union agreed to put together distinct climate and energy policy to respond the challenges of the climate change and securing of energy supply. To get a start for the needed actions the European Council set targets to be met by 2020. These targets are commonly known as the "20-20-20" targets.

Three main targets were set. The greenhouse emissions should be reduced to the level of 20 % under the emissions level in 1990. Secondly, renewable energy sources should produce at least 20 % of the total energy produced in Europe. Finally, the primary energy consumption should be reduced by 20 %. This means that in 2020 the energy consumption needs to be 20 % smaller than estimated at the time of setting the target. It was also stated that EU could be ready to aim higher. European Union would be ready to reduce greenhouse gas emissions by 30 %, if other developed and developing countries in the world would do their fair share to reduce greenhouse emission. (European Commission 2010)

In January 2008 European Commission proposed these targets to be accepted by the European Parliament and the Council of the European Union. The EU climate and energy package was accepted in December 2008 and became law in June 2009. One of the key targets of this package is to make sure that Emission Trading System (ETS) is being used effectively. Basically this system obligates the large emitters of carbon dioxide to monitor and annually report their carbon dioxide emissions. The EU countries have a certain amount of emission allowances that matches a certain amount of carbon dioxide emissions. EU believes that this system is the most cost-effective way to reduce CO2-emissions. Starting from 2013 there will be a single CO2-emission limit to the whole Europe, which will be annually reduced. Also the free allocation of emission allowances will be replaced with auctioning while the ETS will be expanded to new energy consuming sectors. (European Commission 2010)

European countries were also demanded to set plans for the reduction of emissions from the non-ETS sectors such as transport and agriculture. Overall wealth of the country affected the demanded reduction. Also the targets for renewal energy usage are national. The targeted shares of renewable energy usages vary between 10-49 %. The EU Climate and energy package also includes legal framework for developing technology for carbon capture and storage (CCS). The European Union believes that this technology is an effective way to safely cut the industrial emissions. (European Commission 2010)

3.1.2 Energy services directive 2006/32/EC

The European Commission proposed a directive for energy services and efficient energy end-use on 10.12.2003. Finally in 17.5.2006 this directive came into force and was required to put into nationwide action before 17.5.2008.

The most important objective for this directive is to contribute making the energy use more economic and efficient. Practically this is done with the following two measures. Firstly, the market barriers and other imperfections for the energy services and other energy efficiency improving measures need to be eliminated by setting indicative targets, incentives and legal framework. Secondly, the beneficial conditions for developing of the markets for energy services and other energy improving measures need to be created. (Directive 2006/32/EC)

According to the Directive 2006/32/EC the member states need aim to reduce the total end-use energy consumption by 9 %. This target includes the consumption which is not included in the ETS. The basis for calculating the amount of energy needed to be reduced is the official statistics of average annual energy consumption in 2001-2005. For example in Finland this means that the energy consumption needs to be reduced by 17.8 TWh by the year 2016. Still, this target is only indicative by nature. (Directive 2006/32/EC)

Directive 2006/32/EC states that more efficient end-use of primary energy can be achieved by increasing the demand for new energy services or by other energy efficiency improvement measures. The European Commission defines energy services as “the physical benefit, utility or good derived from a combination of energy with energy efficient technology and/or with action, which may include the operations, maintenance and control necessary to deliver the service, which is delivered on the basis of a contract and in normal circumstances has proven to lead to verifiable and measurable or estimable energy efficiency improvement and/or primary energy savings”. (Directive 2006/32/EC)

Furthermore, the directive includes requirements for the energy sector. These requirements affect energy distributors, distribution system operators and energy retail businesses that sell electricity, natural gas, heating oil and district heating. This kind of companies should not take any actions that would affect negatively on the development of energy services and other energy efficiency measures. In addition they need to supply information for the final customers which is needed to implement energy efficiency programmes. Furthermore, EU nations together with the previously mentioned companies should develop and promote new energy services or other measures which could help the final customers in achieving more efficient energy usage. (Directive 2006/32/EC)

In Finland the implementation of the Directive 2006/32/EC has been based on the National Energy Efficiency Agreements. These voluntary agreements are important tools to achieve the targets of the directive. These Energy Efficiency Agreements are used among industries (industrial, energy and private sectors), municipal sector, oil sector, property sector, transport (goods and public) and farms. The companies and communes which participate the agreements set their own targets for making the energy use more efficient, implement actions to achieve these targets and report the progress annually. (Motiva 2011)

3.1.3 Directive 2009/72/EC on the internal markets in electricity

Directive 2009/72/EC on the internal markets is a part of the EU's Third Energy Package, which influences the smart metering policy in the member countries. Directive states that the consumers must be informed about the actual energy consumption and the costs of the consumption. This would enable the consumer to regulate their own energy usage and encourage more efficient energy usage. (Reller et al. 2011)

Directive further demands for the implementation of intelligent metering systems. The member countries must produce cost-benefit assessments for the rollout of smart metering before 3 September 2012. In the countries where the results of cost-benefit assessment are positive 80 % of the consumers should be provided with an intelligent metering system before 2020. (Reller et al. 2011)

3.1.4 EU energy efficiency plan 2011

The EU Commission estimates have indicated that Europe would achieve only half of the 20 % saving target for the primary energy consumption by 2020. This means that new energy efficiency measures are needed in addition to the present actions. This is the reason why the European Commission published a new Energy Efficiency Plan in March 2011. This plan was produced in order to respond for the call of the European Council of February 2011 to take "action to tap the considerable potential for higher energy savings of buildings, transport and products and processes" (Energy Efficiency Plan 2011)

According to the EEP 2011 the greatest energy saving potential lies in the buildings. Therefore the plan aims to trigger the renovation of the buildings into more energy efficient direction, by using more energy efficient appliances and equipment in them. EEP 2011 also emphasizes the example role of the public sector. In addition EEP 2011 points out that there could be a need for obligations to the utilities in the energy sectors to help the customers to achieve reduction in their energy consumption. (Energy Efficiency Plan 2011)

Transport has the second largest energy saving potential according to the EEP 2011. The Energy efficiency of the industry will be improved by setting energy efficiency requirements while also setting up measures to introduce energy audits and energy management systems. EEP 2011 aims to affect the whole energy supply chain so the requirements are set also for the efficiency of power and heat production. (Energy Efficiency Plan 2011)

The implementation of the EEP 2011 is planned to be done through a new Energy Efficiency Directive that has been proposed 22.6.2011. This proposed directive aims to establish a common frame for the countries in European Union in order to achieve the energy saving target of 2020. The directive verifies the rules that aim to remove the barriers and fix the flaws that interrupt the efficiency of energy production and delivery. In addition, for example energy distributors and suppliers could be obligated to help the customers to reduce the energy consumption annually by 1.5 %. Finally, the proposal obligates the European Commission to give an estimate of whether it is possible to achieve the targets of 2020. European Commission should do this in 2014. Commission also needs to propose mandatory national objectives if needed. (European Commission 2011)

3.2 The effects of the improved energy efficiency on the electricity distribution business

There has been some research on how more efficient energy use could affect the different market actors. EU's energy policy demands more efficient energy use and therefore it is important that electricity market actors recognize potential changes in the business environment and adjust the operations according to these.

Energy end-use efficiency affects the electricity distribution business in two ways. It has effects not only to the energy usage but also to the peak power demand. Therefore, there are effects on the incomes and on the costs of the electricity distribution. The energy efficiency activities reduce the electric energy demand almost without exceptions. However, heating methods and the electric vehicles are examples of energy efficiency actions, which does not always affect the electricity demand similarly. For example if the heat pump replaces oil heating, the overall electricity need will actually rise. On the other hand, if it replaces electric heating, it will reduce the need for electrical energy. The future effects of the electric vehicles are depended on the charging solution. If there is none, the effects on peak power need could be significant. Alternatively, if a smart charging solution is implemented the effect could be meaningless. (Honkapuro et al. 2010b)

As discussed earlier, there are two parts in the electricity distribution tariffs, a part of fixed amount of money and a part depending on the electricity use. Thus, the energy efficiency will reduce the incomes from electricity use depended component. This means two things. The effects of energy efficiency use could be reduced by using tariffs based more on the fixed price. Likewise, the influence level of effective energy use into the incomes of a DSO is depended on the DSO's tariff structure. There is some variation between the DSOs on how much the distribution tariffs are based on fixed price and what is the share of the energy part. Tariff structures based more on the fixed price are not affected that heavily due to the energy efficiency. (Honkapuro et al. 2010b)

The effect of the peak power reduction is more far-reaching. Electricity distribution network and its components are designed and chosen according to the estimated peak power. Hence, the effects of the peak power reduction will arise when the networks are renewed based on the new peak power level, neither it is bigger or smaller. These decisions affect the investments costs and thus the capital costs, which are significant when considering the total costs of the distribution operation business. The effects of the energy efficiency on the electricity distribution business are illustrated in the following figure. To sum up, the most important questions for the DSOs is how the energy efficiency will affect the total energy need and the peak power demand. (Honkapuro et al. 2010b)

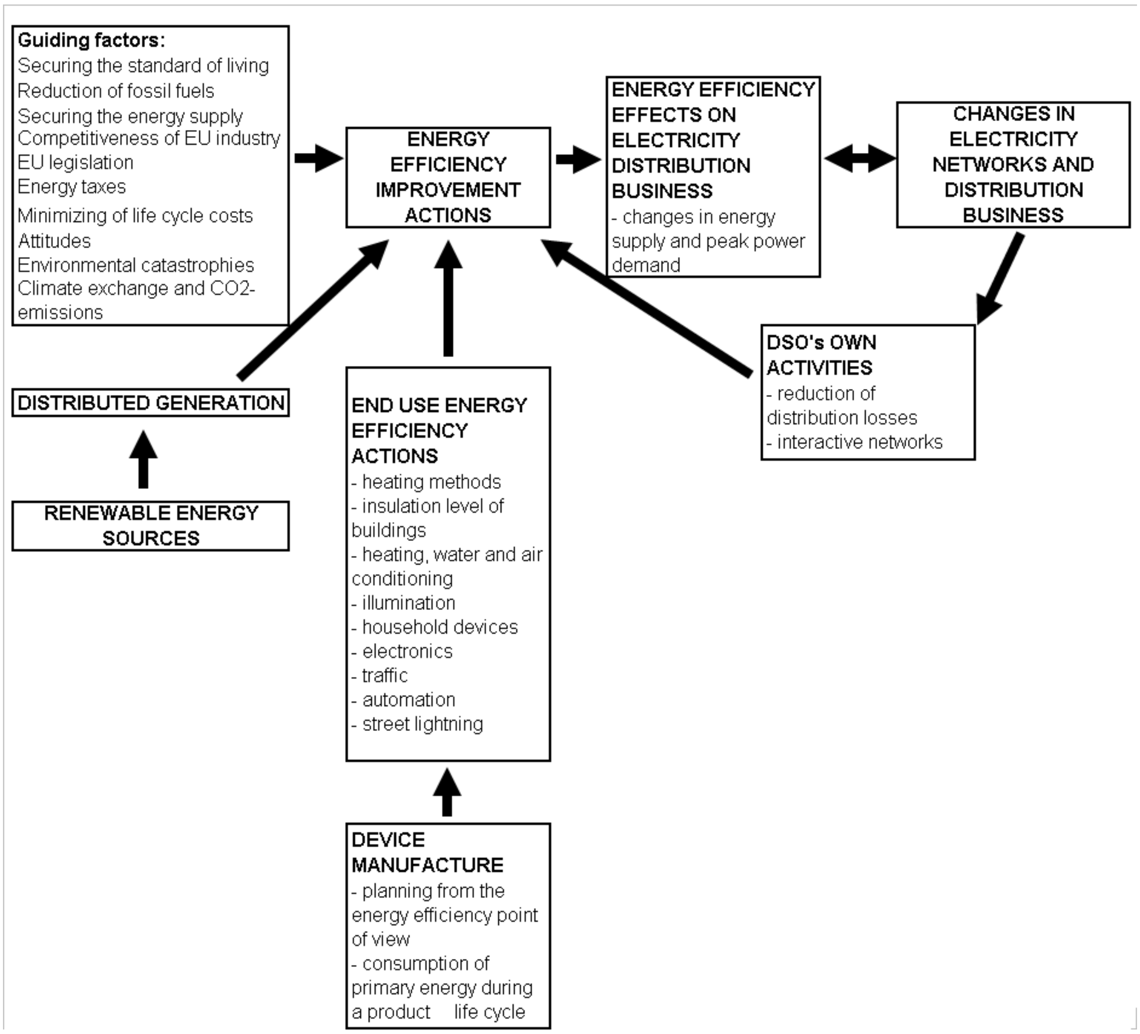

Figure 3.1. *The effects of the energy efficiency on the electricity distribution business. (Honkapuro et al. 2010b)*

The different nature of these two effects must also be taken into consideration. The effects of the changes in the total energy need are not depended of the location in a network area. Conversely, the effects due to changes in the peak power can vary much depending on the network area, because the network planning is based on the peak power demand in a certain part of the network. (Honkapuro et al. 2010b)

Customers of a DSO are usually divided into different user groups. Different kind of energy efficiency activities will have an effect on different user groups. On the DSO point of view the most interesting group is the household customers. This group is the largest in both, customer number and the supplied energy when considering the whole Finland. (Honkapuro et al. 2010b)

Because the more efficient use of energy can reduce the profits of traditional electricity distribution business, there is an economical incentive to find new business opportunities. The technological development, especially the interactive customer interface could help the implementation of new services that also help to achieve more efficient energy use. The challenge is to get the cost of new technology to the economically lucrative level. This together with new operation models could help to achieve more efficient energy usage and also create business opportunities for market actors.

4 THE FUTURE TRENDS OF THE ELECTRICITY MARKETS

In this chapter the future development of the Nordic electricity market is introduced. The reader should be able to have a basic picture of the potential changes that are planned to be implemented in the coming years. The planning process for the Nordic end-user markets is already on and there is also some research on how the electricity distribution tariffs could be developed in a way that corresponds to the development needs in the electricity markets. These together with demand response, which is believed to have a major role in the future electricity market, are therefore introduced. The introduction of smart meters can enable new kind of services in the future. The concept of smart metering services is also introduced in this chapter.

4.1 Introduction to the Nordic electricity markets

Norway was the first Nordic country to deregulate its electrical energy market and the Energy Act of 1990 formed also the basis for deregulation in the other Nordic countries. In 1996 the joint Norwegian-Swedish electricity market was introduced. It was the first multinational exchange for the trade of electrical energy contracts. This exchange was named as Nord Pool ASA. Finland joined the market in 1998 and currently Norway, Sweden, Finland, Denmark and Estonia operates in the Nord Pool Spot's day-ahead and intra-day power markets. (Nord Pool Spot AS 2011)

The basic operation of the electricity market is illustrated in the following figure. The electricity wholesalers produce electrical energy and sell it to the wholesale market. Wholesalers sell electricity also to the biggest consumers with mutual contracts. This trade outside electricity market is called the over-the-counter trade (OTC-trade). The retailers buy the electricity from the wholesale market and sell it to the end-users. The profits from the retail sales are quite limited and the risks notable while the profits from the wholesale have grown bigger for example due to the emission trading. (Partanen et al. 2010)

Figure 4.1. *The wholesale and the retail electricity markets. (Partanen et al. 2010)*

The power exchange is an open, centralized and neutral market place, where the market price of electricity is determined according to the demand and supply. The power exchange acts as a counter part for the trades, therefore the trading is anonymous and there is no counterparty risk. In other commodity markets there could be a risk that the counter part is unable to deliver the commodities. The power exchange is also market-oriented, which means that the members of the exchange participate in the decision making. (Partanen et al. 2010)

In the Nord Pool Spot the electricity wholesale is carried out by two different market mechanisms. The Elspot market is a day-ahead market based on closed auction. This means that the purchase and sale offers are made without knowing the offers from others. The offers include the delivery hours and the volume information. This trading procedure is executed once a day and the wholesale market price of the following day is determined based on these offers. Hourly market prices are formed by uniting the hourly purchase and sale offers in a way that produces one demand and one supply curve for the operating hour. The market price is at the intersection of these curves. (Partanen et al. 2010)

This price is the same for all market sides. However, the price formation does not take into account the transmission limitations between the market areas. Because of this, the Nordic market area is divided into price areas. For example Finland is one price area, while Norway forms five and Sweden four price areas. Therefore, if the transmission capacity is not sufficient the electricity wholesale price cannot be the same in every price area. Hence, if there is not enough production in a certain area, the area price will be higher than the market price. Conversely, if there is overproduction in the area, the local price will be lower than the market price. (Partanen et al. 2010)

The Elbas market is an intra-day market offering the possibility for the electricity trades inside the delivery day. Therefore it is a secondary market place for Elspot market. The bids must be placed not later than one hour prior the delivery hour. (Partanen et al. 2010)

The wholesale market operates in the whole Nordic area. This means that retailers can buy electricity from the power exchange that has been produced by the Nordic wholesalers. Instead, retail markets are still national. Thus, the consumer in the Nordic country cannot use the services of a retailer from another Nordic country. Nevertheless, the common Nordic end-user market is planned to be implemented in 2015 (NordREG 2010).

The retail market means the selling of electricity to small customers like households and small enterprises. The majority of the retailers are previous energy companies that were local monopolies, but there are also DSO-independed electricity retailers. The retailer which has the largest market share in the DSO's operating area acts as an obliged supplier. It must sell electricity with reasonable price if required by a customer. Usually customers and suppliers make indefinite contracts or periodic contracts with a fixed price. This is the reason why the fluctuation in the wholesale market price is not immediately reflected in the end-user prices. (Partanen et al. 2010)

It is in the retailer's incentives to make sure that the planned electricity sales are covered effectively by planned purchases and financial protections in advance. With financial protections it is possible to secure the price level for a certain amount of electricity. The retailer predicts the future consumption hourly based on the load curve. Load curves present the average fluctuation of electricity consumption in a certain customer group for example during one year. The retailer must continuously update the total load curve because of the changes in the customer number. (Partanen et al. 2010)

Usually retailers make long-term agreements with the electricity producers in OTC-market to cover the basic power need. After the basic power need is secured, the retailer uses the Elspot and Elbas markets to purchase electricity to cover the hourly varying need. It is rare that the actual consumption matches the predicted consumption. This difference is covered with the balance electricity bought from the Fingrid's Balance Service Unit or if the supplier is not balance responsible market participant, difference is covered with a trade between the supplier and the supplier's open supplier. (Partanen et al. 2010)

4.2 The common Nordic end-user market

The implementation of the common Nordic end-user market has been the goal of the NordREG for the past years. NordREG is a cooperative organization for Nordic regulatory authorities in the energy field. This kind of market model would mean that a single consumer could freely choose the electricity supplier in the Nordic area, without being limited by the national borders. In addition, the market area for the suppliers would greatly increase. This target has been given a wide support from politicians and the implementation plan was set in autumn 2010. The preliminary time-table for this process is illustrated below.

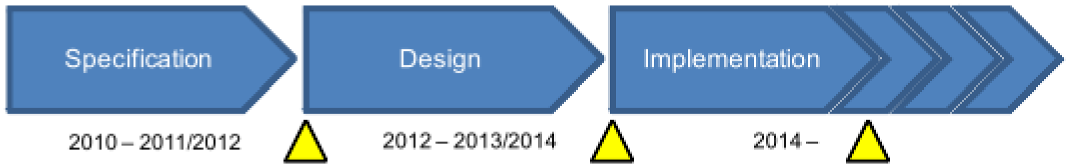

Figure 4.2. *The implementation process of the common Nordic end-user market. (NordREG 2010)*

During the specification phase the target market model for the common Nordic end-user market is specified and also the analysis made of the required changes in the processes. The target market model includes basically three issues. First one is the issue of how the contracts between the customer and the supplier/DSO should be arranged. The other issues are the models for customer interface and for the billing regime. These issues are discussed more in detail in the following chapters, except the contractual arrangements which should be remained as present according to NordREG. (NordREG 2010)

In the design phase the common processes and systems will be further developed and the national regulations should adapt the required changes. The implementation process includes coding, testing and deployment of new systems while the staff of the market actors is also trained. The target is that the common Nordic end-user market is implemented by 2015. This requires a lot of work and cooperation from stakeholders including regulators, DSOs, suppliers and TSOs. (NordREG 2010; NordREG 2011b)

NordREG has set general objectives for the common Nordic end-user market. The fulfillment of the objectives will be affected by many decisions that will be made during the implementation process. It can be said that the overall objective is to have well-functioning common Nordic electricity market including both, the wholesale and the retail market. The new market actors, products and business models are believed to bring closer the wholesale and retail markets, which could ultimately contribute to the demand response and the consumers' activity to react on the market signals which would have a positive impact on the market. (NordREG 2010; NordREG 2011b)

One important objective is that the Nordic electricity market is customer friendly, which means that it should be easy for customers to be active in the market. The market should also be open for all consumers. Accordingly, it should not be limited for the specific consumers for example for the hourly metered consumers. In addition the safety and the rights of the customers must be ensured regardless of the geographical location of the supplier. There are also potential benefits for the consumers. The common Nordic end-user markets could set pressure on the electricity prices and enable wider offering of services and products. (NordREG 2010; NordREG 2011b)

Furthermore, improved competition between suppliers and the overall efficiency of operations are among NordREG's objectives. To achieve these goals it has been stated that the suppliers should be able to operate with the same systems and processes regardless of the country. This requires that the processes, such supplier switching, are harmonized between the Nordic countries. There are also potential benefits for the suppliers.

A larger market area could lower the unit costs of the suppliers and therefore become more attractive for new market participants. (NordREG 2010; NordREG 2011b)

NordREG has stated that DSOs should have a neutral role in the market. This means that DSOs should only act as market facilitators. The role of the DSO is discussed more in the next chapter. The benefits for the DSOs (and for the TSOs) are the improved efficiency and automated processes. Also the quality of information is expected to improve, which would reduce the required amount of manual work. Finally, NordREG has stated that the implementation of the common Nordic end-user markets must match with the EU regulation and development plans, which ultimately target the common European electricity market. (NordREG 2010; NordREG 2011b)

4.2.1 Supplier centric market model and the role of the DSO

One of the most important issues regarding the common Nordic end-user market is the question of how the customer interface should be organized. The customer interface defines how the different market actors and processes appear from the customer angle. In addition, this definition will greatly affect the roles of different market actors. NordREG has stated that the customer interface should be based on the so called supplier centric model. In this model many issues that are now being handled by the DSO would become supplier's responsibility. (NordREG 2011b)

In the supplier centric model the suppliers and the ESCOs (Energy Service Company) would be responsible for the customer interface concerning the products and services of the free market. The supplier would also be the primary contact point for the customer in issues such supplier switching, moving and demand response related issues. Only issues concerning the physical network or the connection that usually requires technical knowledge and information about local conditions would be handled with the DSO. Typical issues of this type would be the quality of supply and new network connections. NordREG also states that customers should be given a chance to authorize the supplier to deal with the DSO on the behalf of the customer. These actions would reduce the need for the customer to contact with two different market actors and therefore make the customers activity in the market easier. (NordREG 2011b)

NordREG points out that the supplier centric model would increase the power of customer's choice for supplier. This is because the customer would now handle most of the issues with the marker actor that can be replaced if the provided services do not satisfy the customer. On the other hand, this also means that the suppliers have the strongest incentives to keep their present customers and gain more by developing the services and products. (NordREG 2011b)

NordREG emphasizes the importance of understanding the different market backgrounds of the DSOs and the suppliers. The suppliers are acting under competitive circumstances, while the DSOs are local monopolies. It is important to ensure the neutrality of the DSOs in order to secure a level market place for the suppliers. This means that all the possible communication between the customer and the DSO should be neutral and strictly related to the specific technical problem. (NordREG 2011b)

According to the NordREG, the DSO's role in demand response should be minimal. DSOs should only provide some of the technical solutions that demand response schemes require. Suppliers should develop pricing formulas that reflect the actual consumption pattern. Furthermore, ESCOs should be the developers of new products and services. Naturally these market actors would also be responsible to deal the demand response related issues with the customers. (NordREG 2011b)

Still, the roles of the suppliers and the DSOs are arguable. The public consultation for the NordREG's report shows that everyone does not agree with the proposed division of responsibilities regarding demand response. Some of the DSOs question if they should be allowed to offer demand response services in co-operation with service providers. There is also DSOs that think they should be enabled to use demand response to reduce the grid investments and the number of critical situations in the grid. Ultimately there was also responds that argued whether it is generally too early to discuss about the demand response and it should not be dealt with at present. (NordREG 2011c)

It is believed that customer interface based on the supplier centric model would bring numerous benefits for the different market actors. The overall functioning of the markets would increase while the growing competition between the suppliers would urge them to develop new products for example for demand response purposes. (NordREG 2011b)

4.2.2 Billing regime in the common Nordic end-user market

One essential issue concerning the common Nordic end-user markets is the question of the billing regime. Basically, this means that how many separate bills customer should receive and which market actor would be responsible for the invoicing. In the current model customer is invoiced separately for the electricity and for the distribution. However, if the customer buys electricity from the supplier which is a sister company of the local DSO, only one bill containing an electricity component and a distribution component is received by the customer. (Lewis 2010a)

NordREG studied this issue by comparing four possible billing regimes. First alternative was that billing regime would not be part of the Nordic harmonization process and should be decided nationally. Second alternative was the mandatory combined billing, which means that the supplier must provide combined bill for customer on both, cost of electricity and cost of network services. Third option was a voluntary combined billing. This means that the supplier can decide whether the customer is provided with the combined bill or with separate bills. Finally, the billing regime could be based on mandatory separate billing, when the supplier must always provide a bill for the electricity costs and the DSO must always provide a bill for the cost of network services. (Lewis 2010a)

NordREG concluded that the billing regime should be based on the combined billing. It was found that if the billing regime would be retained as it is today many new market opportunities would be lost. NordREG prefers the mandatory combined billing while states that the voluntary approach could also be possible. Basically this would mean that the supplier would provide the customer with a single bill that includes the electricity and the distribution components. (Lewis 2010a)

During the spring and summer of 2011 NordREG hired Dr. Philip Lewis to analyze what would be the most appropriate billing regime. Finally in November 2011 the cost-benefit analysis was finalized. This analysis was performed in co-operation with the NordREG Market Rules Task Force (TF), which is one of the five task forces among Customer empowerment TF, Business process TF, Structures of network tariffs TF and Metering TF that has been formed to further work for the common Nordic end-user market. (Lewis 2011b)

The cost-benefit analysis considered three different billing regimes, which were mandatory combined billing, voluntary combined billing and mandatory separate billing. The results from the cost-benefit analysis support the previous proposal for the future billing regime as the mandatory combined billing was qualified as clearly most preferred option for a Nordic Billing Regime. The result was based on the long-term financial outlook and also on a long list of additional, non-quantifiable benefits. (Lewis 2011b)

4.2.3 Data exchange

NordREG states that for the common Nordic end-user market it is a prerequisite that market actors have an easy and safe access to high quality market data. This is used for example for supplier switching, moving process and billing purposes. (NordREG 2010) Customers should also have unified identification code to identify single customers from the data base. Good quality data will improve the customers' confidence on the market by reducing incorrect billing and switches. (NordREG 2010)

According to the NordREG one potential way to arrange the easy data access would be by having national data hubs or databases that would interact with each others. The DSOs and the suppliers would have contract agreements with the national databases of the countries in which they wish to operate. NordREG believes this solution would lower the long term costs and the market entry barriers while market actors would only need to communicate with single system for accessing the information in each country. Still, the research on this subject has just begun and the final decisions concerning data access will be done after deeper analysis. (NordREG 2010)

4.2.4 The balance settlement

Electricity trades are agreed beforehand, but the trades must be settled afterwards. This is because it is extremely hard to predict the actual consumption beforehand. This settlement process is called the balance settlement. This means that all the electricity trades within a supply hour are being settled and the power balance and the imbalance are calculated. (Elovaara & Haarla 2011)

In Finland, the Electricity Market Act states that all the market participants are responsible to take care of that the electricity production and purchase agreements correspond to the electricity usage and delivery within an operating hour. This is called the balance responsibility. (Elovaara & Haarla 2011) Hence, all the market participants must have a so called open supplier that delivers the difference between consumption/sales and production/purchases. The market participants that have Fingrid as an open supplier are called as balance responsible parties. (Partanen et al 2010) Every supplier must have a balance responsible party or act as one. (Elovaara & Haarla 2011)

The balance settlement process is introduced in the figure below. The DSOs (Network operator) are responsible for arranging the balance settlement in their own operating area. In practice this means that the DSO must determine the hourly supply of all suppliers in the operating area. Balance responsible parties arrange the balance settlement of the open deliveries. Finally, the Fingrid's Balance Service Unit determines the national electricity balance and the imbalances between Fingrid and the balance responsible parties. (Partanen et al. 2010)

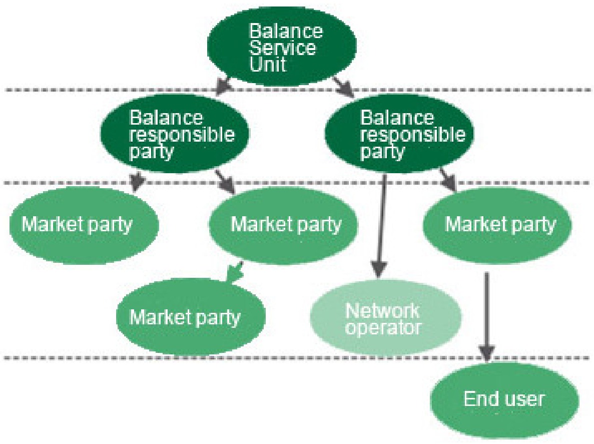

Figure 4.3. *Hierarchical balance settlement model in Finland. (Fingrid 2011)*

A common Nordic balance settlement is a requirement for a well functioning common Nordic end-user market. This would lower the entry barriers for new retailers and market participants willing to operate as a balance responsible party in all of the Nordic countries. In addition, it would be economically more cost-effective to have a one common balance settlement instead of many national ones. (NordREG 2010)

NordREG states that there should be a common operational unit responsible for balance settlement and invoicing. This could be a completely separate company or a company operating under Nord Pool AS. Basically, the common Nordic balance settlement would require that common rules and standards for issues such balance settlement, business processes, invoicing, balance responsibility and electronic communication must be introduced. (NordREG 2010)

4.3 Smart metering in Europe

Smart meters are generally electrical metering devices that record the electric energy consumption in intervals of an hour or less. Smart meters communicate this information back to the utility for monitoring and billing purposes usually on a daily basis. A two-way communication between a meter and a central system is also characteristic for smart meters.

Smart meters are prerequisite for the development of energy metering services like consumption feedback tools based on displays, websites and informative billing but also for demand response operations. Reller et al. (2011) studied the overall smart metering situation in the Europe. The study focused on the legal and regulatory framework and the progress of smart metering implementation process in the EU member countries and Norway. Reller et al. (2011) points out that the regulatory push and the actions of the market actors vary strongly between countries. Legal and regulatory framework in this case means a clear framework for the smart meter installation process aiming energy savings and/or peak load shifting. The progress of implementation process means that is there a clear and realistic roadmap for the implementation of the complete smart metering rollout. (Reller et al. 2011)

Reller et al. (2011) divided the countries into five categories based on the situation in the two criterions. The results are presented in the figure below. The "Dynamic movers" have a clear program for the implementation of the Smart Meter rollout. It can be seen that all the Nordic countries are included into this group. The "Market drivers" do not have legal requirements for a rollout but due to the demands from the customers some DSOs have started a smart meter rollout process. The countries included in "Ambiguous movers" have set a legal framework to some extent and the issue is regarded as highly important but still only some of the DSOs have started the rollout process. Finally, the "Laggards" are countries where the implementation of smart meters is not yet an issue. (Reller et al. 2011)

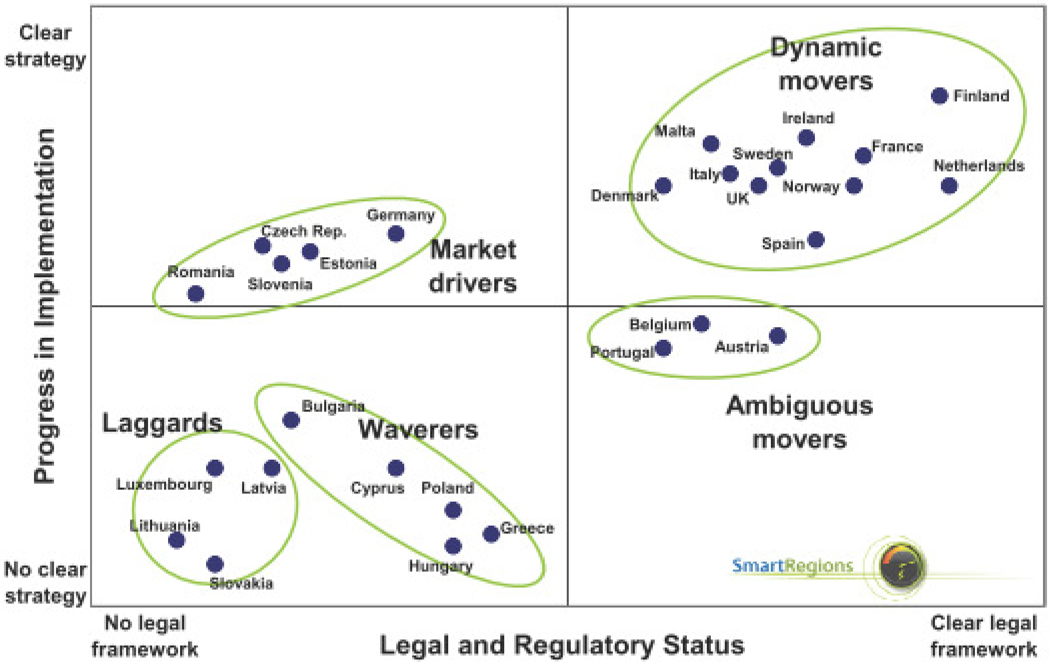

Figure 4.4. *A Graphical overview of the legal and regulatory situation vis-à-vis the process of implementation of smart metering. (Reller et al. 2011)*

As earlier mentioned the Nordic countries are among the "Dynamic movers". In Finland Electricity Market Act (66/2009) demands 80 % smart meter rollout by the year 2014 while the national regulator defined the minimum functional requirements for the metering system. Over one million meters have been replaced with a smart meter while approximately two million meters are still to be replaced. All the DSOs have started their rollout process. (Reller et al. 2011)

In Denmark there is no legal framework for the Smart Meter rollout, but still many DSOs are installing Smart Meters. The cost-benefit-analysis led to a negative result and therefore there is no mandatory metering of the households. The major driver for the voluntary metering is demand response. There is a total amount of three million meters and at the time of the research it was estimated that by 2011 half of them would have been replaced. (Reller et al. 2011)

The first country to indirectly mandate a full rollout of smart meters was Sweden. The monthly meter reading has been required since July 2009. By the 2009 nearly all of the final customers had remotely readable meters. Still, only 750,000 meters can perform hourly metering and data handling. Almost four million meters need some investments to be capable of that. The situation in Norway is discussed more in the next chapter. (Reller et al. 2011)

As to smart metering services, Reller et al. (2011) states that there is a wide range of feedback tools in the Europe that are currently available or in a piloting phase. The development of smart metering services is a prerequisite being able to utilize the energy saving potential among customers. Smart meters benefit energy companies for example by remote reading and more precise billing, but without feedback tools and additional metering services there is no true benefit for the customers. Reller et al. (2011) concludes that “only metering services will provide added value to the consumers”. (Reller et al. 2011)

4.3.1 Implementation of the smart meter rollout in Norway

The Nordic countries are leading the way in smart metering. However, Norway decided to wait a bit longer before the full rollout of smart meters. In general, this was because Norway waited the finalization of the EU standardizing work related to the metering. Currently only the large customers are hourly metered. Finally, in July 2011 Norwegian Energy Regulator took a decision on the smart metering.

Because of the delay, Norway had a possibility to develop the smart metering system concept before the rollout and also learn from the implementation processes in other European countries. Norway’s Energy Regulator mandated that all 130 of the country’s utilities deploy smart metering systems. All of the final customers must be provided with a smart meter system by the end of 2016 (Echelon 2011), while there should be 80 % rollout by the end of 2014. (Grammeltvedt 2011)

Norway’s Energy Regulator set some specific requirements for the smart metering systems. The metering data must be collected on a daily basis with 15-minute interval. Furthermore, there is a possibility to integrate the meter with other meters like gas and water meters. (Echelon 2011) Norwegian DSOs must also provide the customers with a possibility to have an in-home display for consumption monitoring purposes. In this case the customers need to pay the extra investments. (Grammeltvedt 2011) These specifications are quite notable when considering the corresponding smart metering rollouts in the other Nordic countries.

4.4 Demand response

Basically demand response means shifting the power demand away from the peak power hours and therefore from peak price hours. The most essential goal of using demand response is to level the daily and seasonal fluctuation of the power demand. Thus, it could be possible to lower the electricity prices with large-scale demand response. (Elovaara & Haarla 2011)

One significant question in the current electricity market is that how to include demand response more effectively into the electricity market. DR is already working quite fluently in the wholesale market and among big consumers. Now the smaller consumers should also be included into the DR actions. It can be said that currently the market price varies according to demand, but demand does not vary according to price. More regular power demand would be beneficial to all market actors and would ease the planning of operations. In addition the DR would relieve the stress on the power grid while also temporarily postpone the need for network renovation and the expansion of the generation capacity (Belonogova et al. 2010).

Generally the DR of small consumers is not possible to develop without metering devices capable of hourly metering. Also hourly balance settlement is required. These are needed to verify the DR actions and allocate the benefits to the right customers and market actors. In Finland, it is required that DSOs have 80 % of metering points hourly metered in 2014 and starting from 2014 the balance settlement must be hourly done including all the metering devices capable of hourly metering. This means that these two market barriers would be partly eliminated by that time. (Belonogova et al. 2010) In Finland the situation among the DSOs vary and some of them are already using hourly balance settlement and some are planning to use it not until the required 2014. While these are the technical and functional requirements the electricity contracts are also needed to develop in a way that gives incentives to adjust the energy consumption. This means for example spot price based electricity contracts.

In Finland there is a high DR potential especially in electric heating. This is because the majority of the consumers living in rural areas use electrical heating in their houses. The benefit of using electric heating in DR purposes is a high demand power related to other domestic appliances and that it can be shifted without affecting the comfort of the consumers. It has been estimated that the small consumers without electric heating does not have any significant potential from the demand response point of view. In Finland the majority of the consumers using electrical heating are using a two-time tariff. This has leveled the fluctuation of the national power demand by shifting the majority of electrical heating to night-time hours, but it still sometimes counteracts the fluctuation of the market price of the electricity. This arise a need for further study also the dynamic pricing, which is discussed later in this work. (Segerstam et al. 2007; Ritonummi et al. 2008)

While the residential households as a whole have a notable DR potential, this is not a case with a single consumer. There have been some research on what would be the most efficient and rational way of controlling the DR resources of a large consumer group. An aggregator means a utility that collects together a great number of consumers and their DR resources and then provides this to the market actors. For example suppliers or totally separate companies could act as an aggregator. (Ikäheimo et al. 2010)

Customers do not necessarily feel that contributing to the national power balance is meaningful. (Elovaara & Haarla 2011) Therefore some economic incentive is needed. These incentives require that the electricity prices for the customers are more based on the market prices. If the electricity prices are fixed or vary only according to nigh/day-time there is not much incentive to adjust the power consumption. In addition the growing fluctuation of market prices would increase the incentive to adjust the energy consumption. Some basic examples of customer-initiated DR actions would be delaying the use of sauna or cooker. Also wood can be used instead of electric heaters during the higher electricity prices.

DR is commonly divided into incentive-based and price-based demand response. (Albadi & El-Saadany 2008) For the residential consumers a direct load control is a conventional type of incentive-based DR. Likewise, dynamic pricing rate is an example of price-based DR used to steer the consumption. (Tiptipakorn & Lee 2007)

Incentive-based DR is a DSO-initiated action used to reduce the peak power demand and it does not take into consideration the comfort of the customers. Still, it has been concluded that customers should have an option to override this control signal, while this is an only way to get the consumers participated in DR operations. The customer receives some kind of sanction when overriding the control signal while one is rewarded of following the signal. (Belonogova et al. 2010)

The price-based DR is a voluntary-based action of the customer. Customer receives for example a price signal and is enabled to adjust consumption according to it. This type of DR takes the customer comfort into account while customers itself can choose whether to take DR action or not. If the consumption is adjusted based on price signal the customer gets savings by reduced electricity bill, but naturally if the price signal is ignored the savings will not occur. The basic DR scheme is illustrated in the following figure. These described DR operations require that the customer is equipped with a system capable of receiving control signals and that the implemented actions can be verified afterwards. (Belonogova et al. 2010)

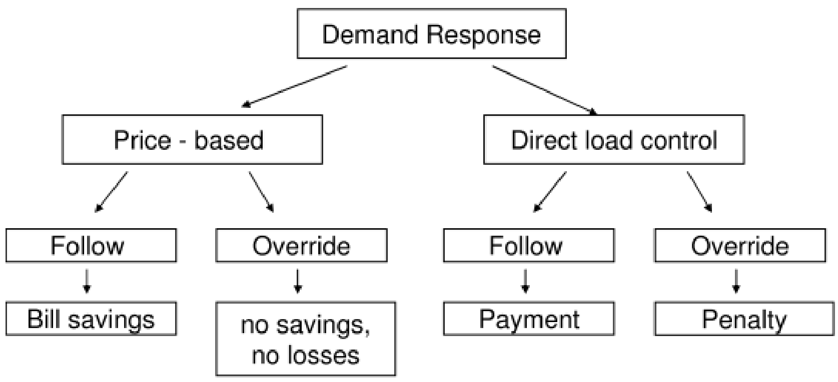

Figure 4.5. *The basic scheme of demand response. (Belonogova et al. 2010)*

There is, without no doubt, a high potential for DR in residential customers. Still, there are also great challenges. One issue is that it is challenging to predict the customers' consumption behavior and actions in DR operations. This would mean that whether the customer is following the control signal or not. This can vary greatly between consumers.

The level of how strongly a customer reacts on the price signal is called elasticy. Elastic loads are very sensible for market signal and are adjusted heavily according to price signals. Inelastic loads are not notably affected by price-signals. (Belonogova et al. 2010) Furthermore the loads can be divided into loads that can be shifted and loads that can be limited. Washing machine is a good example of a load that can be shifted as the usage is not typically bound into a certain time. Loads that can be limited can be switched partly or totally off and the corresponding consumption does not reoccur later. (Evens et al. 2009)

In the real network, there are a number of power stations and feeders that all possesses a unique mix of different customer types. This means that the DR effects vary according to the network area. As a result, when considering the effects of DR the whole network should be taken into consideration. (Belonogova et al. 2010)

Belonogova et al. (2010) studied the effects of incentive-based and price-based DR on the electricity distribution business. It was estimated that DR would bring two kinds of benefits for the DSO, due to decreased peak power demand. Temporary savings can be achieved by the possibility to postpone the network investments. Permanent annual savings are possible because of the peak power reduction. Those savings would ultimately reflect also the consumer prices.

Belonogova et al. (2010) emphasizes the important fact that these benefits only occur if the peak power is reduced and it will remain at reduced level for the whole period under consideration. In a case of price-based DR this would mean that the consumers should react similarly to DR signals for the whole time period, which is only theoretically possibly. In the study the calculations were made with a feeder located in the rural area which means that a majority of the consumers were using electric heating. The load curve of the considered feeder is on the figure below. In the figure it is also presented that what type of demand response is needed to reduce the peak power level.

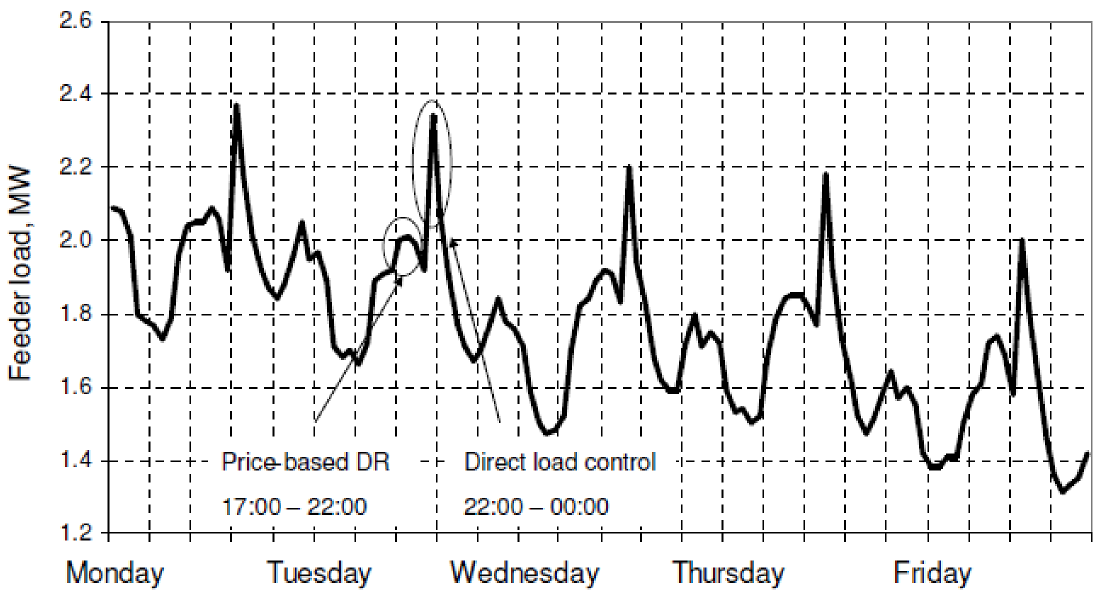

Figure 4.6. *Feeder's load curve and the occurrence of different DR actions. (Belonogova et al. 2010)*

Belonogova et al. (2010) concluded that price-based DR should be used together with incentive-based DR to be able to smooth both of feeder's power peaks. This is also illustrated in the previous figure. With the effective combination of these two DR activities it would be possible to achieve around 10 % reduction in peak power of a feeder. However, Belonogova et al. (2010) emphasize that the result depends strongly on the load curve, meaning the type, number and the behavior of the customers on the feeder. Still, this gives an order of magnitude of the potential there is. The figure 4.6 also illustrates the usage of price-based and incentive-based DR to reduce the daily peak powers. (Belonogova et al. 2010)

Nationally there are typically three daily peaks in the power demand. First one occurs at the morning because the companies start the working days and the processes. Second one occurs typically between 5-8 p.m. when consumers get back home from work and use for example cookers and entertainment devices. Last one occurs at 10 p.m. because of the electric heating loads are switched on. Normally the latest peak is not as high as the peak during 5-8 p.m. The variation of national power demand is illustrated in the figure 4.7 below. The figure shows the power demand during a one week in December 2011.

The market price of the electricity follows quite well the national power demand and during peak power hours the price also has peak values. This is also shown in the figure 4.7. Still, this is not the case with the last peak power hour at 10 p.m. The peak caused by electric heating loads does not cause a peak in the market price. According to Belonogova et al. (2010) this is the reason why price-based DR does not help in smoothing the feeder's second peak power.

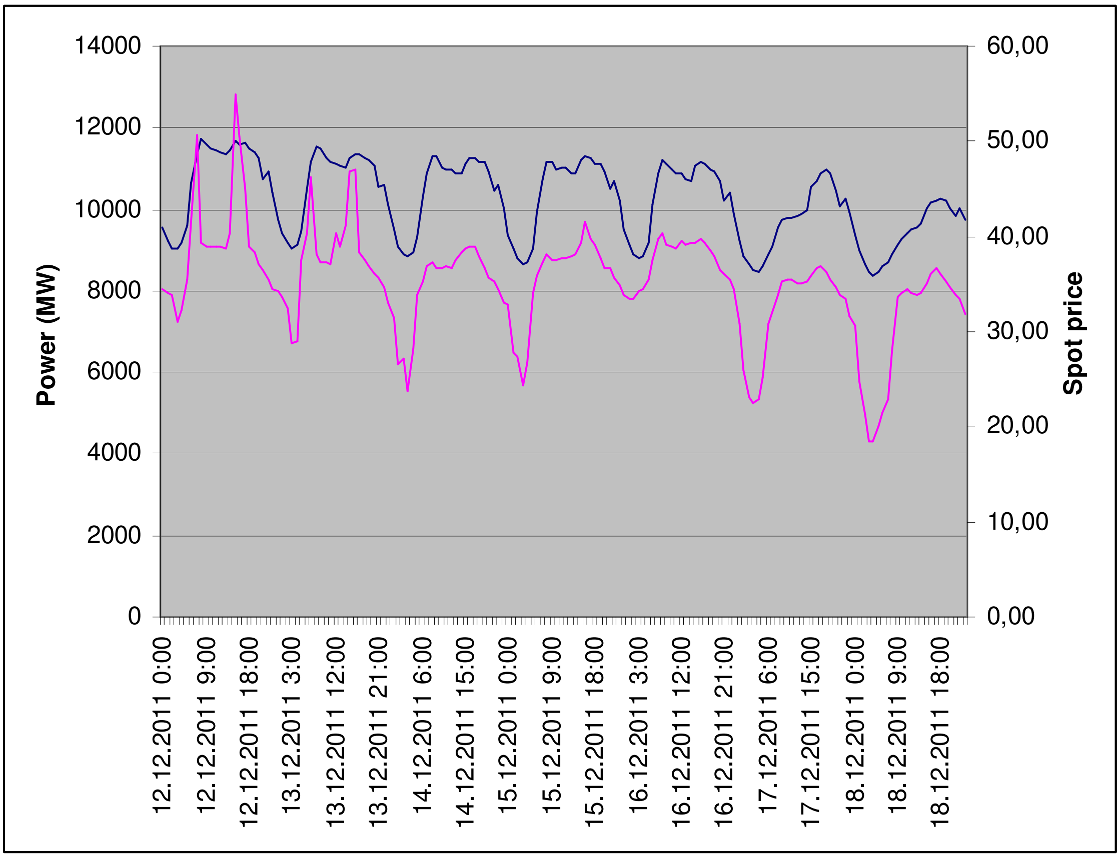

Figure 4.7. *Fluctuation of national power demand and the spot price of electricity in Finland.*

There are potential benefits for the DSO from DR. The savings realized to the DSOs with reduced annual peak power level could also reduce distribution fees for the customers. DR actions could enable to delay the network investments with multiple years. Still, it must be remembered that most of the benefits only occur when the customers response to the control signals are permanent within the consideration period. This can be achieved only with direct load control. (Belonogova et al. 2010)

Belonogova et al. (2010) concludes that it is important to develop a model for an intelligent load controller. This means determining the shifting or reduction actions of the home appliances that should be done and for how long, while also the precedence of the actions needs to be evaluated. This could possibly be a part of the future home energy management system of the customers.

Demand response can bring benefits when used regularly, but the biggest relative benefits from the electricity market point of view can be achieved in a case of extreme peak prices. When extreme peak prices occur the demand and supply curves cut each others being almost vertical. This is illustrated in the following figure. This means that even a small amount of demand response could affect the prices significantly.

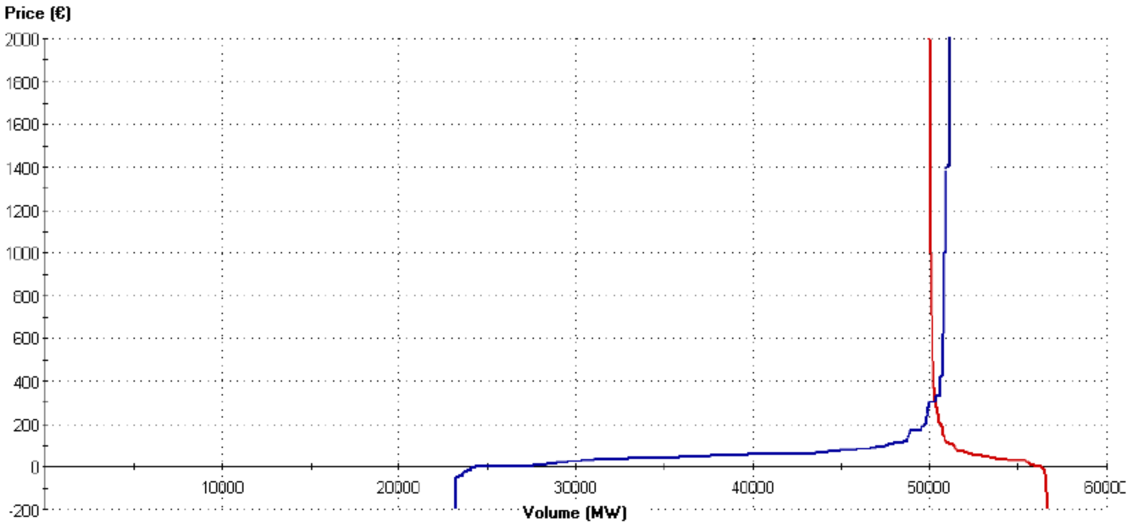

Figure 4.8. *Demand and supply of hour 9 in 22.2.2010. (Partanen 2011)*

There has been recognized a need to include demand response already to the formation of spot prices. For example in Finland there has been recognized a significant amount of demand response after the publication of spot prices. The problem is that the effects of demand response are not transferred to the spot prices. Basically this would require new types of purchase offers. The volume of these offers would decrease when the price increases. (Lepistö 2010) Currently the majority of electricity is bought from Nord Pool Spot regardless of the price levels. This is illustrated in the figure 4.9. which demonstrates the distribution of hourly purchased power to different price caps of the purchase offers. (Partanen 2011)

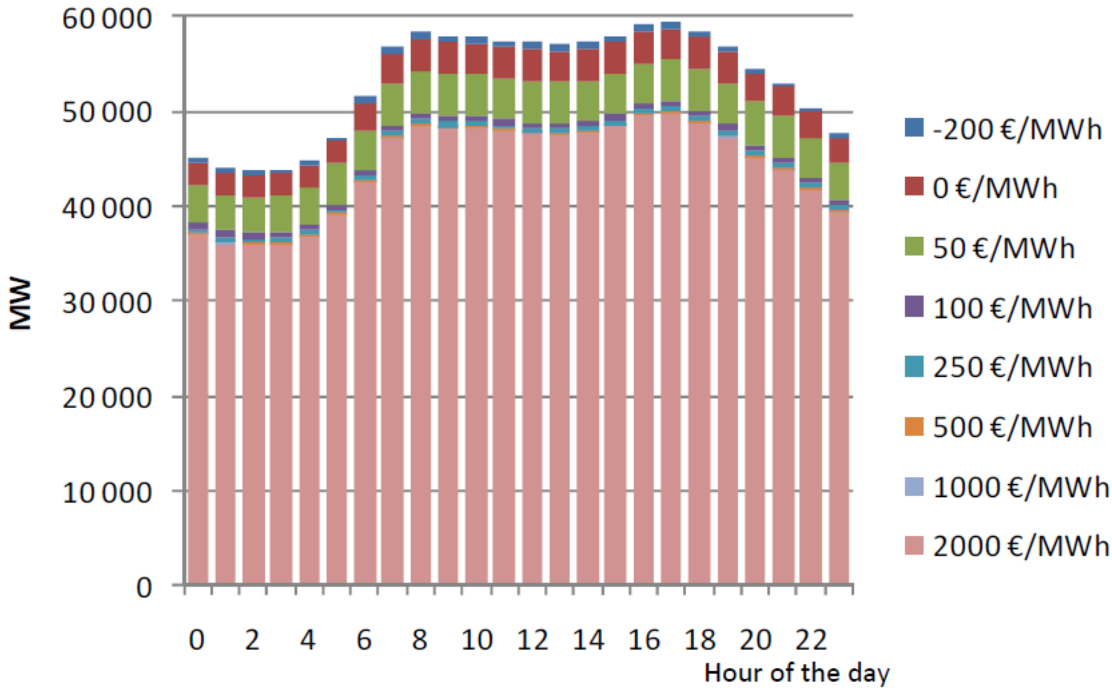

Figure 4.9. *Distribution of hourly purchased power according to the price caps of the offers in Nord Pool Spot. (Partanen 2011)*

In 2011 NordREG commissioned Gaia consulting group to examine and propose actions for promoting demand flexibility on the Nordic wholesale electricity market. The peak prices during the winter 2009-2010 were among the incentives for the study. It was concluded that there could be around 4 000 – 7 000 MW of demand response potential in the Nordic electrically heated households. (Bröckl et al. 2011) Ritonummi et al. (2008) estimated that there could be around 300 MW of demand response potential in the Finnish electrically heated households while Bröckl et al. (2011) estimate the potential to be around 600 – 1200 MW. These numbers illustrate the difficulties to estimate the potential as it depends on how much load can actually be steered and how much would be available at the same time.

Still, to achieve short term effects the demand response should be further promoted among industry. Long term effects could be achieved with small customers. The report points out the importance of regulators and legislators to take actions in order to promote demand response. It was also concluded that the distribution of market risks will change between the retailer and the customer, but only if efficient and active demand management is possible for consumers. (Bröckl et al. 2011)

4.5 Future network tariffs

Future trends of the electricity market such more efficient energy use, demand response and distributed energy storages will affect the peak power level in the electricity network and the overall energy consumption. This could decrease the incomes of the DSOs with the current tariff structure. In addition, the development of metering devices and the load control possibilities enable to give incentives for customers to adjust their consumption behavior in a way that is beneficial from the power system point of view.

The basic starting point is that the future network tariff structure should enable the demand response, but in a way that not lead into unnecessary network investments, that could be also nationally uneconomic. If the consumption behavior is only adjusted according to energy production and market prices it could result incentive conflicts between the DR needs of the DSOs and the suppliers. This is the reason why the suitable distribution tariffs are needed. They ensure that also the DSO would benefit from the DR actions. (LUT 2011)

Figure 4.9 illustrates the interaction of the tariff structure between the different stakeholders in the electricity market. This figure illustrates how widespread are the effects of the tariff structure and on the other hand how many different things form a basis for the development of a suitable and effective tariff structure.

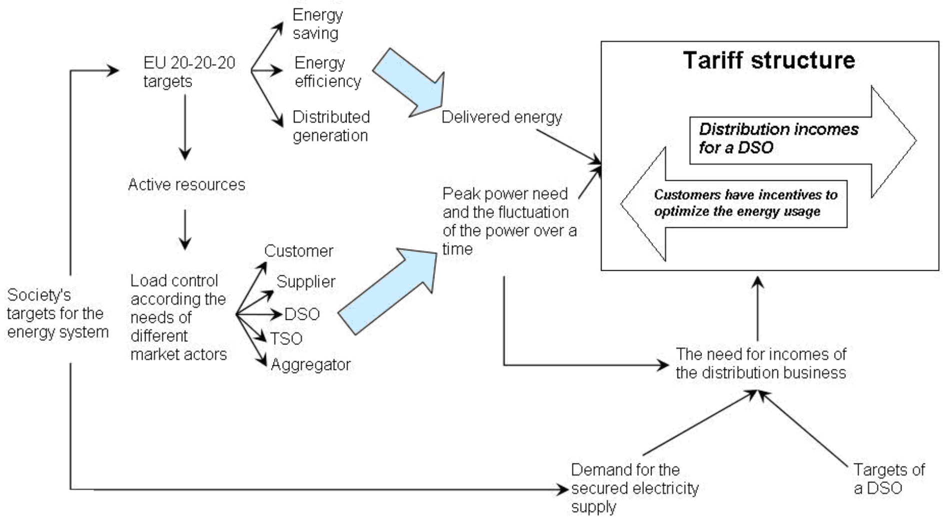

Figure 4.9. *The effects of the distribution tariff structure. (LUT 2011)*

Actions to save energy and the improved energy efficiency reduce the delivered electrical energy and therefore reduce the incomes of the DSOs with the present tariff structure. Further, the peak power need on the network does not necessarily reduce. As a result it is important issue to re-evaluate that should the tariff structure be updated according to the changes in the business environment. According to the recent studies the share of fixed price in the distribution tariffs is growing which also refers to the need for the structural changes in the tariffs. When considering demand response there is many market actors that would benefit from the DR, while there could be conflicts between the player’s incentives if the interactions between tariff structure and the load control are not thoroughly considered. (LUT 2011)

Lappeenranta University of Technology has started the study of the possible future tariff structure. Basically LUT considers three different possible distribution tariffs. First option would be that the distribution tariff would be totally based on the peak power need of a consumer or on the size of the main fuses. This means that there would be only one monthly fixed price based on the highest hourly average power. The second option is a dynamic distribution pricing which means that the price varies according to time of the day and it would be more dynamic than the present two-time tariffs. This would give an incentive for consumers to adjust the electricity consumption more according to the DSO needs. This tariff type is introduced in the following figure. (LUT 2011) Basically the distribution prices would reach the peak level when the peak power on the distribution network is usually reached.

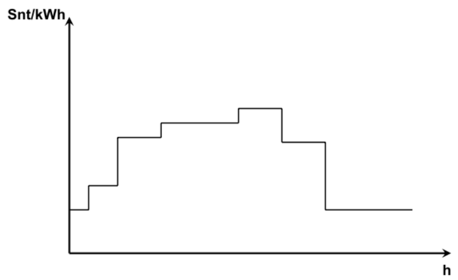

Figure 4.10. *The simple model of a time-of-use based tariff. (LUT 2011)*

Last one of the three basic tariff types is called the adjustable fuse. The main idea is that the consumer receives a sanction when the agreed peak power level is reached. The level of the sanction could be depended on how much the peak power differs from the agreed level and on the other hand how long the power level is above the agreed peak power level. This tariff structure is visualized in the following figure. (LUT 2011)

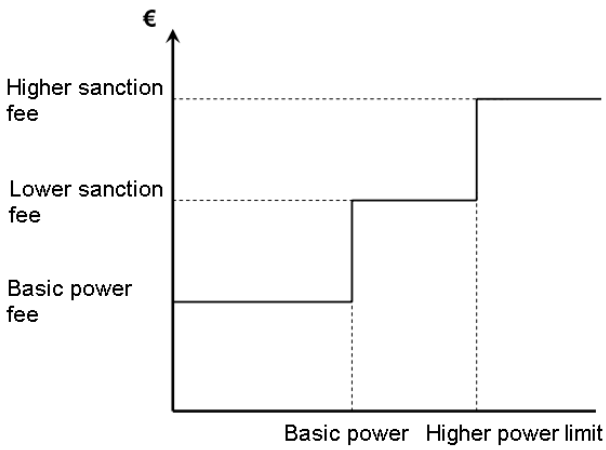

Figure 4.11. *An example of adjustable fuse tariff. (LUT 2011)*

LUT will study the needs for the distribution tariff structure from the customer, DSO and the electricity market point of view. It can be predicted that the energy tariffs vary more according to the electricity spot-price in the future. Customer's behavior must be evaluated based on the overall effects of both, future distribution tariffs and the future energy tariffs. This is because the basic driver of the customer's consumption behavior is the total price of the electricity. It is also important that the future tariff structure is clear and easy to understand for the customer. (LUT 2011)

LUT emphasizes that from the DSO point of view it is important to analyze the effects of the customer's behavior on the distribution business and how well the possible tariff structures match the DSO's need for incomes especially if there is great changes in the consumption behavior. Furthermore, there is a need to determine how well the tariff structure matches to the DSO's cost structure. (LUT 2011)

When considering the distribution tariff structure from the electricity market point of view the most important question is that how well it works together with the electric energy tariff structures that urge customers for the DR actions. In the following figure this kind of conflict situation is introduced. In the figure there are the area market price and the power of a certain feeder. The market price-based DR could shift the consumption from the peak price hours to the hours when the consumption in a certain feeder is already at the highest level. Therefore, there is a clear conflict between the price-based and the network-based DR. (LUT 2011)

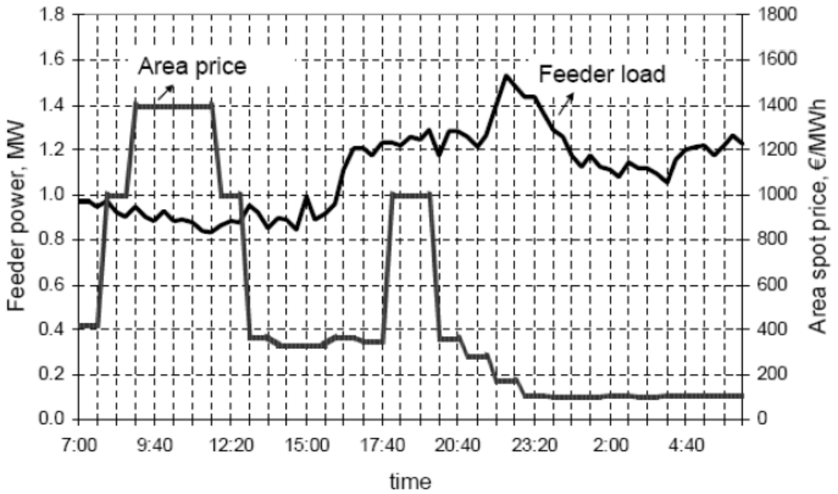

Figure 4.12. *The feeder load and the area price of Finland in 22.2.2010 (Belonogova et al. 2010)*

The developing of the tariff structure is a challenging issue. There are number of interactions between the tariff structure and the market stakeholders. The tariff structure should be developed in a way that satisfies the customers and is accepted by them. Also it should match the changes in the distribution business environment and finally contribute to the overall development and functionality of the electricity markets.

4.6 Smart metering services in private customer interface

Smart metering technology together with new ICT-technology enables the development of innovative smart metering services. The goal of these services is to provide consumers opportunities for more efficient energy usage and to use more dynamic pricing tariffs. Generally these services provide feedback on the energy consumption with displays or reporting tools. Consumers benefit from these by acquiring higher understanding of their energy usage and the costs from it. This gives motivation to avoid unnecessary use of electricity and to adjust the consumption behavior to be more efficient. According to Fischer (2008) efficient feedback on energy consumption has following characteristics:

- Feedback should be based on actual consumption
- Feedback should be given regularly and at least once a day
- Effective feedback is interactive and includes choices for the household
- Effective feedback includes device specific information
- Feedback can include historical comparison or comparison between a control group. Also it is important to have chance to set own goals.
- Feedback should be presented by understandable and appealing way.

Smart metering services can be divided into energy saving services and demand response services. Energy saving services give information and provide feedback on the energy consumption. Demand response services are combined with dynamic pricing tariffs and are tools for adjusting the consumption according to the price levels, or the service can be built in a way that customer gives a possibility for some market actor to control some of the loads and gets a compensation for that. This chapter introduces examples of the smart metering services of both types and that have been piloted in Europe and what kinds of effects services have brought and what was the customers' response during the pilot.

Energy saving services

As earlier mentioned these are services that allow the consumers to monitor the consumption more in detail, based for example on the hourly or half-hourly consumption data. In Finland some of the DSOs are providing an internet-service that enables customers to view their hourly electricity consumption. This data is collected from the smart meters. These services are under development and in the future will provide opportunities to view the monetary costs of energy and to compare the consumption with other same types of consumers. The services have been generally welcomed by the consumers. These also benefit the DSOs by the reduced number of customer calls as they are now able to check their electricity consumption from the service by themselves.

The following figure introduces the service provided by the UK's largest independent energy company First Utility. It allows consumers to view the consumption with a half-hour time span and to download the information for further study. The service does not contain an in-home display so the service requires an access to the internet and a PC. The data is not also real-time information. The customer react had been that this kind of service causes a change in their consumption behavior and they would recommend it to the others. (Renner et al. 2011)

Figure 4.13. *User interface of the service provided by the First Utility. (Smart Regions 2011a)*

Generally the customers are pleased with a more specific consumption data and are using the services that have been offered. They think that these services has improved their understanding of the electricity consumption and helped them to achieve more efficient energy usage. (Renner et al. 2011)

Demand response services

In Denmark, Syd Energi and SEAS-NVE piloted a demand response service between 2007 and 2009. More than 500 residential customers were involved in the trial and they were provided with different types of price information and technology for load steering. 238 customers were participated in the test group who were offered hourly spot price based electricity contract and different kind of technology. 46 of these customers were equipped with automatic load control system that would steer the heating according to the pre-defined price-levels. 172 customers would receive daily e-mail or SMS with price information in order to perform manual load control. 20 customers got a display where the price levels were presented in order to perform manual load control. To give a more informative price levels for the customers three levels were defined. High level was the level of 5 % above the daily average price. Low level was the level 5 % under the daily average price. Rests of the hours were average hours. The figure below illustrates this method. 5 % were chosen as a reference because it would cause that there would be high and low level prices almost every day. (Renner et al. 2011)

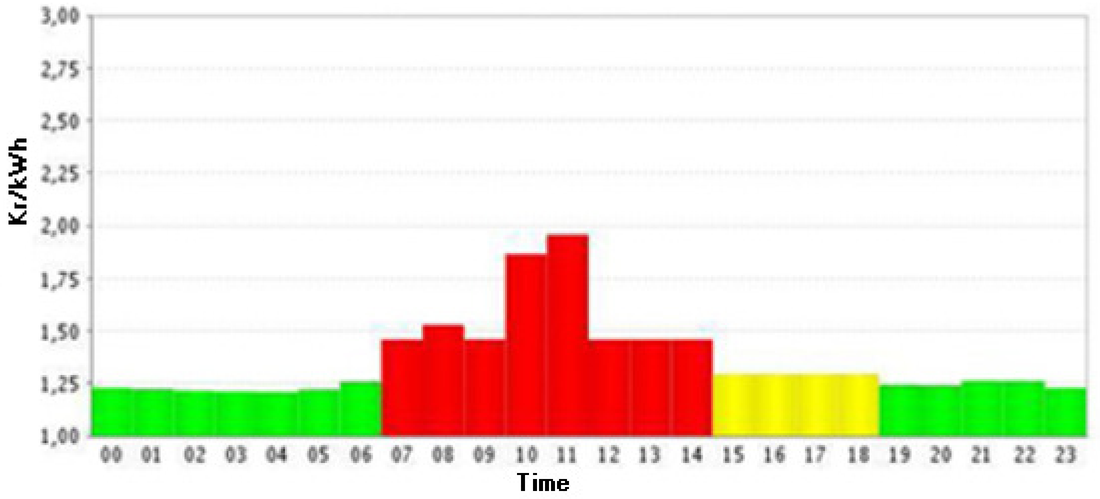

Figure 4.14. *The price information of 16.5.2007 for the customers during the pilot of demand response service. Red stands for high level prices, yellow for regular price level and green for low level prices. (Smart Regions 2011b)*

Trial results were that there were annual savings of 200-400 euros. These savings were mostly achieved with the automatic load control as the customers receiving only the price information did not have big benefits. Still it must be pointed out, that the high level of savings were mainly due to the new hourly spot price based electricity contract. In Denmark consumers commonly buy the electricity from the local power company with a price that is highly regulated by the authorities. During the study the spot price levels were significantly under the level of regulated prices. It was also emphasized that this trial showed the importance of the availability of technology for the load steering in addition to the price incentives. (Renner et al. 2011)

In Norway a demand response trial was carried out with 40 customers using water-borne space heating. The customers were offered a time-of-use distribution tariff that included two peak price periods. First one occurred in the morning between 8-10 a.m. and the second in the evening between 5-7 p.m. Also the peaks in spot prices can be expected to occur during the same period. Customers received a magnetic token that could be placed near to the domestic appliances to remind of the peak price hours.

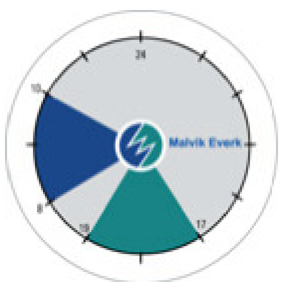

Figure 4.15. *The magnetic token to remind from the peak price hours. (Smart Regions 2011c)*

In addition to the time-of-use distribution tariff, the supplier offered the customers an electricity contract based on hourly spot prices. A needed installation for the remote load control of low-prioritized loads was also installed. This load control would be performed by the DSO according to the peak price hours of distribution tariff. In practice the low-prioritized loads were disconnected for the peak price periods. The load control is illustrated in the following figure. Blue line illustrates the load profile during the week and the purple line during the weekend. Grey area is a time period for the load control.

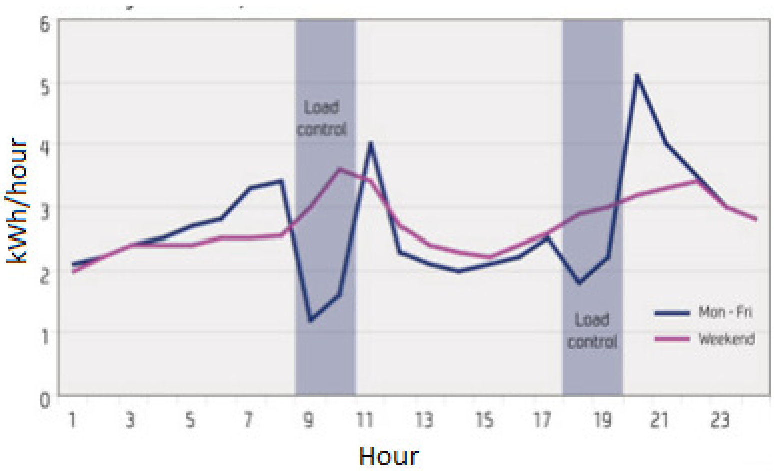

Figure 4.16. *The average load profile during the pilot. (Smart Regions 2011c)*

Customer response during the pilot was that they do care about their electricity consumption but personal economy has a higher value. Customers accepted the remote load control as long as it does not affect negatively their comfort of living. This pilot also demonstrate an easy way to inform the consumers of the high prices as the magnetic token illustrated when the high prices of both, the distribution tariff and the spot price contract would occur. As a result the peak power demand of the customers was decreased during the peak power hours without any distortion for the customers.

These are just examples of smart metering services. Numerous pilots about different kinds of feedback tools and dynamic tariffs have been made. Mostly the results have been encouraging as the customers have shown interest towards the services and the usage has in many cases resulted changes in the overall energy consumption and the peak power demand.

Still, it is not clear who offers the future demand response related services. Oksanen (2011) studied the subject by interviewing 25 specialists in Finland and Sweden. It was concluded that the roles of the DSOs, suppliers and third market parties need better definition. It could be good if market actors that need the regulation of the demand would offer the services. On the other hand, the regulation authorities in Finland and Sweden want to keep the role of the DSO as electricity transporter who does not benefit from extra services. This leads to the issue that it would be suppliers who offer the services. In this case there would be incentive conflicts between the DSOs and suppliers as described in the chapter 4.4. Again, it is important that the roles will be defined in order to enable the development of future services. (Oksanen 2011)

5 CUSTOMER PILOT OF HOME ENERGY MANAGEMENT SYSTEM

In this chapter the most important research methods and materials are introduced in detail. This chapter provides information that helps to evaluate the reliability of the results of this thesis work. The whole process of implementing the piloted HEMS-system from the pilot consumer choosing to the installations is introduced. The customer feedback was collected from the customers through interviews and the main results from these are also introduced in this chapter.

The main goals of this pilot were to learn more about the possibilities and requirements of HEMS while also evaluating the most potential functionalities of such systems. There was a need to study further the possibilities of energy efficiency services and the technological requirements. One target was also to evaluate the business potential of these kinds of services and the potential profits for different market actors. On the other hand it was also important to analyze the potential benefits for the consumers, like energy and money savings. Large electricity consumers in Finland are already offering their loads to be used in the electricity market, while private customers are not capable to actively participate the electricity market. This leads to another issue to be further studied during the pilot. It needed to be studied that in which way it could be possible to enable private customers to more actively participate the electricity markets and could the piloted system provide these possibilities in the future.

5.1 Background and the basic concept of the pilot

Technical description

Vattenfall Verkko Oy and There Corporation decided to implement a pilot study of Home Energy Management System, HEMS. There Corporation develops and produces programmes, devices and systems for energy efficiency management. There Corporation's role in this pilot was to deliver the required devices and systems and to offer technical support for issues concerning the functionalities of the pilot system.

The pilot started in June 2011 and was planned to run until the end of February 2012. Therefore it would be possible to have experiences of the winter time also, when the heating requires more energy. After this it would be evaluated that could the pilot be further developed.

The most essential single component in the pilot was the ThereGate-unit (later TG). The basic idea is that TG collects wirelessly data from the chosen metering devices and stores it. Monitoring of these measurements is done through a web-based user interface.

In practice, this monitoring can be made with any device equipped with an internet connection. This means laptops, PCs as well as modern cell phones. In this pilot the customers were provided with an iPad tablet computer for this purpose. The basic concept of TG based HEMS is illustrated in the following figure.

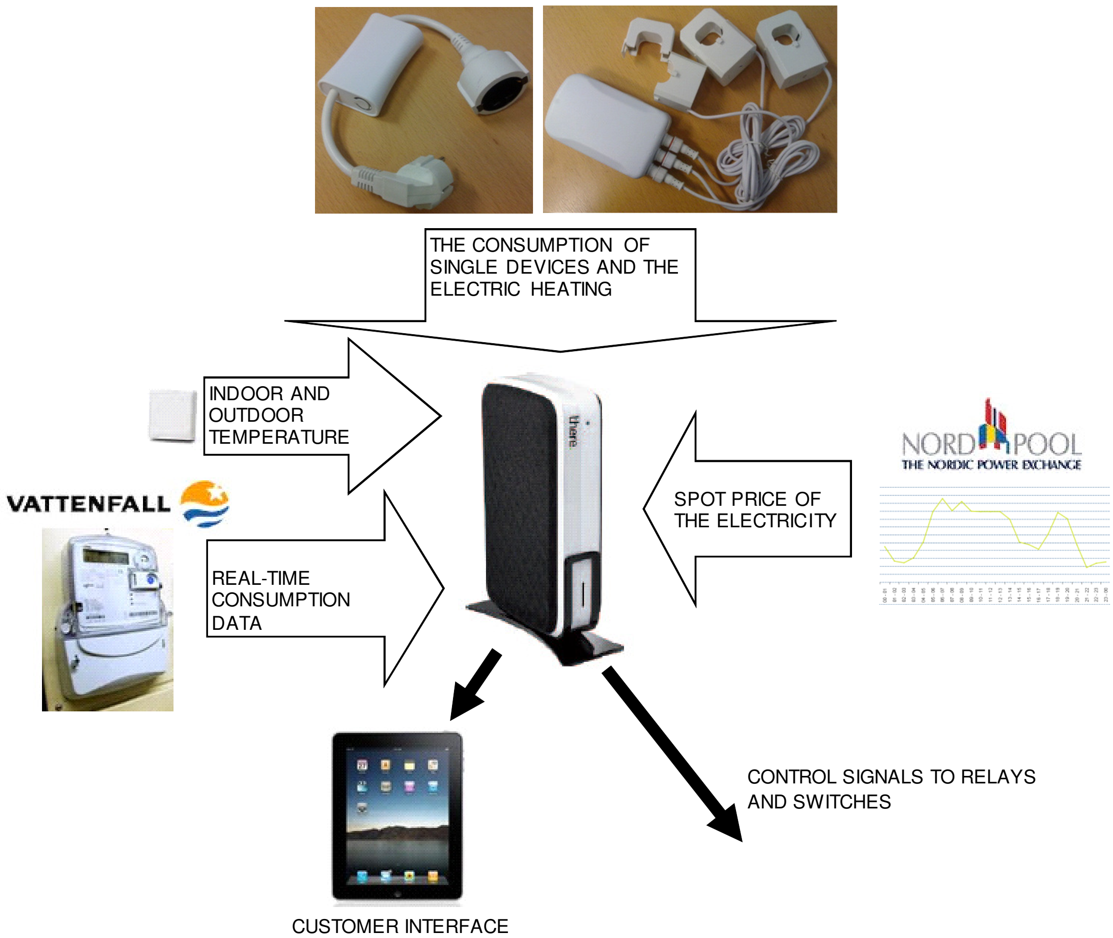

Figure 5.1. *The basic concept of the piloted HEMS-solution.*

The main data of the household's electricity consumption was red from the Vattenfall Verkko Oy's metering device and delivered to the TG. In this pilot the reading was made with led-sensor and the data was transmitted wirelessly to TG. Depending on the characteristics of a customer's house, it is also possible to add different types of sub meters. In this pilot it was desired to measure the power demand of the electric heating. For this reason, the sub meters were installed to the main cabinet to meter the consumption of the heating circuits. TG supports wide range of wireless meters, especially based on Z-wave, which is a wireless communications protocol designed for the home automation purposes and especially for remote control applications.

Also so called Smart Energy Switches (SES) were used. Smart Energy Switches are plug-in-meters placed to a socket and used as a sub meters to be able to meter a single device's or device group's consumption. SES also allows user to remotely switch off or on devices that are behind the meter by using the web-interface. SES also communicates by Z-wave protocol. The picture of the SES device is below.

Figure 5.2. *Smart Energy Switch.*

In addition, thermometers were used to meter the inside and outside temperature. Thermometers were installed to help the customers get a better understanding of how the outdoor temperature affects the heating energy demand and on the other hand, how the energy consumption could be reduced by lowering the indoor temperature.

Web-based user interface enables consumer to monitor energy consumption and to control devices. Energy consumption can be monitored almost in real-time, which is a major improvement compared to the situation where consumer gets the feedback from consumption only after couple of days. It was possible to monitor the consumption even with a one minute time scale and the delay was also minimal. This enabled consumer to try different methods to reduce energy consumption in order to improve the energy efficiency while the feedback was delivered without a time-delay. Consumptions can be monitored over a different time periods from last 10 minutes-view to last year-view.

TG-system used in the pilot enabled using of electricity spot-price based load control. TG receives the information of NordPool spot prices from the server and can use this information to steer loads that are under control. In this pilot the steering was used to electric heating and to hot water boiler. TG-system requires the desired amount of heating hours from the user and then directs the heating on during the cheapest spot price hours. The steering can be based only on the spot-price or the distribution fees can also be taken into account. During the pilot, it was not possible to offer hourly based energy contract to pilot customers so this steering did not produce any actual money savings.

TG-system used in the pilot can be described as a basic solution. There are a lot of possibilities how this system could be expanded and what kind of functionalities added. Security cameras, alarms and water consumption meters are just few examples of possible system expansions. Still, the main focus is at energy awareness, heating management and demand response.

Customer selection

It was decided that five households would be selected into the pilot. This set requirements for the customer selection, because it would be necessary to select motivated and truly interested people who would be willing to give feedback and actively use the system. So called forerunners were needed. On the other hand, the selected consumers should represent the different types of private consumers. Naturally there are also a lot of passive customers, but it would not have been practical to include that type of customer into a pilot of five customers. Additionally, there should be potential for the demand response purposes. Thus, four electrically heated houses were chosen and one using air-water-heat pump as a major heating method. Characteristic for these households were relatively high energy consumption in the past year, so it was estimated that there could be a big potential for more efficient energy use.

A total number of over 200 customers showed interest towards pilot. The consumer’s potential from the pilot point of view was evaluated first based on the information of the heating method and annual electric energy consumption while also the consumer’s distribution tariff was considered. The most potential customers were phone-interviewed shortly to evaluate the technical suitability. There were some major questions to be evaluated before the actual selection of the customers could be made.

The customers needed to have an own internet-connection to be used for pilot purposes. TG-unit must be connected to the router to be able to control it from wed-based user interface. TG-unit can also operate in 3G-network, but it was decided that it is out of the focus of this pilot. Additionally, the location of the electricity main cabinet needed to be examined. In practice, TG-unit would be installed next to the internet router, while the readings from the Vattenfall Verkko Oy’s metering device would be transmitted wirelessly, setting requirements for the distances between these devices. Thus, the smaller the distance between the main cabinet and the internet router would be, the better. The main cabinet can be located in various places. It can be installed inside the house, or to the outside wall or even into pole outside.

A number of other electricity usage related topics were also discussed. In a case of electrically heated house, it was interesting to know how big the house was and what kind of heaters were installed. Also the demand power of the water boiler was asked, because it could be used to spot-price based steering. It was also decided that the pilot focus would be on customers who don’t already have a home-automation system. Due to that, TG-system would bring more added value for consumers.

After the phone-interviews the most potential customers were sorted out. These households were visited personally to confirm the information provided by interviews and to get a clearer picture of the characteristics of the house. All the distances between the devices that would potentially be metered needed to be estimated. Again, this is because all the metering data would be transmitted wirelessly. Likewise, the construction material used to the building, especially walls, could affect the signals.

As mentioned, it was planned to install sub meters to measure the consumption of the heating circuits. The amount of required free space in the main cabinet varies depending on the sub meter device. In addition, the wireless transmitters need to have a power source and if a socket for this purpose was not originally available it needed to be installed inside to the main cabinet or at least near to it. As well as the location of the main cabinet varies also the type of it can be very different. Old houses have a main cabinet with plug fuses while new houses are provided with main cabinet using MCBs (Miniature Circuit Breaker). These differences between different types of main cabinets set challenges for the installer. Therefore, also the main cabinet needed to be evaluated and documented.

5.2 Installations and functionalities

After the phone-interviews and household reviews five pilot customers were chosen. Hence, the installations needed to be planned and the devices to be chosen. By planning and discussing the possible problems beforehand the unnecessary failures during the actual installations could be avoided. This was important also because the installations would be made during the working day and consumers would possibly have a tight time-schedule of their own.

The most important task was to evaluate the need for different components and what kind of sub meter should be used in a certain main cabinet. Different meter types require different amount of free space in the main cabinet and in the DIN-rail. It is also important to know how different circuits are placed in the main cabinet. For example if it is desired to meter some 3-phased load it eases the installations if the circuits are placed closed each other. The problem is that even if it is possible to see the electrical diagram of the main cabinet, the actual situation can be seen not until installer opens the main cabinet and actually becomes aware of how the different circuits and wires are placed. So in practice, the installer needs to have different types of meters ready to be used.

Actual installations are being discussed next. Installations were carried out by two persons. Electrician was needed to install the sub meters into the main cabinet while the second person was able to pair the wireless devices into TG-system and initialize the HEMS-system. However, the need for two persons raises the level of installer costs, even if making the installations process faster. The pairing of the meters in to TG-system means that the TG-unit needed to form a connection to each wireless meter and therefore recognize the devices from where the data should be received. There were some minor difficulties in this process, but it can be estimated that not more than with any wireless devices. Also, the pairing of the devices could be done beforehand, so that the device package would be completely ready in the time of the actual installations. This would also probably remove the need for two installers.

The readings from the Vattenfall Verkko Oy's metering device were collected with a led-sensor. This sensor reads the blinking led-light on the top of the metering device. The blinking light reflects the energy consumption. There is a certain pulse constant that tells how many light impulses correspond to certain energy consumption. In this case the constant was 1000 pulses/kWh. Depending on the metering device there could actually be two blinking lights. One light is for the active power and second one for the reactive power. This is a situation with the metering device installed after 2007. One thing that needed to be considered was the possible interruption caused to the led-sensor by these lights. It was desired to measure the active power and it was estimated that the other led light could add some interference to the measurement. Finally, this was solved by programming off the reactive power led-light. Once the led-sensors were installed it was also noticed that in some cases the led-sensor was interrupted by the light of the surroundings. This means regular light-bulbs used in the room where the main cabinet was located. These problems were solved by blocking the light of getting into led-sensor.

In some cases the most suitable sub meter for the heating circuits metering was the one with current transformers, sometimes called clamp-meters. This means that the wires of the desired heating circuits were placed to run through a coil-sensor. It was noticed that this type of meters can be interrupted by the surrounding loaded wires. This is because of the magnetic field that the current causes. Still, this can be avoided by using only reliable meters which are accurate enough. On the below is a picture of a clamp-meter that was used in the pilot.

Figure 5.3. *Clamp meter.*

In two households the spot-price based load control was implemented. Both of the households were already using the night-time-tariff, which means that the water boilers and the storage electrical heating were steered on during the night-time. In the pilot this steering was replaced by the TG-systems own steering algorithm. This was implemented by installing wireless relays into the main cabinet that would get the steering signals from the system. In addition to the spot-price based steering, it is also possible to switch the relays on and off manually from the system. This could be useful in a case of the failure in the spot-price based steering.

As earlier mentioned the customers were also provided with a so called SES. This combination of an energy meter and a remote switch allows not only monitoring of the energy consumption but also the remote control of a desired device. For example in one household it was used for air-conditioning device that was located in a place that was not easily reachable. The picture of Aeon Lab's Smart Energy Switch was presented earlier.

As a result the measurements and functionalities introduced in the table 5.1 were installed to the five pilot customers. As it can be seen, there were some differences in the functionalities due to differences in heating solutions and the technical limitations. Table 5.2 introduces the background information of the piloted households.

Table 5.1. *The functionalities in the piloted households.*

	Customer 1	Customer 2	Customer 3	Customer 4	Customer 5
Real-time energy consumption measurement	x	x	x	x	x
Sub meter for heating circuits	x	x		x	x
Sub meter for water boiler	x	x			x
Sub meter for heat pump			x		
Spot-price steering for electrical heating	x	x			
Spot-price steering for water boiler	x	x			
Plug-in-meter (for example for airconditioning device or consumer electronics)	x	x	x	x	x
Thermo meter for outside temperature	x	x	x	x	x
Thermo meter for indoor temperature	x	x	x	x	x

Table 5.2. *Background information of the piloted households.*

	Customer1	Customer2	Customer3	Customer4	Customer5
Annual electricity consumption (MWh)	26.9	31.9	28.8	23.7	25.8
Primary heating method	res.electric heating	res. electric heating	air-water-heat pump	dir. electric heating	res.electric heating
Secondary heating method	no	dir.electric heating	no	fireplace	heat pump, fireplace
Heat pump	no	yes	yes	no	yes
Electric sauna (P)	yes, 6 kW	yes, 8 kW	yes, 12 kW	no	no
Fireplace	yes	yes	yes	yes	yes
Hot water boiler (l)	500	300	Air-water-heat pump	200	300

As earlier mentioned the monitoring of the measurements is done by web-based user-interface. The start-up menu is illustrated in the figure 5.4 on the right hand side. There were actually two different user interfaces that were designed for slightly different purposes. The main user interface provides more information and access to system configurations while also being more complex. Widget version is more simple and suitable for cell phone browsing while providing all the most important information in a compact way. Widget version is also illustrated in the figure 5.4, but on the left hand side. Finally, figure 5.5 illustrates the overall electricity consumption of one household during the last 10 minutes.

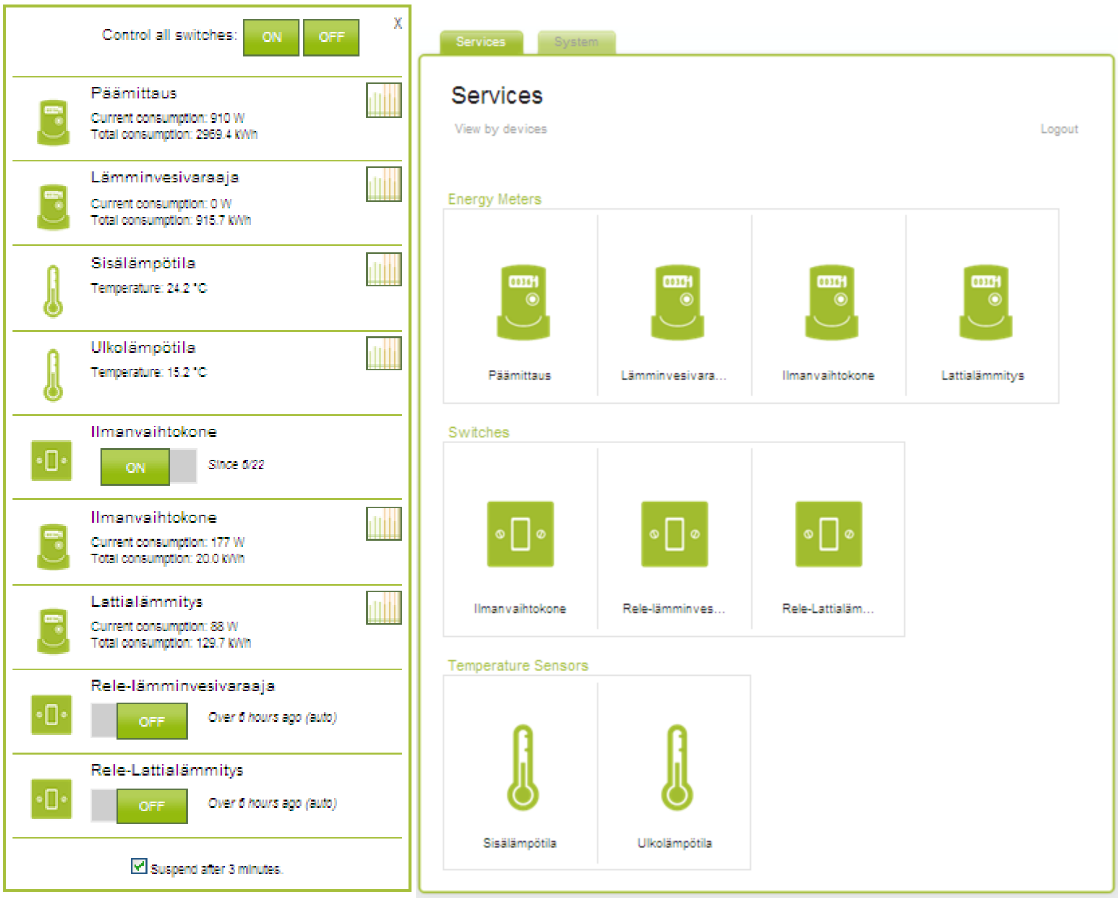

Figure 5.4. *The widget- and the main user interface*

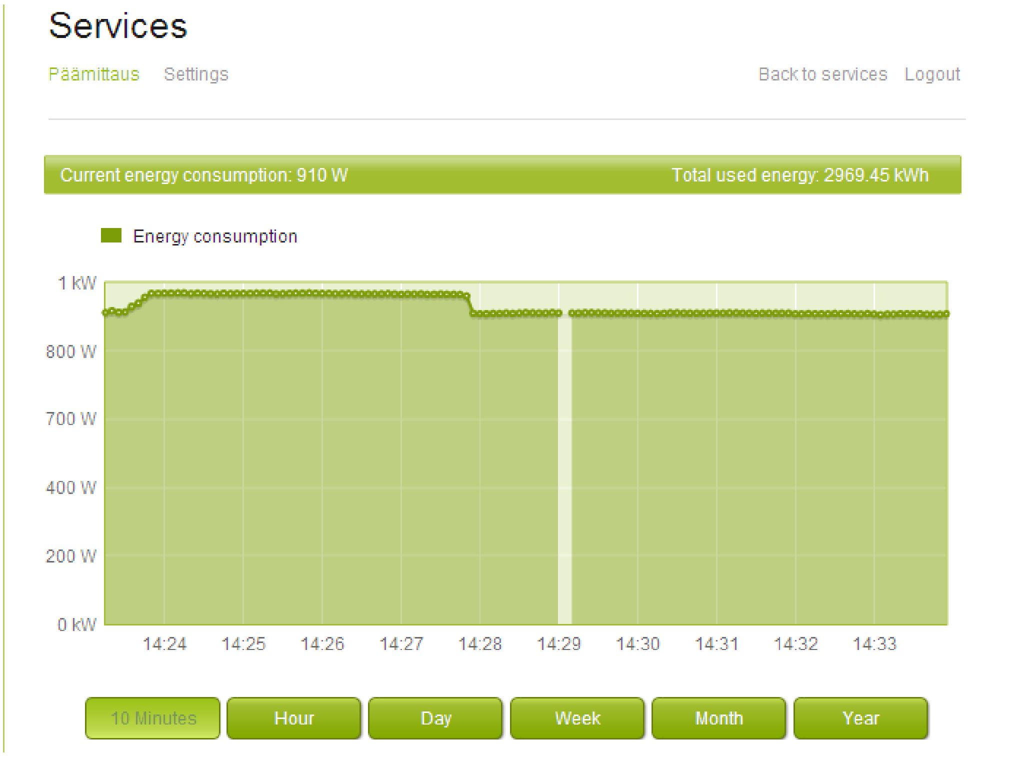

Figure 5.5. *The real-time main consumption data.*

During the pilot a technical support regarding technical issues was provided to consumers. All the issues were documented to be later evaluated. Above all, a pilot study is a learning process that should bring out the possible technical problems and malfunctions that need to be solved before the possible larger scale installations.

5.3 Customer response

Customer feedback was collected by interviews during the pilot study. Questions used in interviews were divided into six groups. After the basic background information were asked there was a couple of questions about the energy efficiency targets of EU and the reasons behind the pilot study. Next, the pilot customers were interviewed about the use of ThereGate-system and the benefits they felt to have achieved. There was also a discussion about how much they would be ready to invest into these kinds of systems and how they felt about hourly electricity prices. The customer interviews were completed at the beginning of October.

With the background questions it was intended to get the basic information of the five pilot customers and about their opinions and knowledge about efficient energy usage. One customer was born in the late 1930s, one in the 1950s, two in the late 1960s and one in the late 1970s. Four of them had a technical education.

All the pilot customers had a good understanding of their annual electric energy consumption as they were able to estimate their annual energy consumption rate. Most of the customers thought that there is enough information available of what would be the reasonable level of energy consumption in a household size of their own. Still it was pointed out that the information is often in a too general level, thus it cannot be used and that there would be a need for extremely neutral information "where would not be an advertisement of an electric company next to it".

Question concerning their energy saving potential was generally hard for customers. They thought it is hard to estimate or did not have thought about it. Customers believed that there could be some savings made by more efficient consumption behavior, but did not generally have any precise actions in their mind. Although some of the customers would be willing to take some actions if someone would inform them of some concrete actions. However, one of the customers had calculated that it could be possible to have the energy consumption cut by almost 20% by changing the windows and renewing the house insulations. When asked about the energy saving actions done within last three years, four of the customers had done something. Two customers had bought a heat pump. One said that he had changed the light bulbs into energy saving ones and one said to have improved the overall consumption behavior. One customer said that he had not done anything special to be more energy efficient.

All of the customers said that they highly value efficient energy usage and do not want to be "energy wasters". One also pointed out that the high price of electricity makes sure that the electrical energy is highly valued. Still, it was also pointed out that naturally there is a limit also for energy efficiency and that it should not interrupt too much the comfort of living. Money was a number one incentive towards saving of energy, while it was also concluded that the energy should not be wasted.

When asked if the customers are familiar with the EU targets about energy saving or the so called 20-20-20-target four of the customers said they did not have information on those. One of the customers knew the targets very closely. When asked that what thoughts they had about the incentives behind the pilot and that distribution system operator is interested about the energy efficiency of their customers there was quite similar answers. Two of the customers suggested that the DSOs would be willing to cut the power peaks and to direct customers to use devices more in different times. Two of the customers said that the company wants to get imago benefits and lead the technical development. One said that it is extremely positive that the DSO is interested of the customer and willing to find ways that would benefit both, the DSO and the customers.

Next questions were about the usage of TG-system. Three customers said they had used the pilot system two or three times a week. Two customers said to had used it weekly. All of the customers said that especially the energy consumption of the hot water boilers and electrical heating was interesting so they estimated that the user activity could rise when the heating period gets properly started.

The customers had multiple ideas on their mind when asked whether the metering data was presented clearly and the amount and presentation method of the information suitable. One customer said that it would be useful to have daily readings of the electricity consumption in addition to the graphical presentation. Three of the customers said that it would be beneficial to have the opportunity to download the consumption data from the system to be able to produce own analysis with a help of computer software like Excel. There was also need to combine multiple graphs into one. In addition the customers hoped for better possibilities to have more precise data when using a longer time periods for analysis. Now for example in one month-mode the system provided only average consumptions over six hours. One of the customers also pointed out that there should be an possibility to highlight a certain time period and system would provide the energy consumption and the cost of energy during that period. He continued that it would also be good if the consumption consumed during the highest electricity prices would be expressed with a certain color. In addition, he said that it would be interesting to see easily that what were the hourly prices of electricity when the electric heating or the hot water boiler was switched on by the system.

Customers were asked if the separate monitor (iPad2) made the using of the system more easy and affected the user activity level. Four customers believed that the activity level had increased and the using was more easy with the possibility to use separate monitor for the purpose. Only one did not believe that it would have increased the usage level. Still, he also added that had only used the system with the iPad.

When asked whether they had used the widget or the regular user-interface, the answers were quite similar. Four customers had used only widget, because they felt it was easier and simpler. One of the customers continued that the regular interface was “scary, because it looked like you could do some damage in the system configurations”. Still, one of the customers said that the regular interface was the simple one and that widget interface was complicated. Only one of the customers said to have used the opportunity of remote access, meaning the possibility to use the system outside home. There was also second one, that could use remote access in the future.

All the pilot customers concluded that in general level the usage of the pilot system was easy and comfortable. One customer added that if the system language would remain English, the term choices should be reviewed. Some of the terms were inconvenient and did not provide clear information of it’s functionality.

All the customers were familiar with the OnLine-service provided by Vattenfall to be used for energy consumption monitoring purposes. Only one of the customers did not have used it, because he though it was hard-looking. Four of the customers though that the pilot system brought clear additional value compared to OnLine-service. It provided clear and real-time information of the consumptions that especially help to better understand the consumption behavior of the household and to recognize the “extra” energy usage. It was also pointed out that the separate monitoring device made the user experience more easy. Still, one of the customers suggested that the interest towards the system would decrease by time while at the beginning it would be interesting to find out the consumption levels of the domestic appliances.

Customers were mostly satisfied with the number of devices that were under monitoring. Three of the customers would like to have also the heat pump under a sub meter. The biggest interest from the customers was towards the electric heating that was already under monitoring.

Customers did not have a clear idea of what kind of energy efficiency benefits they could achieve with the real-time consumption information from the pilot system. However, three of the customers estimated that it would help to adjust the consumption behavior in long run. One customer said that he cannot estimate the matter and second said that he does not believe in benefits from the information.

At the beginning of the pilot, the customers were provided with a check-list that introduced possible energy saving actions in a household. Four of the customers did not red the list and one said that the actions were already familiar to him. At least at the time of the interviews none of the pilot customers had took some special energy saving actions.

All of the customers said that the pilot system helped to better understand the households energy consumption. One customer added that “the pilot system also had risen a general interest towards energy usage and made him really think of his consumption habits”. The customers told that especially the energy consumption of the electric heating and hot water boiler were not clear at all to them. So this can be put in a way that, the consumers does not understand maybe the most important and central part of their household energy consumption, electric heating.

When asked if the pilot customers would be willing to invest 1000 euros for the pilot like system if it could be possible to achieve energy savings up to 10% all of the customers were ready to invest. Still, this means that the customers should be “convinced” that this amount of savings would truly occur. General opinion was that repayment period of 3-4 years or even longer would not be problematic in a case of system like this. One customer added that energy companies should have to take responsibility if the promised or estimated savings would not occur. The energy company should compensate the difference between the promised and realized energy savings after a certain period. This would naturally be extremely difficult to implement because the savings level from the system is higly related to the activity level of the consumer. When asked that how highly they appreciate the real-time energy consumption, the feedback was mostly that it is not worth of great amount of money. As one customer put it “I would not pay tens of euros per month just for the real-time consumption information”.

When asked about the stance towards dynamic price rates the answers were quite similar. All the customers except one said that they would be ready to do at least some changes in their consumption behavior according to the price of electricity. One customer who was not willing to do actions according to changing price rates added that it would take serious differences in the prices if he would do some changes as it is hard for the family with children to adjust certain household operations. He said that this kind of adjustment should be totally automatic and it should not require any actions from the resident. It was also pointed out that the adjustment operations cannot interrupt too heavily the comfort level of life. One of the customers was already using some of the domestic appliances such dishwasher and washing machine during the lower night-time-tariff. Second one immediately suggested that he could be ready to burn wood during the peak price hours to avoid using electric heating. Customers are not willing to spend too much time comparing electricity price levels and planning the operations according to them every day. Two of the customers were already retired and they were willing to take some effort to adjust the household tasks in order to benefit from it. As one customer put it “As a retired person I have time and urge to take some actions to achieve the more efficient energy usage and savings”.

Customers were also asked if they were ready to change the time of use for sauna if the cost for one sauna visit would be halved when changing it. The most common answer was that sauna is used when it is used even if it would cost two times more than a little bit later or earlier. When asked that how much in advantage the customers would need the price information, two of the customers said that it would be enough to get the price signal the day before. One said that it should be delivered couple of days in advantage and one said that the time depends on the overall situation with weather and so on. Sometimes the day before would be enough but sometimes there would be a need for more time to plan for example the using wood instead of electric heating during the price peak hours.

To get more information on the customers’ stance towards the HEMS-related issues, a customer survey was implemented among the customers who were interested of participating the HEMS-pilot but were not selected. A total of number of 187 answers were received. The summary of the survey can be found from the appendixes. When viewing and analyzing the results it must be noted that these consumers were interested of the HEMS-pilot and therefore they have potentially higher level of interest towards energy efficiency and maybe for new technology than average people. In this work, the results from the customer survey are mostly discussed in the chapter of market potential for HEMS.

6 EVALUATION OF THE HEMS-CONCEPT

In this work a HEMS is a system that enables real-time consumption monitoring and customers' self-imposed actions to adjust the electricity consumption by utilizing added home-automation. HEMS-solution provides tools for managing the household's energy consumption in order to achieve more cost-efficient energy usage. On the other hand, HEMS could also provide load control possibilities for market actors. Parkkinen & Järventausta (2011) carried out a survey to find out the overall opinion about the future development of smart grids and energy markets among the people working in energy sector. The HEMS-concept was among the issues. The general opinion was that some kind of HEMS-solution could be installed to 20 % of the private homes by the end of 2010s. It was estimated that by that time the private customers could receive economical benefits from the demand response actions. In practice, this would mean that after the full implementation of smart meters and hourly balance settlement, this kind of concept would become lucrative, first most likely among the customers using electric heating or having some other loads, like heat pump, that could be steered.

HEMS-pilot enabled to recognize some potential customer needs that should be considered when designing future home energy management systems. These are discussed in the chapter 6.1. Chapter 6.2 evaluates the benefits that HEMS could bring to the customers and includes calculation of how big savings could be possible to achieve by steering the electric heating based on the market prices of electricity. The following chapters provide an evaluation of some of the potential possibilities for the suppliers and for the DSOs around HEMS-solution. These benefits are mostly related to the possibility to include load steering to the HEMS-solution that could be done according to the needs of a market actor. In this chapter the preliminary market potential for the HEMS is also discussed mostly based on the results from the customer survey. Finally, some of the different possible operation models around HEMS are briefly introduced.

6.1 Customer point of view

The most important objective for the HEMS is to enable the more efficient energy usage for the consumer. Therefore it is important to define the needs of the consumers regarding the future solutions. In this chapter the customer needs regarding HEMS are discussed and the amount of benefits is evaluated.

6.1.1 Customer needs for HEMS

In this chapter the needs concerning the home energy management systems are discussed from the customer point of view. The evaluation is mostly based on the discussions and interviews with the customers during the pilot. When it comes to the functionalities of HEMS it can be said that the needs are very different among different types of customers. According to the customer interviews the evaluation is still possible to be made that what kind of functionalities were seen as highly important parts of HEMS and what kind of functionalities were not given that much of a value and can be regarded as secondary functions. At the end of the chapter there is a sum up for the most important issues that needs to be taken into consideration when designing the future HEMS. After all, it is necessary to design the HEMSs in a way that fills the customer needs and provides true value. Only then they would be willing to make possible investments for such systems and use them actively which would not only benefit themselves, but ultimately contribute also to the functionality of the electricity market and the goals for improved energy efficiency. Naturally the customers can benefit also indirectly from the HEMS-solutions if for example the suppliers will start to develop demand response products that compensate customers that are willing to participate in load control.

The first issue that aroused during the discussions was the significant need for extra information about the issues around the pilot. It is essential that consumers' awareness of the need and significance of demand response and electricity market operations would be increased. This would help the consumers to understand how they could use the loads of their household to improve their energy efficiency and benefit from the steering of them in the future, ultimately contributing to the better functionality of the electricity market and the power system. Currently the private consumers are just getting used to the electric bills that are based on the actual consumption. Some of the consumers are not happy with the fact that now their electricity bill varies according to the time of year, instead of receiving more equal bills during the year. This is also the reason why these kinds of pilots are important. To let the people know about the future development plans of the electricity markets. It would just be important to somehow spread the information of these subjects and future opportunities for the big public.

Already during the pilot interviews customers' response towards demand response related matters changed to more positive stance once the issues were properly explained to them. While the consumers do not have enough information about the electricity markets or even about their own electricity consumption it is hard for them to describe what would be their needs concerning HEMS and to understand in which ways they would possibly benefit from it. At this point it can be pointed out that for example in the larger customer survey 69 % answered that they do not have an opinion on whether they would be interested of hourly priced electricity and felt they need to have more information first, while only 18 % answered that they would not be interested.

One good example of this is that none of the pilot customers were aware of how much electricity the hot water boiler and the electric heating are consuming. This leads to a fact that if the customers don't know the consumption of those devices and how the power demand is timely spread, they can't be aware of how to benefit for example for the more intelligent steering combined with hourly based tariffs. This information would have been possible for the customers to estimate from the hourly consumption data provided by Vattenfall Verkko Oy's OnLine-service, but seemingly it was either too challenging or the subject had not been meaningful enough. Still, all the customers told that acquiring this information had been one of the major benefits during the pilot.

As mentioned earlier the dynamic electricity contract is a prerequisite for the savings that can be achieved by shifting the electricity consumption to a different time of the day. Spot price based contracts are quite common in Norway and Sweden, but most of the contracts are based on monthly average prices that again does not give economical incentives for the customers to shift the consumption. (Bröckl et al. 2011) In Finland even the monthly price based of contracts are rare. The possibility for hourly electricity pricing is a one issue in particular for which customers should be informed effectively. Naturally some of the customers are ultimately happy with a stable and predictable electricity prices and would not even consider switching to hourly based contract even if the saving potential would be demonstrated to them. Still, there would be also consumers that would be interested of the potential saving opportunities with more dynamic electricity contract.

Hourly varying price of electricity does not sound as a very simple thing at first which came up also in the interviews. Because there is not enough knowledge about the functionality of electricity markets there is no knowledge of how the prices generally vary according to the time of the day and what causes the fluctuation. This means that there is sometimes a misunderstanding that the electricity prices would fluctuate somehow without any logic and that it is not possible to predict the hours when the prices are high. This naturally leads the customers to think that they would not be ready to daily make totally new usage plans for domestic appliances. For example in the pilot that was discussed in the chapter 4.6 a simple magnetic token was used to remind the customers for the high prices of the distribution tariff and the expected high level of the spot price.

Customers should be informed that the price fluctuations within a day generally follow a same pattern as there are peak periods in the price in the morning and second in the evening. Also, almost all households have similar domestic appliances that use relatively high amount of electrical energy. These are for example dishwasher, washing machine and electric sauna. So basically if the usages of the high consuming devices are mostly limited to the hours outside these most potential high price hours, in the limits of personal possibilities, the worst price risk can be avoided. Naturally there can be some price peaks outside the regular ones but the customers can be informed about these beforehand. Briefly, customers do not need to generate new "consumption plan" every day, but rather adjust their consumption routines in a new way and follow the new routines as effectively as possible. HEMS-solution could be used to inform for the peak price hours that are either extremely high or occur on the time of the day that was not expected.

Great deal of consumers know that there could be some general improvements made in their consumption habits, but too often it stays on that general level. Consumers need clear and easily understandable incentives for energy efficiency actions and the information of real, actual and concrete measures that could be performed in order to get the desired energy savings and achieve more efficient energy consumption behavior. These combined with a HEMS would potentially bring results. Still, it must be pointed out that for example the pilot customers did not use this kind of information that was provided to them in the beginning of the pilot in a form of a info letter.

A separate display (iPad) was regarded as a useful part of the HEMS that made the usage easier and lowered the level for entering the user interface. Therefore it also raised the customers' activity level. The overall opinion was that the pilot system was also easy to use by one's own PC, but it was good to have a separate display only for this specific purpose. This kind of easily handheld device also makes it easier to study the consumption of different domestic appliances as you can carry it with you during the trials. It needs to be pointed out that in the pilot system the price of the display was approximately half of the costs of the HEMS-solution. The smart phones with large displays are becoming more in common very fast. Also the consumer that buys one usually combine it with a mobile internet connection. Among the pilot customers these phones did not exist, but in the future the need for separate display will most likely decrease. The displays are large enough so that the usage of the HEMS-solutions is comfortable with them and also the speed of mobile internet connection is not a problem. This can be seen as a benefit when considering the market potential for the future HEMS as the investment costs decrease when there is not necessarily a need for a separate display unit. Still, the influence of real-time consumption information on the consumption behavior is also strongly based on the effects that come when the consumption level or reading is always visible and reminding about the consumption level. This would mean a separate in-home display. In the piloted HEMS the reading was still behind a login to the system, even though separate display (iPad) made the usage as easy as possible.

According to the interviews the most interesting devices for the consumption monitoring were the electric heating and the hot water boiler. In the households where there was also a heat-pump it was told that it would have been also interesting to follow. Added to these, there were actually no more highly interesting devices from the customer's point of view. Basically this means, that maximum of one plug-in-meter to be used for monitoring of the consumption of single devices is probably enough. This does not mean that there should not be for example plug-in-switches, controlled with HEMS. These are cheaper and if used efficiently they could provide an easy way to control device groups and switch of unnecessary consumption. For example all of the household's appliances that are connected to the wall socket could be equipped with a simple switch and therefore switched off simultaneously when leaving the house. This would for example cut off the stand-by consumption of the devices. But if considering only the consumption monitoring, there could not be a need for continuous monitoring of smaller devices.

The automatic spot price based steering of electric heating was regarded as a highly positive part of the HEMS. This is easily believable as the steering did not require any actions from the customer and it did not affect the comfort of living. In addition it would enable the savings when combined with hourly electricity price, which are discussed in the next chapter.

Customer response on the user interface was mostly positive. The usage was seen as relatively easy and basically there was only differences in which one of the user interfaces the customers were favoring. There were different reasons behind the selection of the preferred user interface which shows that there is differences that what kind of information is needed, how specific it should be and in what form. Due to this, the customers should have a possibility to personalize the user interface in the future HEMS. This means that they would be able choose whether the consumption is shown numerally or in graphical way and for example what kind of information should be shown immediately in the start up view.

One thing that occurred during the interviews was the need to be informed and alerted of the high prices in case of spot price based electricity contract. This might be one of the most important parts of the future HEMS and, if designed properly, might increase the level of interest towards hourly based electricity contracts. There are many possibilities to implement this. The HEMS used in the pilot was capable of sending e-mails or text messages to inform about the exceptionally high spot-prices. Because there were no hourly based contracts in use, this function was not tested during the pilot and the customer response is not available for this matter. But one option could be that the customers have a solution like the magnetic token to remind of the potential high prices and the HEMS-solution would alarm about the unexpectedly high price rates and if they occur outside the expected hours. In the future if the distribution tariffs would be based more on the peak power demand, the customers could benefit from the alerts about the high power consumption.

Some of the pilot customers felt that they should have a possibility to download for example the consumption data of the electric heating for the purpose of self-made analysis. This is also possible with the present internet service provided by the DSO if the need concerns total hourly consumption data of the household and not for example data with a 15-minute time interval. The downloading of the consumption data was also possible through a user interface, but it was still under development and thus used only to acquire the consumption data for example for the analysis of this thesis work. So if there seems to be general need for the download possibility it should not be hard to be implemented in a user-friendly way.

6.1.2 Benefits for the customers

Two major things must be evaluated when considering the benefits that customers would potentially acquire by using HEMS that enables more accurate consumption monitoring and the steering of electric heating. Firstly, the more accurate consumption monitoring gives a better understanding of the household's energy consumption and if the customer is actively using this information the economical benefits can be achieved through more reasonable electricity consumption. Second thing is the economical benefit achieved by the automatic steering of electric heating. The savings from the steering are depended on the fluctuation of the market price. When steering the reserving electric heating the difference in spot price between the 10 p.m. and the later nigh-time is a determinative issue. In Finland the night-time tariffs have already shifted big amount of electric heating to the night-time and to cheaper hours which limits the economic benefits of steering it to more later night and to most cheapest hours. The steering of direct electric heating could be based on avoiding the morning hours of 8-10 a.m. and the evening hours 5-7 p.m. when the peak prices commonly occur. In the following evaluations it has been assumed that customers would have hourly spot price based electricity contracts.

The estimates of the savings that can be achieved with the real-time and more device specific consumption information vary. Studies have shown that the in-home-displays can enable energy savings of averagely seven percent. Still, there are variations in these estimates and the energy saving levels varies between 3-13 percents. (Similä & Pihala, 2010) It is clear that to get for example the savings of 10 percent the customer must be very active in using the information to reduce the electricity consumption. Passive monitoring of the more specific consumption information naturally does not bring benefits, excluding the higher understanding of household's energy consumption.

The usage of this more accurate information is not always clear. Maybe the most valuable information is that how the single devices consumption affects the whole household's energy consumption and simply that how much energy single devices consume. With the system it would be relatively easy to learn the consumption rates of all household devices that could afterwards motivate to avoid unnecessary usage. It would probably be even more motivational if the energy consumption is transformed to money. Everyone does not necessarily understand kilowatt hours that well, but everyone understands euros. Finally, HEMS and more specific consumption information can help to maintain the new more efficient electricity usage by for example enabling consumer to set goals for the decreasing of the electricity consumption.

Generally the possibility to monitor the electricity consumption of the electric heating was seen as a major benefit during the pilot. As mentioned previously in the text, the consumption rate of the heating was not clear at all. This information was more interesting for the customers with the spot price based steering as it was easy to follow-up that the steering was working correctly and electric heating was operating. Also if there would have been hourly based electricity contract this would have given the incentive to verify the correct functioning of the steering as it would have been possible to compare the spot-prices to the consumption data and see if the lowest market prices and heating hours were actually matching. In other words, this would increase the level of transparency and customers confident for the spot-price based steering. On the other hand for the customers that were not equipped with the spot-price based steering this information would only increase the overall knowledge of the household's energy consumption. Maybe with the direct electric heating it would make the customer to re-evaluate the needed temperatures in the different parts of the house as it would be noticed how much energy the heating is consuming.

Still, the pilot customers were not actively utilizing the real-time consumption data and their general opinion was that the utilization is not straightforward. There would have been probably more incentives if the customers would have had hourly electricity contract. Customers were also provided with a check-list on the actions that every regular household can perform to achieve more efficient use of electricity. Most of the customers did not exploit this list or thought it was information they already knew.

Currently some DSOs provide possibility to use internet services to monitor the hourly electricity consumption. These services are cost free but the consumption data can be monitored only couple of days after the actual consumption and naturally there is only a possibility to monitor the overall consumption. It is relatively easy to monitor the consumption rates of large consuming devices like electric sauna, but it is more challenging to recognize the effect of smaller devices from the overall electric consumption data. Also the energy consumption of reserving electric heating can be estimated from the overall consumption data as there is usually not much other electricity consumption during the night-time. With the direct electric heating the case is different as the electric heaters are on and off over a whole day steered by the thermostats. It is challenging to recognize the consumption during the daytime when there is commonly also other consumption.

The pilot customers did put value on the real-time monitoring of the consumption, but it was mentioned that they would not be ready to pay tens of euros per month just for that. Also the results from the customer survey support this as 83 % of the respondents felt they have a need for a real-time consumption data, but 77 % of those would not be ready to pay anything for the information. HEMS can provide possibility to monitor more device specific and real-time consumption monitoring compared to the internet services of DSOs, but those are probably the main benefits. All kinds of reports and analyses can be basically done also with an internet service.

One of the pilot study's objectives was to evaluate that if the customers would have an electricity contract based on hourly spot-prices, how big savings the steering of reserving electric heating and hot water boiler would enable. As earlier mentioned there were two customers equipped with the steering. Customer1 had a hot water boiler with a power demand of 6 kW and also the house's floor heating behind the steering. The peak demand power of the floor heating was 2.8 kW during October and approximately 9 kW in November. This would give a total of 15 kW of peak power under steering. Customer2 had the hot water boiler with a power demand of 3 kW continuously behind the steering. This steering was operating since the end of September. This means that only the metering data from the October was available from this customer. Also the floor heating with a peak demand power of 2.5 kW (October) was enabled for steering but it was decided during the pilot that it would not be steered.

The following two figures illustrate the effects of market price based steering of electric heating on the households consumption profile and how the consumption is timely spread compared to the market prices of electricity. The figures illustrate metered consumptions of the Customer1 from January and October. In January there was no steering, but October was during the pilot and the steering was operating.

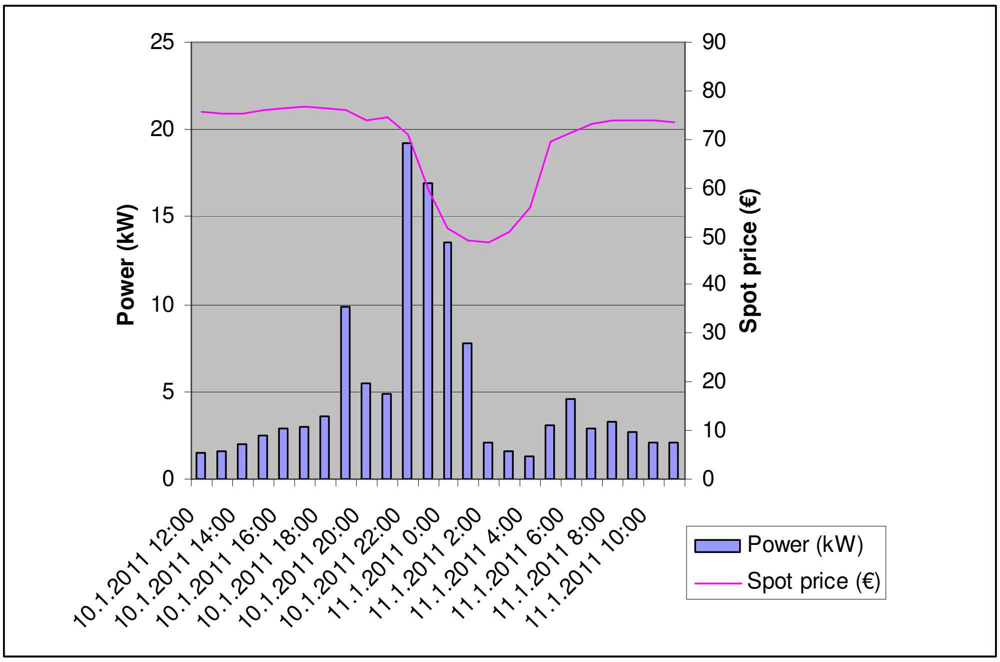

Figure 6.1. *Electricity consumption of the Customer1 in January and the spot price for Finland region.*

The figure 6.1 shows a typical load profile from January as the peak power demand has emerged after the 10 p.m. When considering market prices this is not the optimal time for the peak power as the price of electricity is only starting to decrease after 10 p.m. In this case there has been no peak price in the evening around 8 p.m. that is the common situation. With hourly based electricity contract the most profitable hours for electric heating would have been the hours from 1 a.m. to 4 a.m.

The figure 6.2 shows how the peak power demand is now shifted to the cheapest hourly prices. During this one night the price difference between 10 p.m. and later night has not been significant. To be accurate it can be seen that the cheapest hours are not fully utilized. This is because the steering algorithm operates on the basis that the need for electric heating is five hours, that was given as an input to the system. The algorithm therefore finds the cheapest time for this number of heating hours. In this case the needed electrical energy for heating was consumed with less than three hours and the fourth and fifth hours were not needed, while the fourth one would have been the cheapest one. This case demonstrates that it would be beneficial to develop algorithm that could predict the needed heating hours for a certain night and therefore utilize the cheapest hours more efficiently. This could be made for example with the information of the temperature during the last day.

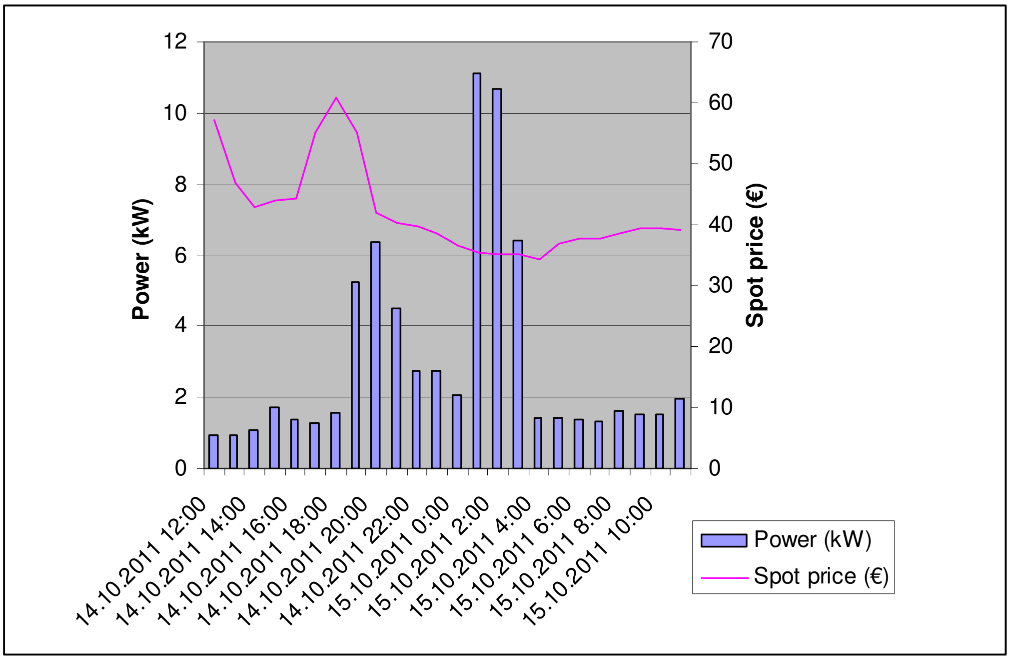

Figure 6.2. *Electricity consumption of Customer1 in October and the spot price for Finland region.*

Table 6.1 illustrates the results from the pilot period of July to October. First row represents the total consumption of the customer during the pilot period. The second row shows the cost of electrical energy based on the average prices for the customers who does not have competed their electricity supplier. These prices vary on a monthly basis and can be viewed for example from the web-pages that are upheld by Energy Market Authority (www.sahkonhinta.fi). The third row presents the total cost of electrical energy if the customers would have made a 2-year fixed-period contract at the beginning of the pilot. The average price level for 2-year contracts in Finland was 7.03 c/kWh at that time. Fourth row is the cost of electrical energy with spot-price based contract. Usually these contracts include a premium that is paid in addition to spot-prices and in these calculations the premium of 0.1 c/kWh was used.

Table 6.1. *Cost of electricity with different types of contracts during July to October*

	Customer1	Customer2	Customer3	Customer4	Customer5
Total energy consumption (kWh)	6353	4314	4423	3551	4126
Supply obligation price (€)	442	300	307	247	287
Bid price for 2-year contract (€)	447	303	311	250	290
Spot price based contract (€)	251	176	189	148	162
Savings compared to 2-year contract (€)	196	127	122	102	128
Relative savings compared to 2-year contract (%)	44	42	39	41	44

The bottom-two rows represent the savings that would have been realized during the pilot period. Sixth row includes the savings that would have been acquired with the spot price based contract compared to the 2-year fixed-period contract and the last row includes the relative savings compared to the same contracts.

The saving rates are seemingly high as the level of spot-prices is traditionally lower during the summer and autumn when compared to the price level in winter. In addition the prices were extremely low this year because of the big amount of available hydro power. It was estimated that the prices were last time as low in 2004. (Siljamäki 2011) On the other hand, the pilot customers did not have any incentives to steer their consumption to avoid the peak prices so this have affected the profitability of the spot price contracts negatively.

To be able to evaluate the actual lucrativeness of the spot-price contracts, evaluation must be done over a longer period. The next table introduces the total costs for the pilot customers during the last twelve months (November 2010-October 2011). The calculations are similar than in the previous table and are based on their hourly consumption data and the hourly spot-prices during that period. The cost with the fixed-period contracts are calculated based on two different cost levels. The lower level of 6.19 c/kWh was the price level in the beginning of November 2010 and the higher level of 7 c/kWh occurred in the late of January 2011. These two levels were chosen because they changed the result of the calculations.

Table 6.2. *The cost of electricity with different contract types between November 2010 and October 2011.*

	Customer1	Customer2	Customer3	Customer4	Customer5
Total energy consumption (kWh)	32130	29440	26824	23858	23272
Supply obligation price (€)	2167	1976	1801	1601	1563
Lower bid price for 2-year contract (€)	1989	1822	1660	1477	1441
Higher bid price for 2-year contract (€)	2249	2061	1878	1670	1629
Spot price based contract (€)	1946	1900	1748	1493	1507

With the pilot customers the spot-price contract would have been always a cheaper option than the supply obligation prices. The fixed-period contracts with a lower price of 6.19 c/kWh would have been a cheaper option with all customers except one, but if the fixed price would have been 7 c/kWh the result would have been that the spot-price based contract would have been a cheaper option.

The next table introduces the savings that were achieved by the spot price based steering of the reserving electric heating. In October the Customer1 had the floor heating and the hot water boiler behind the steering, but in July, August and September the heating period had not started and only the hot water boiler was in active use. Customer2 had the hot water boiler behind the steering in October.

The comparing of the cost levels with and without the steering was made as follows by using the consumption data of the electric heating and hot water boilers. The cost with the steering was calculated by multiplying the hourly energy with the corresponding hourly spot price. The cost without the steering was estimated by transferring the steered hourly energies of electric heating and the hot water boiler from the cheapest hours to start from the 22:00 when the electric heating is normally switched on. This means that if the corresponding energies during the hours 02-03, 03-04 and 04-05 would have been 3 kW, 3 kW and 1 kW those would have been transferred to the hours 22-23, 23-24 and 00-01 in the same order of 3 kW, 3 kW and 1 kW.

Table 6.3. *Savings achieved by spot price based steering of the electric heating*

	July	August	September	October	
	Customer1	Customer1	Customer1	Customer1	Customer2
Consumption (kWh)	1116.8	1389.1	1645.1	2201.0	1599.4
Spot price based contract without steering (€)	49.0	67.8	64.8	80.7	59.7
Spot price based contract with steering (€)	46.6	65.4	61.2	77.9	58.8
Savings (€)	2.4	2.4	3.6	2.8	0.9
Relative savings (%)	4.9	3.6	5.6	3.5	1.5

The results show that the spot price based steering enabled estimated savings between 3.5% and 5.6% per month from the electric energy costs for Customer1. Results illustrate the fact that the potential savings are depended on the fluctuation of the market price. For example for the Customer1, the savings were relatively higher in September with less power under steering because of higher level of fluctuation in the spot prices. Moreover, in the pilot case the difference between the market price during the night-time and the hours right after 10 p.m. is the determinative issue. The more there would be power for the steering the more there would be potential economic benefit. By steering the 3 kW hot water boiler Customer2 would have only achieved the saving rate of 1.5 %.

As mentioned earlier the steering algorithm was not as optimal as possible, because the steering was made with an estimated need for five heating hours for a day. For example if the Customer1 would have had an optimal steering algorithm the savings in October would have increased to 3.76 euros and the relative savings to 4.7 %. This calculation was made by shifting the hourly energies of the steered loads precisely on the cheapest hours. The future algorithm could be based for example on the information about the outdoor temperatures from the last day and the forecast information for the next day.

As the market prices during the pilot study can be regarded as lower than during the previous years the calculation should also be made with the prices of some more expensive month. In this case the calculation was made based on the prices of October 2010 when the average price of the month was 51.23 €/MWh. In October 2011 the average price was 36.90 €/MWh. The power demand of the Customer1's electric heating and hot water boiler in October 2011 were used in calculation. Now, two scenarios are calculated. First the heating energies will be placed starting from 10 p.m. Second case is that the heating energies are placed on the cheapest hours during the night. The results were that there could have been savings of 1.8 € that month. So even though the prices were generally at higher level the fluctuation between 10 p.m. and later night was not significantly high.

The savings from the spot-priced based steering demonstrates the level of savings that could be potentially achieved automatically. During the colder winter time the need for electrical heating will rise and therefore the power that can be steered is higher. It must also be noticed that the number of heating hours will rise at the same time, meaning that there is less room for the steering. This means that for example if the heating is needed to be on for the whole night, there is no possibility to steer it based on the spot-price.

The automatic savings could be possible also with a direct electric heating. In this case the steering algorithm could avoid the peak price hours by turning the heating off for example for the peak price hours. This would not most likely affect the comfort level as the temperature would not decrease too much by that time. In addition, when the house is equipped with reserving fireplace that can be used instead of electric heating the saving potential will rise as the electric heating can be easily turned off for the whole evening.

The estimation of the potential savings could be made by the same method as in the case of reserved heating. For example if a customer would have a possibility to daily shift power demand from the peak price hours of 5-7 p.m. to the later hours of 7-9 p.m. it would bring some savings. The issues such cold load pick up need to be taken into consideration as the total energy need can be higher after the steering than it would have been without the steering. In the pilot this algorithm was available but it was not used as the customers did not have hourly based contracts and the steering would have affected the normal functionality of the heating during the daytime without bringing any benefit for the pilot customer.

The results show that the savings of at least five percentages from the electric energy costs (the distribution tariff not included) is possible to achieve automatically without requiring any action from the customers. Real-time information also enables additional savings of 3-13 % that is depended on the customer's own activity. In addition to the benefits that can be measured in monetary terms the HEMS systems also bring benefits by increasing the understanding of the household's energy consumption and by rising the overall interest towards energy related issues. Demand response could help to reduce the national peak power need and the need for polluting production methods. This would mean that with demand response the customer would ultimately reduce one's carbon foot print. These would mean that the customer is enabled to do one's share in improving the overall energy efficiency and contributing to the achieving the national targets of energy efficiency set by European Union.

Still, the savings enabled by HEMS-solution must be compared to the investment costs of the system. Table 6.4 shows the total investment costs of a HEMS-solution that was installed for the Customer1 and Customer2. Table includes also the estimation that how the prices could change in a case of large-scale installations with economics of scale of 30 %. With the saving level of 2.4-3.6 € per month it would be very challenging to promote a HEMS-solution of this kind. The yearly savings would be annually around 30-42 euros and the repayment periods very long. If the HEMS-solution would also efficiently improve the more efficient energy usage the additional savings would come with decreased energy consumption.

Table 6.4. *The prices of the piloted HEMS-solution.*

	Price (€, VAT 0%)	
Component	**Pilot**	**-30 %**
HEMS-unit	250	175
Indoor thermometer	72	50
Outdoor thermometer	91	64
SES	74	52
LED-sensor & transmitter	142	99
Sub meter for the heating	124	87
Sub meter for the heating	124	87
Wireless relay	98	69
Wireless relay	98	69
Installation material	10	7
Total cost	**1083**	**758**

The results show that it is challenging to get savings with the shifting of loads. This would be the case even with the electric heating that has the highest demand power of the household's electric devices. This could mean that future HEMS-solutions should be more based on the reduction of electricity consumption during the peak price hours of the day rather than shifting the electric heating during the night-time. The best results would be achieved by combining these both methods. HEMS-solution should enable the reduction of all unnecessary consumption in one's household.

Most of the households using reserving electric heating have already shifted their biggest consumption to the nighttime and to the cheapest hours. Shifting it from the 10 p.m. to the later night does not give a high profit, because the highest prices occur already around 6-8 p.m. and starting from that the prices commonly decrease until the nigh-time of 3-4 a.m. Of course there is situations like during this autumn when the prices were close to zero during the nighttime, but those are rare situations and would provide benefits only within a short period.

The thing that affects the future economic potential of steering the electric heating will be the fluctuation in the market prices. It has been for example estimated that the prices will fluctuate more when there will be high amount of wind and solar power. Power production with these energy sources is highly depended on the environmental issues such wind and sun. If the fluctuation in the prices would increase, it would also increase the profitability of load steering. Also the future distribution tariff structure could increase the benefits of the load steering. Theoretically the customer steer the consumption according to the overall cost of electricity, including energy part and the distribution part. For example if the cost of distribution will be higher during the expected peak power hours the economic incentives of the customers' for load steering will increase as the energy prices are potentially also highest at the same time.

6.2 Potential benefits for the DSO

The large-scale implementation of a HEMS-solution that increases the demand response could bring benefits also to the DSOs. HEMS-solutions help customers to reduce their energy consumption which affects negatively on the incomes of the DSOs with the current tariff structure. On the other hand, the demand response side can decrease the peak power need that ultimately can have positive effect on the costs of the DSO. The potential problem is that the decrease in the peak power needs to be permanent to give long-term benefits for the DSOs. Practically direct load steering would be needed. As mentioned earlier in the text the effects vary according to the customer types in the network area under consideration and the amount of loads that are steered. In this chapter two kinds of potential effects are discussed. First, the effects of the load steering on the peak power need is examined. The load profile of the main substation feeder where the Customer1 is located is introduced. Then it is analyzed if the steering of the electric heating could have an effect on this feeder's load profile. Also the load profile of the low voltage network is similarly analyzed. Again, the analysis is being made if the steering of the single customer had had an effect on the load profile.

Figure 6.3 shows the load profile of the feeder and the spot price of the electricity in Finland during the same period. This graph is from the February 2011 and over a one week. The figure illustrates that there are three power peaks on the feeder during the day. These power peaks has been numbered in the figure. The first one occurs at the morning around 6 a.m., the second in the evening around 7-8 p.m. and third after 10 p.m. Table 6.5 provides information of what kind of customers are located in that feeder according to their distribution tariffs. As the numbers show there are a lot of small consumers with main fuses of 25 amps.

When comparing the spot price to the feeder load it can be noticed that the spot price peaks of a single day collide with the morning and evening peaks but not generally with the peak after 10 p.m. This would mean that if the customers have spot price based electricity contracts they would have strong incentives to shift the consumption away from the peak price hours but not necessarily from the peak power hours after 10 p.m. Still, the late evening break generally is caused by the electric heating which would most likely be steered automatically according the market price. This would mean that the electric heating would be steered to the night-time even if the prices would be just slightly lower. This would be a very different from the customer initiated demand response as in this case also the price differences between the peak hours and other times would significally have an effect on the level of activity. If the price difference is not great enough the customers would not see it beneficial enough to adjust their electricity consumption. The evening peak power is on this feeder commonly higher than the latest peak around 10 p.m. This would mean that in this case just the steering of the reserving electric heating would not affect the overall peak power demand, as the peak power level is defined generally according to the first evening peak. The steering of direct electric heating, on the other hand, would affect the evening peak. These both steering activities together could level the overall power demand and the distribution losses.

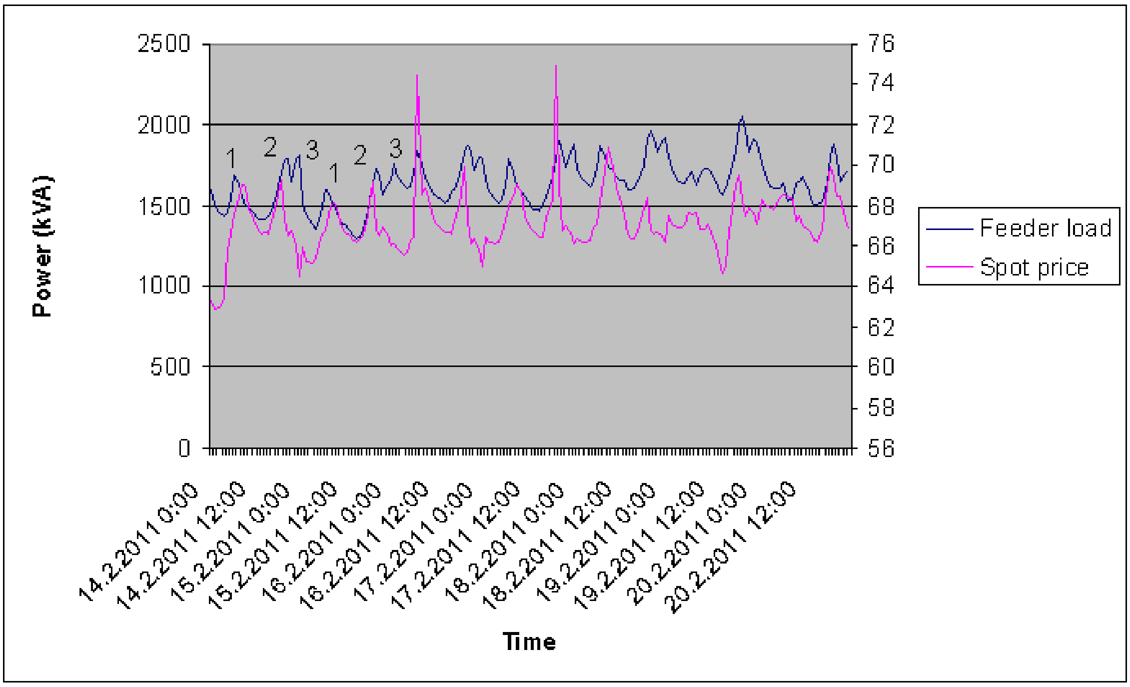

Figure 6.3. *Load profile of the Customer1's feeder and the spot price of electricity.*

Table 6.5. *The types of distribution tariffs in the feeder .*

Tariff type	Fuse size (A)	Number
General Electricity	1x25	32
	3x25	327
	3x35	20
	3x50	2
	3x63	5
	3x100	1
Night-time Electricity	3x25	146
	3x35	27
	3x63	1
	3x100	2
Seasonal Electricity	3x80	1
Demand Tariff	-	5
Total customer number		**569**

Table 6.6 provides more in detailed information of the 19.2.2011 when the highest peak power of the year had occurred so far. It shows that the peak power hour was 7-8 p.m. and the peak prices had occurred between 6-8 p.m. Now there would have been only a slight incentive for the customers to manually shift their consumption from the peak power hours, but it might not be strong enough. It must be pointed out that during this event the prices have been very stable. When considering the potential effects of the steering of reserving electric heating there is two things to be considered. First, as the peak power demand on this feeder had occurred during this day, it might have been also the coldest day of the month. This would mean that the demand for the heating hours is at the highest level and therefore, there would have been only small opportunities to shift the heating loads. Secondly, the prices show that potentially the cheapest time period for the heating would have been starting from the 10 p.m. So to summarize, the market price based demand response would have not brought significant relief on the strict power situation and direct load control would have been needed from the DSO point of view.

Table 6.6. *The load of the feeder and the spot price of electricity.*

Time		kW	kVAr	kVA	Spot price
19.2.2011 18:00	19.2.2011 19:00	1965	369	1999	69.47
19.2.2011 19:00	19.2.2011 20:00	2012	386	2049	68.30
19.2.2011 20:00	19.2.2011 21:00	1930	374	1966	67.44
19.2.2011 21:00	19.2.2011 22:00	1799	304	1824	67.91
19.2.2011 22:00	19.2.2011 23:00	1882	314	1908	67.66
19.2.2011 23:00	20.2.2011 0:00	1865	298	1889	67.08
20.2.2011 0:00	20.2.2011 1:00	1741	257	1760	68.28
20.2.2011 1:00	20.2.2011 2:00	1680	237	1696	68.09
20.2.2011 2:00	20.2.2011 3:00	1598	226	1614	67.90
20.2.2011 3:00	20.2.2011 4:00	1586	231	1603	67.76
20.2.2011 4:00	20.2.2011 5:00	1583	229	1599	68.02
20.2.2011 5:00	20.2.2011 6:00	1591	219	1606	68.40

Figure 6.4 shows the load profile of the low voltage network where Customer1 is located. Graph is from the October 2011 and the temperature correction has been made. Correction was made by using the long time average temperature for October and the average temperature from the October 2011. It was estimated that one degree difference between the temperatures would cause 4 % change in the consumption.

The graph shows that the peak power of the Customer1 had collided with the lowest market prices during the night-time. The peak power of the transformer had occurred after 10 p.m. This would mean that the daily peak power of the transformer had decreased with the amount of power demand of the reserving heating of the Customer1. The problem is that the peak power had not decreased when the cheapest hours did occur after 10 p.m. This does not show in the figure but there was also these kinds of days during the month. This would lead to a fact that it would not bring benefits for the DSO in a form of lower lever peak power levels as the decrease in the peak power should be repeated day after day bringing a permanent effect. This problem was considered also in the literature as the permanent effect of demand response was considered mostly as a theoretically possible. In practice it would mean that the heating should be steered similarly every day and sometimes this steering would act against the incentives from the market prices. Theoretically it could be possible to reduce the daily peak power of this transformer by shifting the heating loads away from the 10-12 p.m. until the power level during the night time would be the same as between 10-12 p.m. Rough estimation could be that in this case it could be possible to further decrease the peak power with around 5-10 kW.

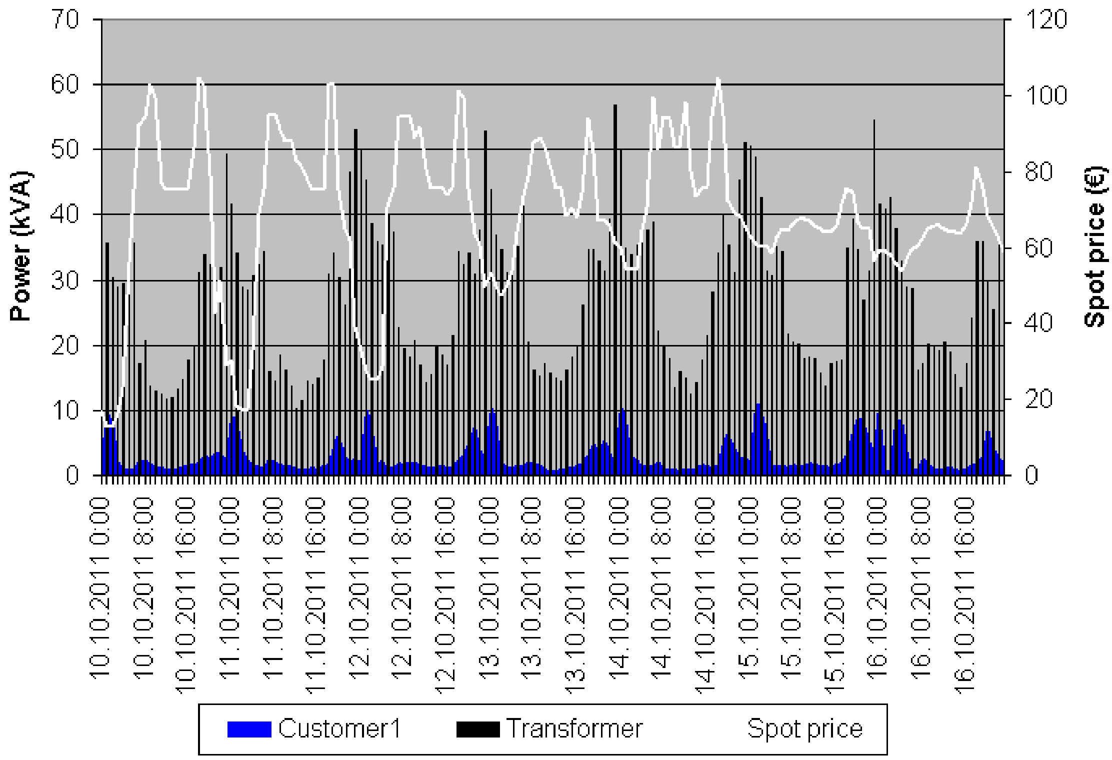

Figure 6.4. *Transformer load, consumption of Customer1 and the spot price of electricity.*

Also the analysis was made of how a large-scale market price based steering of reserving electric heating would affect the distribution losses and the costs of distribution losses. Generally the switching status of the network is optimized in a way that leads to efficient level of distribution losses. This optimization is done regularly for example in every three years or so. Once the optimization is done, there is not a lot of saving potential during the next coming years. One way to affect the distribution losses is to shift the consumption to the time of the day when there is less consumption. The general opinion is usually that the steering of the consumption should be made according to the market price that reflects the overall market situation. Practically this would mean that the DSOs do not have an opportunity to exploit the steering in a way that would be most beneficial from the distribution losses point of view. Still, it can be estimated that even when made according to the market price of electricity, steering of the consumption could bring benefits also for the DSOs. (Pöyry 2010)

For the consideration of how the steering of electric heating would affect the costs of distribution losses the estimation of the hourly losses is needed. The loss percentage is determined as follows. The time period of the calculation of loss% depends on the meter reading practices and the majority of the meter reading data must be collected from the load points. (Seppänen et al. 2011)

$$loss\% = 100 \times \frac{E_{L,a}}{E_{I,a}} \quad (1)$$

$E_{L,a}$, annual loss energy
$E_{I,a}$, annual input energy

The equation 2 can be used to estimate the hourly loss from the hourly network input energy. Total losses are the sum of the idle losses and resistive losses.

$$P_L(t) = P_0 + k \times P(t)^2 \quad (2)$$

$P_L(t)$, loss power at hour t
P_0, idle losses of the network
$P(t)$, input at hour t

According to Seppänen et al. (2011) the coefficient k is calculated like shown in equation 3 so that the loss function results to the loss% over the period T. Period T is usually one calendar year or multiple years.

$$k = \frac{0.01 \times loss\% \times \sum_{t \in T} P(t) - \sum_{t \in T} P_0}{\sum_{t \in T} P(t)^2} \quad (3)$$

In the calculations of this thesis the value of the term k is estimated as follows.

$$k = \frac{P_{L,\max}}{P_{D,\max}} \quad (4)$$

$P_{L,max}$, loss power with maximum distribution power
$P_{D,max}$, maximum distribution power

The effects of the steering were calculated by using these methods. The calculation was done for one month which was the February 2011. This was the coldest month of the winter 2010-2011. The base for the calculations was the information of the hourly distribution energies, the total fixed losses, the maximum distribution power and the losses with maximum distribution power in Vattenfall Verkko Oy's distribution network. Three steering methods were evaluated and the cost of distribution losses calculated using spot prices. In all methods it was assumed that it would be possible to steer the constant amount of power during four subsequent hours starting from 10 p.m. This is the value that is presented in the table as "Load behind the steering". The 60 MW steering power could be acquired for example with 10 000 customers each having 6 kW of steering power. In steering method A, the four hours from 10 p.m. to 2 a.m. were shifted to 2 a.m. to 6 a.m. In steering method B, the four hours were shifted to 0 a.m. to 4 a.m.

Finally in steering method C, the four hours were shifted according to the cheapest four hour market price time span during the night-time (10 p.m. to 6 a.m.).

Table 6.7. *The savings from distribution losses by steering of reserving electric heating.*

Steering me-thod	Load behind the steering (MW)	Amount of relative savings (%)
A	1	0.002
	60	0.045
	120	- 0.066
B	1	0.002
	60	0.081
	120	0.084
C	1	0.001
	60	0.039
	120	0.034

The best results from the distribution point of view were achieved with method B. Amount of relative savings means the savings achieved by the steering related to the original costs of the distribution losses calculated with spot prices. This means that the most efficient way would be to steer the heating regularly from the evening to the night hours, without taking into consideration the market prices. When steered according to the market price there was actually no steering during many nights because the cheapest hours happen to occurred after 10 p.m. during this precise month. In these cases it would have been still more beneficial to shift the load to the nighttime from the peak power hours, even if the prices would have been little higher, because the distribution losses would have been limited.

The market price was extremely even during this month without taking into consideration the couple price peaks that had occurred during the mornings. The results show that with the normal market situation there is not possible to have great economical benefits from the steering of electric heating during the night-time. It must be noticed that the saving level would be higher if the customer would also have incentives to shift the consumption away from the evening peak that has occurred around 8 p.m. Usually at this time of the day, the price peak collides with the peak power of the day. This means that even smaller amount of demand response could bring relatively high savings as the distribution losses vary according to the square of the consumption.

The results verify some of the issues discussed in the literature. DSO could have benefits from the load steering actions if the effects are permanent. Lower level peak power demand of the consumers would make it possible to optimize the investment as the grid would not have to be planned according to the short peak power periods. Continuous steering of the reserving electric heating could not bring significant benefits from the distribution losses point of view. The calculations did not consider the ultimate peak price hours. If there would be extremely high peak prices combined with peak power hours it would be beneficial for the DSO to have possibility to switch of some customer loads in order to reduce the consumption. As the distribution losses increase related to the square of the consumption, the costs of losses can increase significantly if the peak consumption hours collide with extremely high peak price.

Added to the potential benefits that were described above there can be also additional opportunities around HEMS. These benefits can be hard to predict without the actual real experiences. One example of these is the savings from the reduced number of customer calls. This would be caused by the limited peak power levels and finally decreased number of fuse overloads. One potential way to utilize future HEMS-solutions would be that the smart meters would be connected to the HEMS-unit to provide information on the quality of electricity. This would mean for example voltage level and the duration of power failures. This would increase the transparency of the DSO operations furthermore and reduce the need for customers to contact DSO on these issues. The quality of electricity can be regarded as growingly significant matter as the modern electronic devices require more from the electricity. The smart meters already collect information on the quality of electricity so to utilize them it just should be created a standard on how to connect the meters for example to the home automation unit.

6.3 Potential benefits for the supplier

Suppliers' interest towards HEMS would most likely be the possibilities to have access to the the customers' real-time consumption data and to easily get consumption reports of the whole customer segment. In addition, depending on the operation model of the electricity market and the electricity market environment the supplier would benefit from the accessing and steering the customer loads. This is the current case as the supplier operates in the electricity market and buys the electricity on the market price while the consumers buy the electricity mostly based on a fixed price. It would be economically beneficial to reduce the consumers' consumption during the peak price hours. In a long run this should benefit also the customers as there would not necessarily be that much of pressure to increase the prices in future to compensate the previous losses.

If the customers would have HEMS-solutions that able them to control for example the heating loads the suppliers could offer demand response products to the consumers that would compensate the consumers if they steer the loads according to the needs of the suppliers. This means that it could not be necessary for the supplier to have the possibility to straightly send steering signals if the HEMS would already provide that solution in itself. Ultimately the suppliers just need to know how the consumer loads behave. It does not matter whether they control the loads directly or does the HEMS-solution perform the control and the supplier is informed that how much load is under steering and what kind of algorithm is performing the steering.

The real-time access to the customer consumption data would enable the suppliers to elaborate the consumption prognosis that would reduce the balance difference and finally the need for expensive balance electricity. Valtonen (2009) evaluated the viability of AMR-based balance management. The evaluations were divided in case studies that concerned the continuous AMR-based balance management and the focused AMR-based balance management. Continues AMR-based balance management means that the supplier would have possibility to read the consumption information from AMR-meters hourly before the actual consumption hour and use this information to elaborate the consumption prognosis. Focused AMR-based balance management means that the possibility to read the consumption information is used only occasionally when the difference between spot-price and balance electricity price is expected to be high. From this work point of view the HEMS-solution would be the interface providing the access to the customers' consumption information instead of AMR-meters.

The private customers are commonly the largest customer group of the energy companies. Because of the relatively low electricity consumption the fluctuation in single consumers consumption does not have a relatively significant effect on the total balance difference. On the other hand because of the large number of small consumers their effects compensate each other effectively. Added to this there are rarely big and sudden changes in the total consumption of the whole sector of the small customers which eases the estimation of the overall consumption. In contrast to this customer sector, there can be big fluctuations with the consumption of industry customers like foundries. (Valtonen 2009)

Valtonen (2009) estimated the potential economical benefits of AMR-based balance management with an imaginary energy company with a customer number of 80 000 (all equipped with AMR-meter that can be red at desired time) and annual sales of 1 200 GWh. It was concluded that by the AMR-based balance management the absolute value of the average error in the original consumption prognosis would be reduced from 4 % to 2 %.

The calculations were made with the average spot-prices in Finland (51.0 €/MWh) and the average prices of balancing electricity (54.8 €/MWh) in 2008. Therefore the average difference between these were 3.8 €/MWh. During the years 2009, 2010 and 2011 the corresponding differences between the average spot-prices in Finland and the average price of balancing electricity were 2.39 €/MWh, 4.14 €/MWh and 4.75 €/MWh. This means that from this point of view the benefits are still valid today. The calculations resulted in annual savings of 103 400 €. This would mean annual savings of 1.3 euros per customer. Furthermore, if the costs for acquiring the readings would be more than 8 617 €/month the AMR-based balance management would not be profitable. These results are compatible with the case when the supplier would be provided with the consumption readings with the HEMS-solution.

When considering these results from this work point of view there are things to be considered. These estimated savings occurred when it was possible to get the real-time readings from every single customer, whether small or large. In this work the HEMS system is evaluated for the small customers. This would mean that it would be possible to acquire the consumption information only from the smaller consumers which would most likely make it considerable less lucrative for the suppliers as the potential for reducing the error in consumption prognosis would be notably limited.

Valtonen (2009) suggested that the real-time balance management should be focused on the large consumers as the total error in consumption prognosis is highly depended on the fluctuation in that customer group and this operation model would bring almost the same benefits than if the consumption information of all the customers would be continuously acquired. This would mean that most likely it would be in supplier's interest to get the real-time consumption information of the large consumers as they are the customer group that produces the greatest effect on the potential error in consumption prognosis. Furthermore, the suppliers would likely not be ready to pay significantly on the possibility to get the real-time consumption information from the small customers.

In this work the potential savings for the supplier from the steering of the electric heating was evaluated as follows. It was assumed that total number of 20 000 customers would have a HEMS-solution that would steer the electric heating according to the spot price. Half of them would have reserving heating that would be steered during the nigh-time. Other half would have direct electric heating that would be steered to avoid the potential peak prices during 8 a.m. – 10 a.m. and 5 p.m. – 7 p.m. It must be pointed out that currently it would not be possible to switch of heating for two hours, as the limit for this is 1.5 hours according to the legislation. Calendar year was divided into three different heating periods. The period from November to March would be the time period when there would be biggest amount of electric heating to be steered. For the reserving heating it was estimated 10 kW of heating power under steering and that required number of heating hours would be five hours. April, September and October would form a time period for less heating. Now the available heating power for steering would be reduced and the number of heating hours decreased. Time period from May to August would be the period with least heating power to be steered and in this calculation it was estimated that there would be no direct heating to be steered. This basic information is introduced in the following table.

The idea was that the reserving heating would be steered to the night-time and cheaper hours. For example during November the heating would be shifted from 10 p.m. – 3 a.m. to 12 a.m. – 5 a.m. Direct electric heating would be steered so that it avoids the most potential hours of peak prices. The cold load pick-up was taken into consideration by adding 5 % to the loads after the steering. The spot prices from November 2010 to October 2011 were used as a market data for the calculation.

Table 6.8. Background information for the calculation of potential benefits from the steering of electric heating according to the market price

Reserving electric heating				
	Customer number	Load/customer (kW)	Original heating hours	Heating hours after steering
November - March	10 000	10	10 p.m. - 3 a.m.	12 a.m. - 5 a.m.
April, September, October	10 000	5	10 p.m. - 1 a.m.	1 a.m. - 4 a.m.
May - August	10 000	3	10 p.m. - 12 a.m.	1 a.m. - 3 a.m.
Direct electric heating				
	Customer number	Load/customer (kW)	Original heating hours	Heating hours after steering
November - March	10 000	2	8 a.m. - 10 a.m.	10 a.m. - 12 p.m.
			5 p.m. - 7 p.m.	7 p.m. - 9 p.m.
April, September, October	10 000	1	8 a.m. - 10 a.m.	10 a.m. - 12 p.m.
			5 p.m. - 7 p.m.	7 p.m. - 9 p.m.
May - August	10 000	0	-	-

The results from this calculation were that the total costs of buying the required electricity for the heating would have been 6 703 000 Euros. After the steering the costs were 6 481 000 Euros. This would mean that the costs would have been decreased by 222 000 Euros. With 20 000 customers it would mean annual savings of 11 Euros/customer. This is just one way to estimate the potential savings for the suppliers from the steering of electric heating. The numbers in these calculations are all arguable, but it gives a size range of the potential of the savings. For example it could not be possible to get 10 kW of heating power under steering or the power level would not be that high for the whole five hour time span.

The calculations show that there may not be significant savings available with the steering of the electric heating of small consumers. There could be relatively higher savings in a case of extreme peak prices like the ones during the winter 2009-2010. Next, the effects of steering of the electric heating is evaluated based on these peak prices. The following figure illustrates the peak price hours.

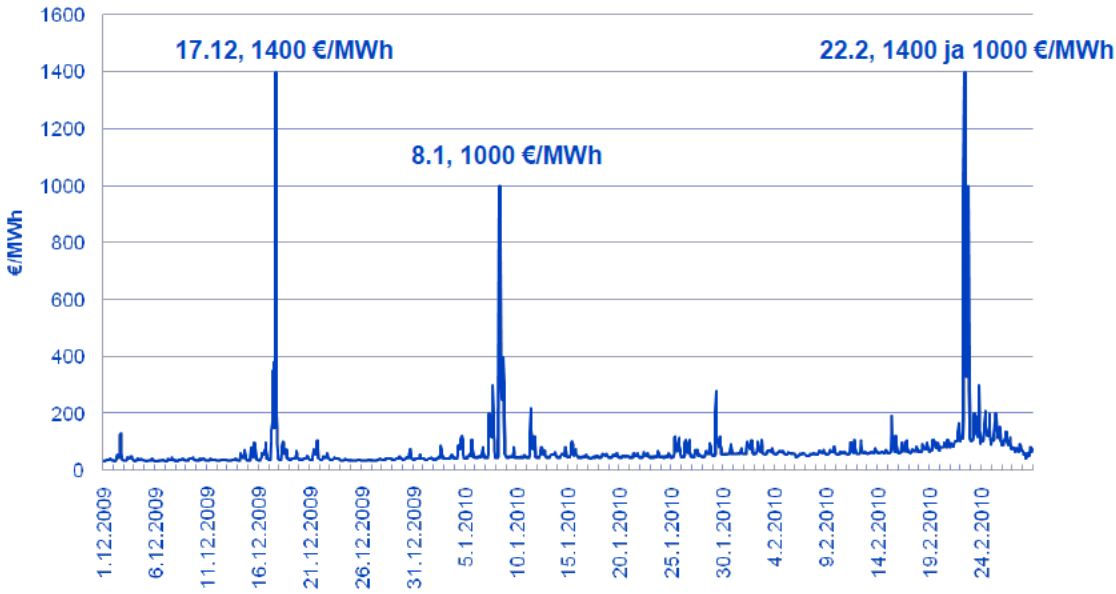

Figure 6.5. *Peak prices during the winter 2009-2010. (Stam 2010)*

The peak price hours occurred 17.12.2009 between 4 a.m. to 6 p.m., 8.1.2010 between 7 a.m. to 10 a.m. and 22.2.2010 between 7 a.m. to 12 p.m. and 5 a.m. to 7 p.m. The calculation of the potential savings will be done based on the previous scenario. This would mean that in the February there would have been a possibility to switch of 2 kW of electric heating for the morning peak hours and for the evening peak hours. These peak prices are outside the usage of reserving electric heating so the steering of it would have not helped. So during the first peak price there would have been a total amount of 20 MW of load under steering between 5-6 p.m. The value of this electric energy would have been 28 000 €. During the next peak price there would have been again 20 MW of load under steering between 8-10 a.m. The value of this energy would have been 40 000 €. During the peak prices of 22.2.2011 there would have been 20 MW of load under steering during 8-10 a.m. and 5-7 p.m. The value of this energy would have been 96 000 €. The total savings based on these numbers would have been 164 000 €. So by making a roughly estimation there would have been a potential for the annual savings of 164 000 € + 222 000 €=386 000€ or 19.3 €/customer in a year including peak prices as high as during the winter 2009-2010.

Theoretically it could be also possible that a supplier or aggregator company would operate in a balance power market by controlling a large number of HEMS-units. It could be possible to make an offer to reduce the consumption for a certain time period. Currently Fingrid requires that there needs to be a possibility to steer at least 10 MW to be allowed to operate in the balance power market. 10 MW can include a large number of small loads, if loads can be monitored in real-time. In practice this kind of operation would require efficient aggregation tools in order to control for example a large amount of electric heating. It would be also challenging to estimate the total load which would be available for a certain time period. Also, Fingrid requires that it need to possible to perform the load steering over a whole operating hour. Basically if the electric heating would be used, this kind of operations would also be possible only during the winter. (Fingrid 2012)

One potential benefit from the growing number of HEMS-solutions could be the rise in interest towards dynamic pricing rates. This would be caused because the customers would have better possibilities to handle the market price risks. Ultimately this could raise the customers' interest of buying the electricity with a more dynamic contract, or even spot price and share the price risks.

6.4 Market potential of HEMS

It is important for the service providers, which develop future HEMS, to be able to estimate the market potential for the HEMS. The amount of potential customers is important in any service or product development. In this chapter the results from the larger customer survey are evaluated. In addition the results are further discussed to estimate how the market potential could be estimated and which issues affect the potential.

Customer survey

The customer survey that was conducted during this work included 187 customers using Vattenfall Verkko Oy's OnLine-service. As earlier mentioned the full results are presented in appendixes. When examining the results one must notice that not all the customers answered to every question. These blanks cause some inconvenience to the results. There have been numerous studies related to the demand response and how it would be technically executed. On the other hand there is not that much research on what is the current customer stance towards the demand response, load control and real-time consumption monitoring. The one of the goals for the customer survey was to get a picture of those issues. In this chapter the most important questions of the survey are being discussed.

The background of the answerers was quite diverse. The different age and education groups were all represented. The distribution of annual energy consumption can be regarded as typical. There were 42 customers consuming more than 20 MWh annually. As discussed earlier these ones could potentially have the biggest incentive towards HEMS-solution as they would have most potential for reducing the energy consumption and achieve savings by load steering. Still, when considering the results one must take into account that the answerers were the users of OnLine-service. This means that most likely they are more interested of their energy usage more than average person.

To be able to somehow examine if the results vary according to the answerers' background the customers were divided into three groups. "High potential" group includes the answerers that are using direct or reserving electric heating and have annual consumption higher than 25 MWh. "Potential" group includes the rest of the answerers using some kind of electric heating. "Rest" group includes the answerers outside these two previous groups. In the results HP stands for "High Potential" and "P" for "Potential"

All except one in HP group answered that one has a need for real-time consumption monitoring and they also believed that it would bring at least some kind of benefits for them. This one is easy to understand as they were the ones consuming biggest amount on electricity. Furthermore, the interest rate was high among the whole answer group. When asked that how much the customers would be willing to pay for the real-time consumption information the most common answers were between zero to five euros per month or zero to 50 euros as a onetime payment. Onetime payment can be regarded as an in-home display or similar. It must be pointed out that great majority would be interested of the opportunity but not willing to pay for it.

When asked whether the answerer would be interested of hourly pricing of electricity 23 % of HP group and 11 % of P group answered yes. What is interesting was that once they were provided with a table showing price fluctuation during a common day and this same question was asked again the rates increased to 39 % and 17 %. For some of the answerers this was the information they needed to be able to form an opinion of the subject. Furthermore, around 72 % of the answerers would also be ready to adjust the energy consumption according to the hourly prices.

The survey described HEMS-solution as a system that gives opportunity to follow real-time consumption data and to steer the electric heating cost-efficiently. They were provided with a picture of user interface of the piloted HEMS showing the real-time consumption data. Furthermore it was said that this could help to achieve 10 % saving in the electricity bill. Around 75 % of the answerers were interested of this kind of system. Generally, the answerers would be ready to pay 0-20 euros per month for this kind of solution or maximum of 500 euros as a onetime payment. For example none from the HP group would be willing to pay more than 500 euros. This would mean that for example the cost of the piloted system would be too high. On the other hand the pilot customer said that they would be ready to pay even 1000 euros for a system, if they would be assured that the 10 % savings would be possible to reach. Naturally the pilot customer did have a better understanding of the HEMS than the survey customers who only received couple of line explanation of what the HEMS is. Therefore the pilot customers did put more value on it. The repayment period of maximum of two to three years were generally considered as acceptable time period. This is in line with the answers about the investment costs.

Discussion

The evaluation of the potential market for HEMS-solutions is challenging as there are so many variables that needs to be taken into consideration. First of all the private customer segment in itself is very diverse as there are many different types of households that can have very different peak power demand and electrical energy consumption. The technical possibility to install home-automation vary also as the electrical installations are different between the houses. Also the customers are different. Some of them are willing to do great deal of effort to reduce the electricity costs while some of them use electricity in a more carefree way.

Some DSOs are already offering their customers a possibility to monitor the hourly consumption data. This data comes usually available after couple of days of the actual consumption. The customers using the internet services can be seen as a potential customer group for the future energy efficiency products. At least they already have interest towards their energy consumption and are using the current possibilities and services.

It would seem reasonable that the customers with the electric heating and high annual consumption would be the most potential ones being interested of the HEMS-solutions. This is because they are the ones with the most potential for reducing the electricity consumption and to achieve savings. Also, the electric heating can be steered without causing inconvenience for the customers. It has been estimated that there is approximately 600 000 electrically heated houses in Finland (Bröckl 2011). In addition there are approximately 400 000 holiday homes, of which increasing number are heated with electricity (Bröckl 2011). One possible way to start to define the market size would be to find out how much the DSO has customers with electric heating and how much of those would be consuming for example more than 25 MWh annually. Some kind of estimation could be made by studying the customer distribution between different tariffs. For example majority of customers using reserving electric heating are using night-time distribution tariff.

There is a high interest towards the real-time consumption monitoring but based on the survey the customers are not willing to invest to acquire this information. Perhaps they think that it should be a free service in the future like the internet services currently are. The limit for the HEMS-solution investment is around 500 euros based on the survey. This would mean that currently the costs of HEMS are maybe too high. In addition to this the automatic savings which can be achieved by steering of the electric heating seems to be relatively low in the stable market situation. Still, the results from the research have concluded that even only with the real-time consumption data the savings around 5-15 % would be reachable. One solution would be to have some extra additional services for the HEMS-platform that would reduce the relative investment cost.

The investment costs would not feel to be that high in a case of a new house. Even one thousand euros investment could feel reasonable because the HEMS solution costs would be low related to the overall costs of the house project. Still, there is doubts that whether the future homes have electric loads to be steered. The passive houses use smaller amount of heating energy and for example the reserving fireplace is relatively common in new houses. Also the heat pumps are becoming more general all the time. These reduce the need for electric heating.

It could be the next step to run a larger customer survey to find out what is the true interest and potential towards the real-time consumption monitoring and steering of the electric heating. Still, this could not be a highly current task at present. It must also be considered that all kind of plug in switches for the remote control of small electronic devices and plug in energy meters are currently coming even in to the grocery shops. This will increase the peoples overall knowledge about the possibilities of remote load steering and consumption monitoring ultimately raising an interest towards HEMS-solution that would include all of these functionalities. On the other hand, these devices are also relatively cheap. This put pressure for example for the service providers designing future HEMS regarding the costs of the system.

Also the electricity market environment is under changes when the enrollment of smart metering is on and the hourly based balance settlement is starting to become more general. This will give a possibility for suppliers to develop new contract types, like the ones based on spot-prices and demand response products which could be contracts with the customers for load steering. There is also discussions going on whether the distribution tariffs should be develop to be more demand power based. These all are changes that can open new service opportunities for HEMS platform. For example in the future if the distribution prices are highly depended on the peak power demand of the customer, one could need services to be able to control the demand power level more efficiently and more easily.

One interesting topic is that could the government participate in order to make HEMS-solutions and therefore also load steering more lucrative. The customers investing to HEMS and load steering could be rewarded as a lower level electricity tax rate. Alternatively the investment costs of HEMS-solution could be made tax-deductible like the current possibility to have support for the renovation costs of one's household. These could be options for the government to support the generalization of the demand response of the small consumers.

Finally, the one of the most important issues is to make the end user aware of the changes that are currently happening or starting to happen. The need to increase the customers awareness is essential in order to raise interest towards new services. Customers need to know what kind of opportunities the changes in the electricity market environment arise and how they could benefit from them. The efficient marketing is needed.

6.5 Operation model

Generally an operation model defines what kinds of operations are required for example around a certain service and how these operations are divided between the actors that are involved. In this case the service would be the HEMS. In this chapter the operation model is discussed from three different perspectives. The actors in these operation models are the DSO, supplier, HEMS provider and customer. This chapter does not provide operation models in great detail, but rather give some point of views that needs to be taken into consideration when further developing the HEMS-concept.

There can be recognized operations that are required directly around HEMS service if it would be run on a large-scale. First of all, marketing is needed to promote the new service. The installations need to be planned and carried out. Furthermore, there would need to be technical support for the customers for the HEMS-solution related issues. Probably the equipment of the HEMS-solution needs also some maintenance, which should also be arranged. Billing needs to be organized especially if the customer is paying for the HEMS-solution over a fixed time period, for example three years. Additionally, the operations around possible load steering needs to be organized. DSOs and suppliers already have relationship with a large customer group and have at least some of needed resources around HEMS. Therefore it could be beneficial from the HEMS provider point of view to co-operate with DSOs or suppliers.

6.5.1 Supplier oriented operation model

Supplier oriented model is based on the idea that the supplier would utilize the possibilities that the customer's HEMS provide. These were discussed in the chapter 6.3. An example scheme of such operation model is presented in the following figure. This chapter introduces the operation model and some possible alternatives around it.

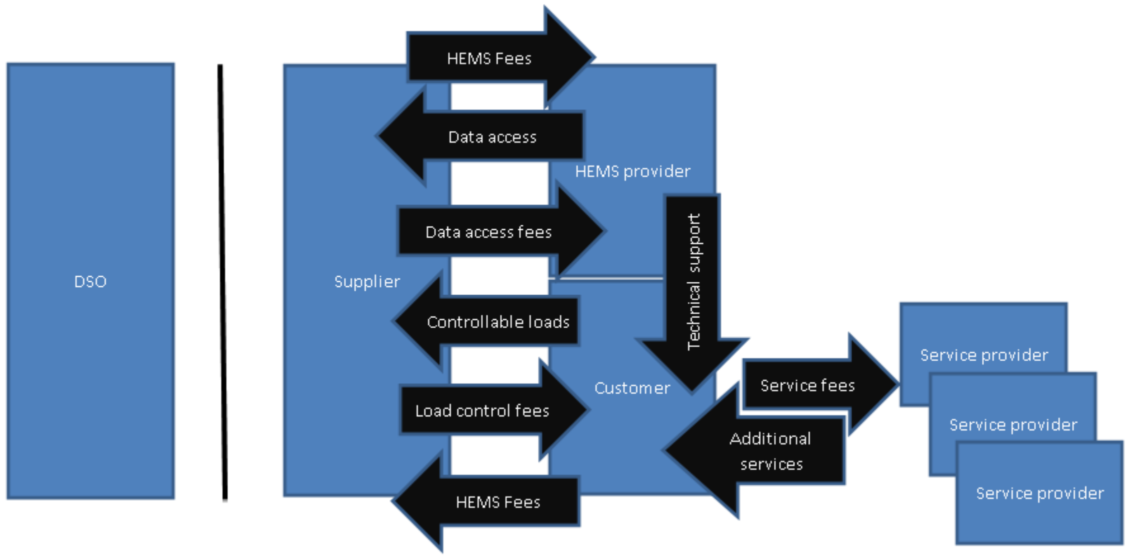

Figure 6.6. *Example scheme of the supplier oriented operation model*

In this model the customer have the ownership of the HEMS-solution. Customer would buy the HEMS solution from the HEMS provider or have a fixed period contract with the HEMS provider and pay a monthly fee.

In the operation model illustrated in the figure 6.6 the HEMS provider is running the HEMS database and provides access to the system for the customer and for the supplier. In this case the supplier's access would require a permission or contract with the customer. In this model the DSO provides a possibility to acquire the main consumption data from the metering device, but generally the role of the DSO is minimal. As the customer owns the HEMS-solution he also provides the installations. In this model it would be required that the HEMS provider arranges for example installation resources.

The issues concerning demand response products such compensations for the load steering would be handled by the supplier. HEMS provider would answer for the questions concerning the physical HEMS-solution and functionalities of it. This would mean that both, suppliers and HEMS provider would need to have customer service resources around HEMS. Naturally the suppliers already have customer service resources. Theoretically this would give HEMS provider a possibility to co-operate with the supplier with this. In addition, the maintenance should be arranged by the HEMS provider.

The steering of the chosen loads would be done according to the needs of the supplier. Customer determines the loads that can be steered and in what limits. Customer can for example set limits that what is the minimum temperature in the house. As the customers would own the HEMS-solution the supplier would pay for the steering possibility. This could be done based on how much power is available to the steering and how often the loads can be steered. Alternatively the customer could have a lower level fixed price for the electricity than the average prices. In this model the supplier could invoice consumers for the HEMS-solution. Supplier would deliver the payments for the HEMS provider. Supplier switch could cause some inconvenience as the billing would be needed to arrange again with a new supplier.

Alternatively, it could be possible that the HEMS provider would use suppliers or DSOs as a delivery channel. It could be for example possible that the supplier would purchase the HEMS-equipment from the HEMS provider and offer the solution for the customers. Now HEMS provider could co-operate with the supplier and organize some of the needed operations in an efficient way with the supplier. For the supplier this would be a possibility to compete in the electricity market not only with the price of electricity, but also with the additional services it provides. This would be a chance for the supplier to establish more secured relationship with the customer. Ultimately, the HEMS-solution could be even given to the customer as a compensation for the possibility to steer the loads. Still, one obstacle might be that the supplier cannot achieve great enough savings by steering the loads of a single customer to be able to offer the HEMS-solution in this way. Therefore, a separate payment for the HEMS-solution would seem more likely.

Alternatively the supplier could offer an electricity contract for a fixed time period and the cost of HEMS-would be added into electricity fee. Basically if the supplier would need to have total payment of for example 500 € over three years and the customer group would be consuming annually average of 20 MWh the additional part for the electricity price would be around 500 €/60 MWh, which would result around 0.8 c/kWh.

Also in this case some of the market processes could bring challenges. Problems could occur again for example with the supplier switching. Currently the customers are urged to be more active and to switch suppliers in order to achieve savings and increase competition in the market. Then it would be needed to remove the additional equipment that was installed for the customer and it would increase the overall costs around the service. Naturally the solution for this could be that the contract would include some penalty payment for the customer if one wants to end the HEMS-contract. This would cover the threat of this.

Alternatively the operation model could include the DSO. This would mean that the DSO would purchase the HEMS-equipment from the HEMS provider and offer the HEMS-solution for the customer. HEMS-solution would benefit the customer and also enable the load steering for the supplier. In this case the DSOs electrician resources could be used to install and maintain the HEMS-solutions. Also the customer service of the DSO could be utilized. It can be argued that whether offering this kind of service would be too far from the core business of the DSO. Ultimately, the DSOs could be obliged to offer these kinds of services in the future. This could be the case if for example EU would radically oblige the energy companies to increase the efficiency of the customers' energy usage.

6.5.2 DSO oriented operation model

DSO oriented operation model would be based on the idea that the possibilities of HEMS would be utilized strictly from the DSO point of view. Co-operation with the DSO would make it possible for the HEMS-provider to organize customer service, billing and installations in an efficient way.

The incentive for the DSO could be to use the HEMS-solution to limit the peak power level of the customer and if there would be large enough customer group with HEMS the beneficial effects could be achieved. According to the earlier calculations the benefits from the reduced distribution losses could be very modest. One way to utilize the lower peak power levels could be for example in a case of new house area in the network. If the houses would be equipped with HEMS the overall peak power level of the area would be reduced and therefore the network investments could be optimized. The DSO would develop the steering methods to achieve the best possible situation according to the peak power level. Naturally customers would also set limits for the load steering. Theoretically it could be also possible to postpone some investments in an existing network area by using load steering and reduce the increase of peak power level. This would give a chance to use the investment for some other network area that would require investment.

It could be required that it would be the DSO who would invest the HEMS-solutions for the customers. This could be the only way to equip relatively large number of customers with the HEMS-solution in a certain area. Single customers in different locations of the network would not bring any effect. Theoretically the costs of the HEMS could be also divided between the DSO and the customer. The basis for this would be the idea that the HEMS would benefit both, the DSO and the customer. DSO would benefit from the load steering part of the HEMS and the customer would utilize for example the real-time consumption monitoring.

This operation model could allow the HEMS provider to only concentrate on the core business of delivering the HEMS-solutions and maintaining the HEMS database. DSO would buy the equipment and pay for access to the HEMS database. The HEMS database would be used to monitor the steering actions and that the load steering operations are functioning as planned. Still, the savings in network investment costs should be high enough to cover the required operations around HEMS in order to make this kind of operation beneficial for the DSO.

6.5.3 Customer oriented operation model

Customer oriented model would be based on the idea that neither DSOs nor suppliers would actively utilize the possibilities that the customer's HEMS provide. In this model the customer owns the HEMS-solution provided by the HEMS provider. As suppliers and DSOs would not be involved, all the required operations around HEMS service would needed to be run by the HEMS provider. HEMS provider would need to have for example the resources for the marketing, installations, customer service, billing and maintenance. On the other hand, if the regulation or legislation would require for example DSOs to offer a solutions like HEMS, then the co-operation between the DSO and service provider would be beneficial and the division of resources could be done effectively.

In this operation model the customer is adjusting the consumption according to the market price to benefit from the lowest prices and therefore to decrease the electricity bill. HEMS can also provide tools to manage the peak power demand of the household if the distribution tariffs are based on it. Basically HEMS would help to optimize the energy usage according to the current electricity contract and distribution tariffs.

Practically this kind of model would not bring significant benefits for the electricity markets from the load steering. On the other hand, the future electricity contract types and distribution tariffs could partly steer the customer to use electricity in a way that is desired by the market actors.

6.5.4 Discussion of operation models

Future operation model for the HEMS will be depended on numerous issues. Currently it is not clear that who can offer the future energy efficiency services, which can also include demand response functionalities. As earlier discussed in the text the current opinion of NordREG is that the DSO's role in the demand response should be extremely limited. The reason for this is that the demand response should be done according to the market price that illustrates the overall market situation and therefore it would benefit the whole electricity market. If the DSOs are not allowed to widely utilize the load steering, it would prevent the DSO oriented operation models. Still, the DSOs might be allowed to offer HEMS-solutions in order to enable the load steering for the suppliers. Further discussions and evaluations should be made in co-operation with the suppliers, DSOs and HEMS providers.

As described previously there will be a need for various kinds of resources around HEMS-service if it would be implemented on a large-scale. Therefore it could be beneficial for the HEMS-provider to co-operate with the suppliers or DSOs, which already have a customer base and for example a billing relationship with them. These companies also have a customer service, although only DSOs have electrician resources. In addition for example the marketing of the new solutions could be more efficient. Basically there could already be a target group for the new services, like described earlier in the work. This would mean for example the customers currently using the internet services provided by the DSO. If the suppliers or DSOs are not actively involved the HEMS provider would have to acquire all the resources that are needed. On the other hand if the suppliers or the DSOs would be involved in the operation model, naturally the operations need to be economically cost-effective also for them.

Customers are a crucial part of every possible operation model. Therefore practically all the described operation models are depending on whether the customer would achieve monetary or other benefits that would make them interested of HEMS. Other benefits would mean for example additional services around the HEMS-solution. These could be services that are not energy related, like security services. Therefore the HEMS-investment cost would not be fully allocated only for the energy efficiency purposes. If the customer is not willing to invest on the HEMS or to participate the load steering, none of these operation models will be possible. Without compensations the customer will not allow the direct load steering. This is one important issue to further study. It should be studied that how great compensations the customers expect to achieve by offering some of their loads for example for the suppliers to be used for load steering. Therefore in addition to that the operations around HEMS should be economically lucrative for the market actors it should be lucrative also for the customers. The investment costs of the HEMS seem to be relatively high at the moment and it would be important that the prices would decrease. In addition as the load steering possibilities of a single customer are limited there would have to be a significant amount of customer that would be equipped with HEMS in order to have significant effects from the electricity market point of view.

7 CONCLUSIONS

During this work, a small-scale pilot study of HEMS was carried through in a co-operation with a service provider company. The pilot included five households. The feedback collected during the pilot study was used to evaluate the most important needs of the consumers regarding smart metering services. To sum up, the needs vary greatly between the consumers. The feedback is discussed in Chapter 6.1. The results can be utilized when designing future services as they enable to recognize what kind of functionalities the consumers regard as beneficial.

The feedback together with the metering data that was collected were also used to evaluate the monetary benefits that could be achieved with real-time feedback of electricity consumption and the market price based steering of electric heating. The pilot also enabled to recognize technical challenges that must be taken into consideration when designing future services that include additional home automation. Briefly, the challenges are caused by the different types of electrical installations in houses, which make it hard to develop an efficient installation process. This increases the required time for installation planning and for the actual installations. Ultimately, this increases the costs of HEMS and therefore it is a significant issue when considering potential large-scale implementation. This issue is discussed in Chapter 5.

The steering of the reserving electric heating enabled relatively small savings compared with the investment costs, when calculated with the market prices during the pilot study. The savings were 2.4 – 3.6 €/month. When considering this result, it must be pointed out that the heating period had not started and the market prices were low. Still, there was relatively high variation in the prices at the beginning of the period that was considered, which should increase the potential savings. Additional calculations could be made with the metering data from the colder winter time. Reserving heating has already been shifted to the cheaper market price hours by night-time tariffs, and therefore the benefits from shifting the heating into the later night and into the cheapest hours are limited.

The previous studies have concluded that real-time consumption monitoring could bring savings of 3-13 % in electricity costs. Pilot customers' response was that they did not significantly change their consumption behavior during the pilot. This would mean that the savings were also limited. One important issue in particular is that future HEMS should challenge and motivate the consumer to save electricity. An alternative for this can be for example the possibility to monitor the consumption during the sliding-year. Only the possibility to monitor the real-time consumption data could not be enough.

The pilot customers' general response was that they could be willing to invest even 1000 € for the HEMS if they would be convinced it would bring savings of approximately 10 % in electricity costs. Practically this issue is challenging as the majority of the potential savings are depending on the customer's own activity. With 10 % saving rate the repayment period for HEMS would be around four years when considering a consumer with the annual electricity consumption of 20 MWh. This was also the cost level of the piloted HEMS.

Furthermore, it would be important to develop additional services around HEMS. Then the costs of HEMS would not be fully allocated only for the energy efficiency operations. This issue is supported by the results from the customer survey as there were high interest towards smart metering services and real-time consumption feedback, but the willingness to invest for example on HEMS was limited being generally around 200-500€. The results from the customer survey were discussed in Chapter 6.4.

One significant issue that came up during the pilot interviews and from the customer survey was that the private customers need more information about the HEMS related issues. They do not have enough information about the possibilities that future development of electricity markets can enable and how to utilize these possibilities. Currently, the consumers do not generally have knowledge of what for example the spot price based electricity contract would mean. The promotion of these subjects would be needed. On the other hand, this also means that effective marketing is needed if a large scale demand for HEMS is desired to be acquired.

In the present market environment it would seem to be challenging to run HEMS business with the piloted cost level. Consumers do not generally have a need to control the hourly energy consumption as the current electricity contracts and distribution tariffs do not provide incentive to do so. Currently, the large-scale installations of smart meters are underway. This will enable the hourly based balance settlement that is already used by some of the DSOs. The large-scale implementations are done by the end of 2013. This will enable the more dynamic pricing of electricity and the distribution of electricity. These together can provide greater benefits from the load control and increase the consumers' interest towards HEMS-solutions. Still, the investment cost of HEMS needs to be reduced. The costs are likely to decrease relatively fast as the energy efficiency equipments are currently becoming more general fast.

One of the objectives for this work was to evaluate the opportunities for the market actors from HEMS. Some of the potential opportunities were evaluated, like the possibility to steer the loads with HEMS. These possibilities would require a system that would enable to control a large number of HEMS-units collectively. Suppliers could use HEMS database to elaborate the consumption prognosis and to steer the loads away from the peak price hours. The potential savings that could be achieved with the loads of private consumers are limited, based on the evaluations. A major obstacle to this is the small amount of load that can be steered in comparison with the required investments. Electric heating would have the biggest potential for this, but this load is available only during the winter time. The biggest needs for load steering would be to reduce the consumption during the highest peak power hours of 8-10 a.m., 5-7 a.m. This operation is difficult to achieve with the other loads of private consumers. During those times there is a lot of usage for cookers, entertainment devices and so on. The willingness of the consumers to reduce this kind of consumption is low. In addition the consumers would most likely expect to have compensation in order to allow the load steering. This further reduces the potential economic benefits for the market actors.

Theoretically, DSOs could use load steering locally to level the power fluctuation. This would enable to optimize the network investment as there would be a decreased need to plan the network according to the short peak power periods. Also the decreased peak power level could delay the investment need in a network. Current regulation model encourages the investments as the level of incomes can be greater when the network investment increase. This reduces the potential for this opportunity. In addition, it was calculated that how the large scale steering of reserving heating could affect the distribution losses. The resulting benefits were low when compared with the required amount of HEMS-units that would be needed. Again, the reserving heating loads have already been shifted into the off-peak hours so by further shifting them there are no significant benefits available.

In this work also some possible operation models around HEMS were discussed. Suppliers and DSOs could have potential to act as a delivery channel for this kind of service in the future. They already have a large customer base, which is a benefit regarding the promotion and delivery of this kind of service. Especially the DSOs have a long-term relationship with the customer. On the other hand, the market processes like supplier switching and the lack of electrician resources are obstacles for the suppliers to deliver this kind of service. Even though NordREG has stated that the future energy efficiency services should be run by the actors in the free market, the DSOs could also provide valuable support for providing the services, even if the central role in offering these kinds of services would be too far away from the core business of the DSO. Therefore the future role of the DSO cannot be totally excluded.

Briefly, it would seem unlike that current market actors would offer HEMS as an energy efficiency service for the private customers with the piloted cost level and evaluated benefit opportunities, if it does not provide additional opportunities or it is not required by the legislation. Therefore HEMS is mainly a business opportunity for the service providers. If energy companies are required to offer this kind of service for the consumers in the future, the co-operation with a service provider would most likely be beneficial as it would enable the efficient division of required resources. From the customer point of view, the current internet services provided by the DSOs already enable good possibilities to learn more efficient energy usage if a customer is active and truly motivated. These services are currently regarded as beneficial and should be further developed.

Further study

In this work some of the possibilities and benefits for the market actors around large-scale implementations of HEMS were introduced. The pilot demonstrated that it is possible to reliably steer for example customer's electric heating according to the market prices by adding home automation. Still, in order to enable the effective utilizing of the potential benefits for the market actors the load steering should be performed according to their needs. To achieve benefits in real electricity market environment the solutions would need to be developed to control a large number of HEMS-units collectively. This requires active co-operation and piloting with suppliers, DSOs, service providers and consumers.

During the pilot study, the customers were not provided with dynamic pricing rates that would have given real incentives to steer the consumption according to the price signals and fully utilize the possibilities of HEMS. For this reason, some of the functionalities of the HEMS were not seen as meaningful. If the pilot customers would be provided with a for example spot-price based electricity contracts, the relevance of for example alert messages related to the high level of electricity consumption or high electricity prices would increase. In the future also the new distribution tariff structures can give more incentives to control the electricity consumption as the distribution costs can be more depended on the power demand.

On the other hand, the pilot could be further utilized by demonstrating the direct load steering. This could be done by developing a load steering algorithm that would steer certain loads. This could enable to study that how much power could be available for load steering collectively from a certain number of private households during certain times of the day. This could be used for example to determine if it would be realistic to control large number electric heating loads in order to operate in a balance market. Furthermore, in the literature there is commonly discussion about the compensations that would be paid for the customers due to load steering. Once the load steering would have been demonstrated it would be possible to discuss with the customers what would be the expected level of compensations for load steering. This is an important aspect as it will affect significantly the overall profitability of load steering initiated by a certain market actor.

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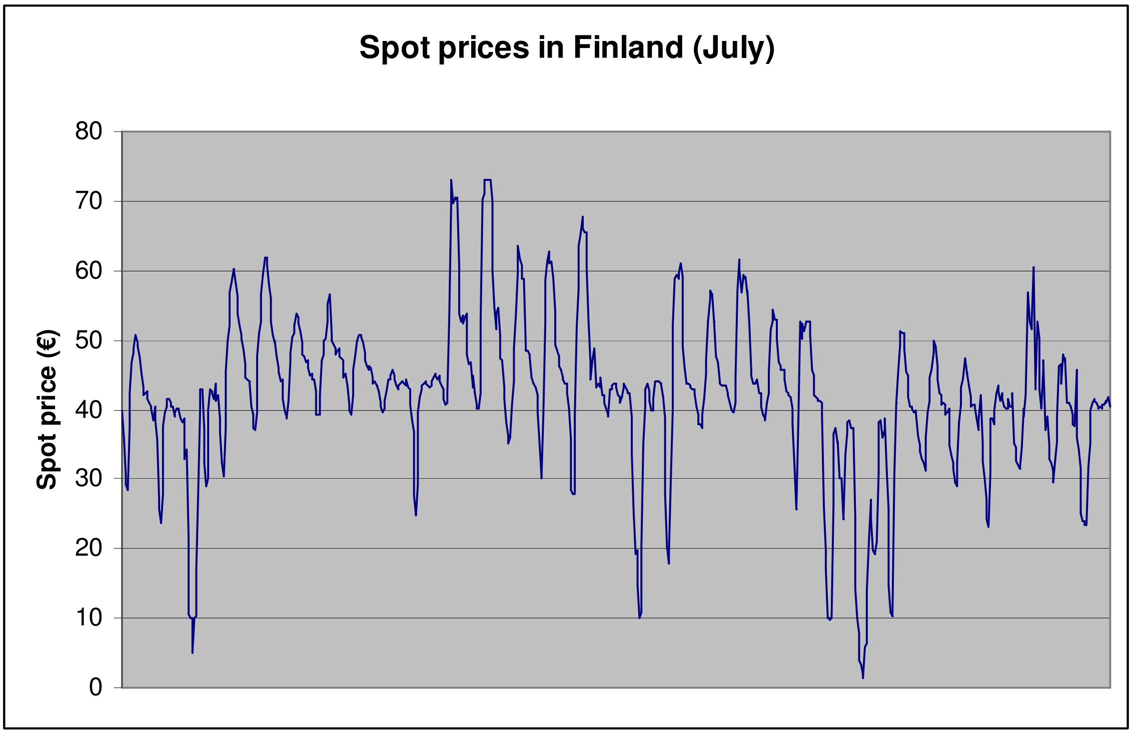
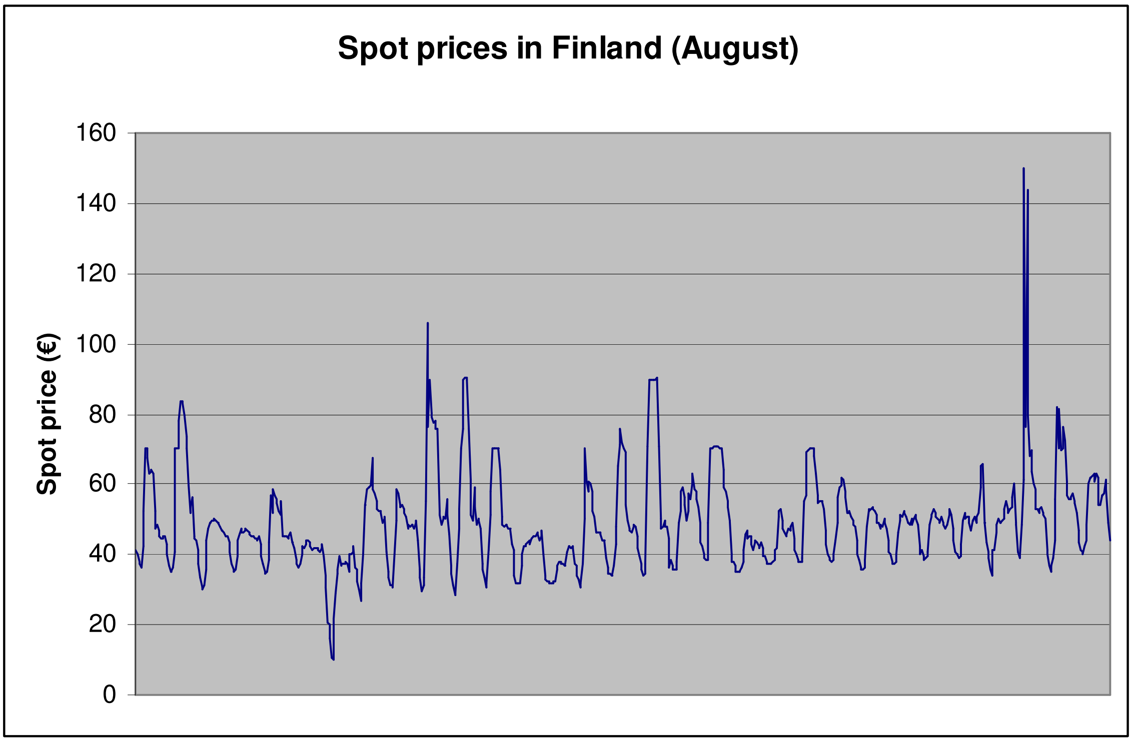
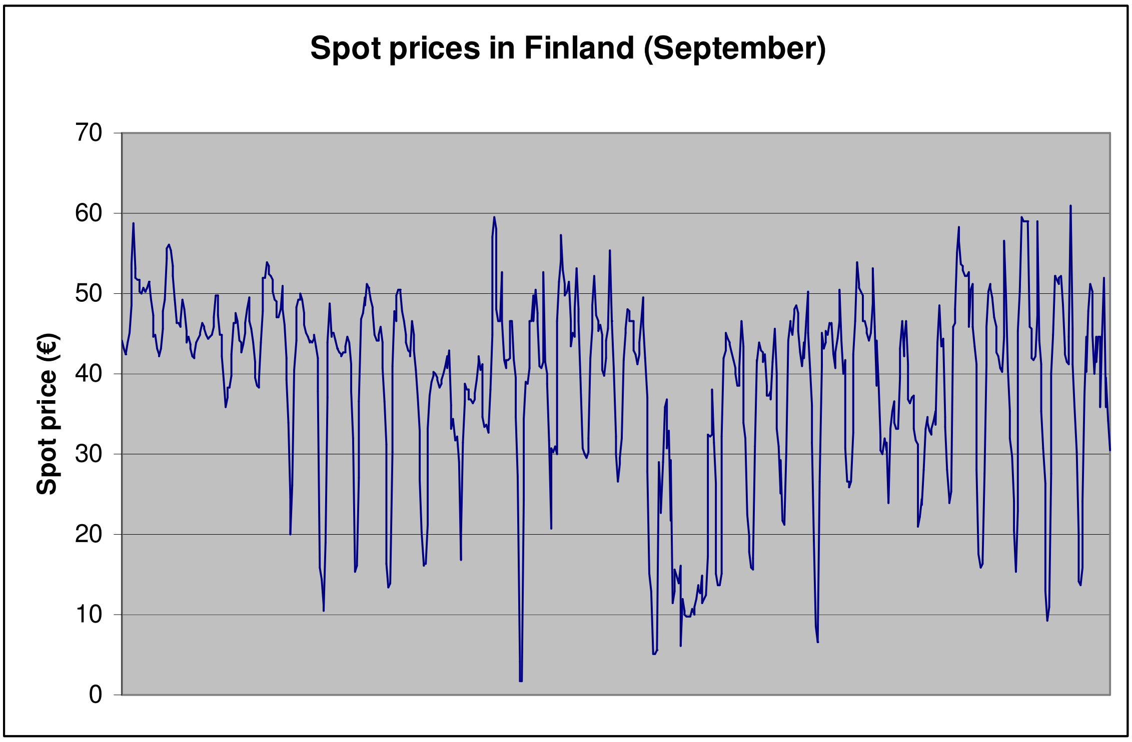
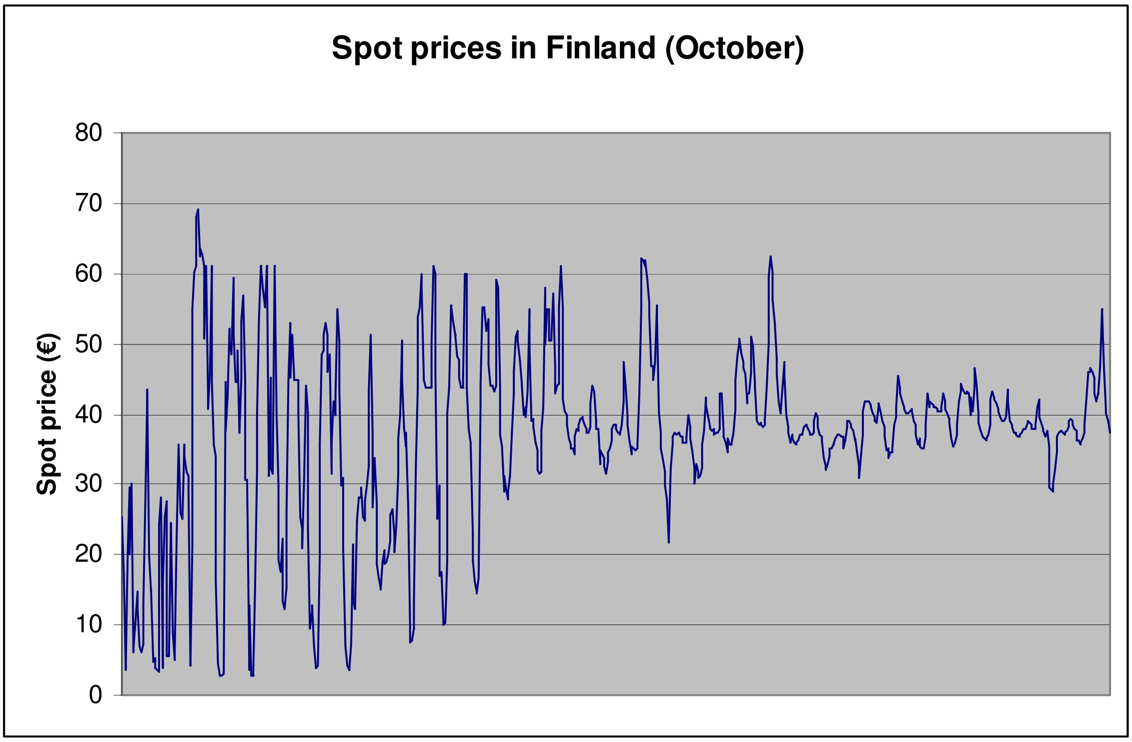
APPENDIX

APPENDIX 1. SPOT PRICE OF ELECTRICITY IN FINLAND DURING THE PILOT






Spot prices in Finland (September)
Spot price (€)
0
10
20
30
40
50
60
70


Spot prices in Finland (October)
Spot price (€)
0
10
20
30
40
50
60
70
80

APPENDIX 2. THE RESULTS FROM THE CUSTOMER SURVEY. (PICTURES REMOVED)

Syntymävuosi

	Vastaus	Lukumäärä	Prosentti
1.	1900-1950	58	31,52 %
2.	1950-1969	71	38,59 %
3.	1970-1989	55	29,89 %
4.	1990-	0	0,00 %
	Yhteensä	**184**	**100 %**

Valitse koulutustasi parhaiten kuvaava vaihtoehto

	Vastaus	Lukumäärä	Prosentti
1.	Peruskoulu	14	7,57 %
2.	Lukio/Ammatillinen oppilaitos	66	35,68 %
3.	Alempi teknillinen korkeakoulutus	41	22,16 %
4.	Muu alempi korkeakoulutus	11	5,95 %
5.	Tekninen korkeakoulutus	29	15,68 %
6.	Muu korkeakoulutus	24	12,97 %
	Yhteensä	**185**	**100 %**

Asumismuoto

	Vastaus	Lukumäärä	Prosentti
1.	Omakotitalo	135	73,37 %
2.	Rivitaloasunto	37	20,11 %
3.	Kerrostaloasunto	8	4,35 %
4.	Muu	7	3,80 %
	Yhteensä		

Arvioi vuosittaista sähkönkulutustasi

	Vastaus	Lukumäärä	Prosentti
1.	30 000 kWh -	5	2,70 %
2.	25 000 - 30 000 kWh	13	7,03 %
3.	20 000 - 25 000 kWh	24	12,97 %
4.	15 000 - 20 000 kWh	50	27,03 %
5.	10 000 - 15 000 kWh	48	25,95 %
6.	Alle 10 000 kWh	45	24,32 %
	Yhteensä	**185**	**100 %**

Valitse kotisi pääasiallinen lämmitysmuoto

	Vastaus	Lukumäärä	Prosentti
1.	Suora sähkölämmitys (Sähköpatterit tms)	76	41,53 %
2.	Varaava sähkölämmitys (Varaava yöaikaan lämmitettävä lattialämmitys tms)	23	12,57 %
3.	Kaukolämpö tai öljylämmitys	32	17,49 %
4.	Lämpöpumppu	35	19,13 %
5.	Muu	17	9,29 %
	Yhteensä	**183**	**100 %**

Testattua energianhallintajärjestelmää käytetään web-pohjaisen käyttöliittymän avulla ja sähkön kulutustiedot luetaan sähköverkkoyhtiön mittarista. Tietoa siirretään langattomasti, mikä asettaa rajoituksia näiden laitteiden välisille etäisyyksille. Missä oma sähkömittarisi sijaitsee?

	Vastaus	Lukumäärä	Prosentti
1.	Sisällä tuulikaapissa	73	39,46 %
2.	Talon ulkoseinällä	31	16,76 %
3.	Ulkona varasto- tai autotallirakennuksessa	39	21,08 %
4.	Sähköpylväällä	12	6,49 %
5.	Muu	30	16,22 %
	Yhteensä	**185**	**100 %**

Onko käytössäsi laajakaistayhteys (nopea internetyhteys)? Jos käytössäsi on laajakaista, miten kaukana sähkömittarista laajakaistan keskusyksikkö sijaitsee?

	Vastaus	Lukumäärä	Prosentti
1.	Minulla ei ole laajakaistayhteyttä	20	10,81 %
2.	Noin 0-5 metrin etäisyydellä sähkömittarista	41	22,16 %
3.	Noin 5-10 metrin etäisyydellä sähkömittarista	62	33,51 %
4.	Yli 10 metrin etäisyydellä sähkömittarista	62	33,51 %
	Yhteensä	**185**	**100 %**

Käytätkö Vattenfallin OnLine-palvelua säännöllisesti?

	Vastaus	Lukumäärä	Prosentti	HP	%	P	%	Rest	%
1.	Kyllä, vähintään kerran kuukaudessa	98	53,26 %	7	53,8	44	50,0	47	54,7
2.	Kyllä, viikoittain	35	19,02 %	4	30,8	17	19,3	14	16,3
3.	En käytä säännöllisesti	51	27,72 %	2	15,4	26	29,5	23	26,7
	Yhteensä	**184**	**100 %**						

Ohessa oleva kuva havainnollistaa palvelua, joka mahdollistaa sähkön kulutuksen seuraamisen reaaliajassa. Tässä tapauksessa kulutus esitetään graafina, mutta se voisi olla myös lukemana. Olisiko sinulla tarve/halu seurata sähkön kulutusta aiempaa tarkemmin, käytännössä reaaliaikaisena?

	Vastaus	Lukumäärä	Prosentti	HP	%	P	%	Rest	%
1.	Kyllä	151	82,51 %	12	92,3	72	81,8	67	77,9
2.	Ei	32	17,49 %	1	7,7	15	17,0	16	18,6
	Yhteensä	**183**	**100 %**						

Kokisitko saavasi hyötyä reaaliaikaisesta kulutustiedosta?

	Vastaus	Lukumäärä	Prosentti	HP	%	P	%	Rest	%
1.	Tieto toisi huomattavia hyötyjä ja mahdollisuuksia	53	29,12 %	6	46,2	25	28,4	22	25,6
2.	Tiedosta saattaisi olla jotain hyötyä	116	63,74 %	6	46,2	54	61,4	56	65,1
3.	En usko tiedon tuovan merkittäviä hyötyjä	13	7,14 %	1	7,7	7	8,0	5	5,8
	Yhteensä	**182**	**100 %**						

Olisiko sinulla kiinnostusta siirtyä tuntipohjaiseen sähkösopimukseen?

	Vastaus	Lukumäärä	Prosentti	HP	%	P	%	Rest	%
1.	Kyllä	24	13,04 %	3	23,1	10	11,4	11	12,8
2.	En osaa sanoa, tarvitsen lisää tietoa asiasta	127	69,02 %	7	53,8	62	70,5	58	67,4
3.	Ei	33	17,93 %	3	23,1	16	18,2	14	16,3
	Yhteensä	**184**	**100 %**						

Miten paljon olisit valmis maksamaan kuukausitasolla mahdollisuudesta nähdä taloutesi kokonaissähkönkulutus reaaliajassa vaikkapa internetin kautta?(Vain tämä yksi lisäominaisuus tulisi siis käyttöön verrattuna esim. nykyisen OnLine-palvelun ominaisuuksiin)

	Vastaus	Lukumäärä	Prosentti	HP	%	P	%	Rest	%
1.	30-40 euroa	0	0,00 %	0	0,0	0	0,0	0	0,0
2.	20-30 euroa	1	0,54 %	0	0,0	0	0,0	1	1,2
3.	10-20 euroa	1	0,54 %	0	0,0	0	0,0	1	1,2
4.	5-10 euroa	8	4,32 %	1	7,7	1	1,1	6	7,0
5.	1-5 euroa	33	17,84 %	1	7,7	16	18,2	16	18,6
6.	Olisin kiinnostunut mahdollisuudesta, mutta en haluaisi maksaa siitä erikseen	134	72,43 %	10	76,9	69	78,4	55	64,0
7.	En ole lainkaan kiinnostunut palvelusta	8	4,32 %	1	7,7	2	2,3	5	5,8
	Yhteensä	**185**	**100 %**						

Entä miten paljon olisit valmis maksamaan kertaluonteisesti erillisestä pienestä näyttölaitteesta, jonka voisi sijoittaa haluamaansa paikkaan ja josta olisi mahdollista yhdellä vilauksella tarkistaa talouden sen hetkinen sähkönkulutus ja vaikkapa vuorokauden kokonaiskulutus?

	Vastaus	Lukumäärä	Prosentti	HP	%	P	%	Rest	%
1.	200-250 euroa	0	0,00 %	0	0,0	0	0,0	0	0,0
2.	150-200 euroa	3	1,62 %	0	0,0	1	1,1	2	2,3
3.	100-150 euroa	4	2,16 %	0	0,0	0	0,0	4	4,7
4.	50-100 euroa	23	12,43 %	3	23,1	10	11,4	10	11,6
5.	20-50 euroa	57	30,81 %	5	38,5	24	27,3	28	32,6
6.	Olisin kiinnostunut laitteesta, mutta en maksaisi siitä erikseen	79	42,70 %	4	30,8	45	51,1	30	34,9
7.	En ole lainkaan kiinnostunut laitteesta	19	10,27 %	1	7,7	8	9,1	10	11,6
	Yhteensä	**185**	**100 %**						

Ohessa on taulukko sähkön tuntihinnoista yhden vuorokauden ajalta. Hintojen vuorokauden sisäinen vaihtelu on usein taulukon hintojen kaltaista. Hinnat ovat muodossa snt/kWh.Olisiko sinulla kiinnostusta siirtyä tuntipohjaiseen sähkösopimukseen?

	Vastaus	Lukumäärä	Prosentti	HP	%	P	%	Rest	%
1.	Kyllä	31	16,85 %	5	38,5	15	17,0	11	
2.	En osaa sanoa, tarvitsen lisää tietoa asiasta	118	64,13 %	5	38,5	56	63,6	57	
3.	Ei	35	19,02 %	3	23,1	17	19,3	15	
	Yhteensä	**184**	**100 %**						

Olisitko valmis siirtämään paljon sähköä kuluttavien kodinkoneiden tai vaikkapa sähkösaunan käyttöä muuttuvan sähkönhinnan mukaan saadaksesi säästöä?

	Vastaus	Lukumäärä	Prosentti	HP	%	P	%	Rest	%
1.	Kyllä	130	71,43 %	8	61,5	65	73,9	57	66,3
2.	En	52	28,57 %	5	38,5	22	25,0	25	29,1
	Yhteensä	**182**	**100 %**						

Olisitko valmis vähentämään sähkönkulutustasi erityisen kalliiden tuntien aikana esimerkiksi kytkemällä sähkölämmitystä hetkellisesti pois päältä ja polttamalla puuta sen sijaan?

	Vastaus	Lukumäärä	Prosentti	HP	%	P	%	Rest	%
1.	Olisin valmis tekemään aktiivisesti toimia sähkönkulutuksen pienentämiseksi kalliiden tuntien aikana	78	42,62 %	4	30,8	37	42,0	37	43,0
2.	Olisin valmis tekemään satunnaisia toimia	84	45,90 %	7	53,8	44	50,0	33	38,4
3.	En olisi valmis tekemään toimia	21	11,48 %	2	15,4	6	6,8	13	15,1
	Yhteensä	**183**	**100 %**						

Pilotin energianhallintajärjestelmä mahdollistaa kodin ja sähkölämmityksen reaaliaikaisen sähkönkulutuksen seuraamisen ja sähkölämmityksen älykkään ohjauksen. Vuodessa 20000 kWh kuluttavalle kotitaloudelle tämä voisi tuoda jopa 200-300 euron säästöt, jolloin järjestelmä maksaisi itsensä takaisin 3-5 vuoden kuluessa. Miten paljon olisit valmis maksamaan tällaisesta järjestelmästä kuukausitasolla ja kahden vuoden ajan?

	Vastaus	Lukumäärä	Prosentti	HP	%	P	%	Rest	%
1.	60-80 euroa	0	0,00 %	0	0,0	0	0,0	0	0,0
2.	40-60 euroa	0	0,00 %	0	0,0	0	0,0	0	0,0
3.	30-40 euroa	2	1,10 %	0	0,0	1	1,1	1	1,2
4.	20-30 euroa	4	2,20 %	0	0,0	1	1,1	3	3,5
5.	10-20 euroa	58	31,87 %	4	30,8	34	38,6	20	23,3
6.	Hankkisin järjestelmän mieluiten kertaluonteisella hankintahinnalla	71	39,01 %	7	53,8	33	37,5	31	36,0
7.	En ole lainkaan kiinnostunut kyseisestä järjestelmästä	47	25,82 %	2	15,4	17	19,3	28	32,6
	Yhteensä	**182**	**100 %**						

Olisitko valmis hankkimaan energianhallintajärjestelmän kertaluonteisella hankintahinnalla, joka olisi..?

	Vastaus	Lukumäärä	Prosentti	HP	%	P	%	Rest	%
1.	1500-2000 euroa	0	0,00 %	0	0,0	0	0,0	0	0,0
2.	1000-1500 euroa	1	0,55 %	0	0,0	0	0,0	1	1,2
3.	750-1000 euroa	2	1,10 %	0	0,0	0	0,0	2	2,3
4.	500-750 euroa	10	5,49 %	0	0,0	5	5,7	5	5,8
5.	200-500 euroa	68	37,36 %	8	61,5	36	40,9	24	27,9
6.	Hankkisin järjestelmän mieluummin kuukausimaksulla	53	29,12 %	3	23,1	28	31,8	22	25,6
7.	En ole lainkaan kiinnostunut kyseisestä järjestelmästä	48	26,37 %	2	15,4	16	18,2	30	34,9
	Yhteensä	**182**	**100 %**						

Montako vuotta arvioisit olevan kohtuullinen takaisinmaksuaika edellä kuvatulle energianhallintajärjestelmälle?

	Vastaus	Lukumäärä	Prosentti	HP	%	P	%	Rest	%
1.	Yli 5 vuotta	17	9,29 %	2	15,4	5	5,7	10	11,6
2.	Noin 4 vuotta	17	9,29 %	2	15,4	4	4,5	11	12,8
3.	Noin 3 vuotta	31	16,94 %	2	15,4	20	22,7	9	10,5
4.	Noin 2 vuotta	63	34,43 %	5	38,5	35	39,8	23	26,7
5.	Noin 1 vuosi	20	10,93 %	0	0,0	8	9,1	12	14,0
6.	En ole lainkaan kiinnostunut kyseisestä järjestelmästä	35	19,13 %	2	15,4	15	17,0	18	20,9
	Yhteensä	**183**	**100 %**						

APPENDIX 3. PRICE INFORMATION OF 2011.