CHALMERS

Evaluation of Demand Response Systems for Smart Grids: state of the art, value potential and the Hyllie case

Master's Thesis within the Sustainable Energy Systems programme

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CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2013

MASTER’S THESIS 2013: DATX05

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ABSTRACT

The thesis is made in order to investigate potentials for reducing or shifting electricity consumption at the demand side. There are many questions none solved within the topic and the aim is to answer some of these questions. The method for reducing or shifting electricity consumption at the demand side is named Demand Response and there are many varieties within the concept. Electricity consumption should be reduced and/or shifted to eliminate GHG emissions, decrease costs, ensure safe electricity supply and enable more integration of renewable intermittencies. There is no such system completed in commercial and large scale projects in Sweden and therefore it is of interest to investigate Demand Response. The project method is literary research and the result comprise of the information and reflections done about Demand Response, in Sweden as well as from international studies. The result also consists of three business models for the role of aggregator in a Demand Response System. Demand Response aggregation is a new concept for the power system and is therefore important to be analyzed. Calculation of saving potentials for residential customers was performed. This calculation shows very small saving potential for customers and the reason for that is lack of regulations and technology to make Demand Response profitable. Learnings from the work is complexity in energy markets, the role of economic incentives for participants, technological possibilities within energy and communication technologies and the great importance of standards and cooperation among organizations. The largest implication was to find relevant information as the topic is comparatively unexplored of today. Behaviour and consumption patterns are aspects that are difficult to foresee and hence the response from higher electricity prices is hard to tell.

Key words: Demand Side Management, Demand Response, Demand Response Systems, Demand Response Programs, Sustainable city, Smart Grid, Smart home, Smart City, Aggregators, Communication Standards

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Examensarbete inom masterprogrammet *Sustainable Energy Systems*

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SAMMANFATTNING

Examensarbetet syftar till att undersöka möjligheterna för att reducera och/eller skifta elförbrukningen på efterfrågesidan. Många frågor inom ämnet är ännu obesvarade och syftet med projektet är att försöka besvara några av dessa. Metoden kallas efterfrågerespons och är ett brett begrepp för att effektivisera elförbrukningen. Elförbrukningen bör reduceras och/eller skiftas för att eliminera utsläppen av växthusgaser, minska kostnader, garantera säker elförsörjning och för att möjliggöra mer integrering av förnybar energi. Det finns idag inget kommersiellt system i stor skala i Sverige och därför är det av intresse att undersöka potentialen för efterfrågerespons. Projektmetoden är litteraturforskning och resultatet består av information och analyser om efterfrågerespons i Svenska såväl som från internationella studier. Resultatet visar också tre affärsmodeller för rollen som aggregator i ett efterfrågeresponssystem. Aggregering i ett sådant system är ett nytt koncept för elsystemet och är därför viktig att analyseras. Beräkningar av besparingspotential för privatkunder utfördes och visar en mycket liten besparingspotential för kunder. Anledningen till det är bristen på reglering och teknik för att göra efterfrågerespons lönsam. Lärdomar från arbetet är komplexiteten i energimarknaderna, vikten av ekonomiska incitament, förutsättningar för energi- och informationsteknik samt betydelsen av standarder och samarbete mellan organisationer. Den största utmaningen var att hitta relevant information eftersom ämnet är relativt outforskat i dag. Beteende och konsumtionsmönster är aspekter som är svåra att förutse och därmed också effekten av att åskådliggöra de högre elpriserna under höglasttimmar.

Nyckelord: Efterfrågestyrning, Efterfrågerespons, Efterfrågeresponssystem, Efterfrågeresponsprogram, Hållbara städer, Smarta Nät, Smarta hem, Aggregator, kommunikationsstandard

Contents

Preface

This thesis aims at investigating state of the art value potential for stakeholders in a demand response energy system. As there is little research and knowledge about this topic, the method behind is literary study and analysis of available information taken from companies, organisations, government and scientific articles, no physical data about demand response was available. The thesis is carried out at the department of Computer Science and Engineering and valuable information has been obtained from the examiner, Marina Papatriantafilou, and supervisor, Georgios Georgiadis, Chalmers. Discussions and seminars of professors from the energy department gave information about energy and market systems. The thesis was made in cooperation with E.ON and initial study visits and meetings provided with information to the thesis. From this information collected, conclusions, analysis and business models are based on gained knowledge from the Master program this thesis belongs to, Sustainable Energy Systems, Chalmers university of Technology, Sweden. Data related to the calculation part for saving potential is collected from the Swedish Energy Authority, Energimyndigheten.

Göteborg June 2013

Notations

SC	Shifted consumption
RC	Reduced consumption
$P_{average}$	Average electricity price
P_{max}	Peak hour electricity price
ΔP	Electricity price difference between peak and off-peak hours

1 Introduction

Seemingly endless, rather diffuse and sometimes ungraspable discussions go on how to solve the climate change. We all know that something has to be done, and that is soon. From the perspective of energy in general and sustainable cities in particular, this thesis will give some state-of-the-art ideas of how to solve fragments of the problem using demand response.

The five Nordic countries of Sweden, Denmark, Norway, Finland and Iceland have together announced goals for decarbonising their energy system by 2050. The International Energy Agency, IEA, defined five challenges facing the process. The first two consider energy efficiency improvements, especially for buildings and industries and development of the electric grid [1]. These are two aspects touching upon the development of sustainable cities, but far the only ones.

Michel Delebarre, Mayor of Dunkerque France, state the importance of European cooperation with long-term commitments, universal concepts and the importance of being pro-active. He says that policies, economies, jobs and growth must all be seen from an environmental perspective in order to create sustainable cities [1]. Janez Potocnik [2] from the European Commission of the Environment shares the same opinion that sustainable cities can only be created by cooperation and heading towards the same targets. The economic crisis in Europe caused hard times for many countries and the political agendas have now strong focus on economic growth. Some people may argue that environmental measures should take place when the economy is stable and when there are enough resources to put in. The perception from the Conference of Sustainable Cities, Geneva 2013, was of different connotation where a common opinion was that economy, growth and sustainability make positive synergies and does not inhibit each other. Mr. Potocnik expresses it as

> "*We are not aiming for a green growth agenda, we are aiming for a growth agenda that happen to be green*".

His point is that a growth agenda automatically will be green as they are strongly connected.

Another well formulated statement of Wolfgang Teubner, Regional Director of ICLEI Europe is that

> "*The notion that social and environmental concerns need to be put on hold until the economic crisis has been solved fails to recognise the linkages between these. There are huge opportunities to strengthen the local economy through sustainable investments. There is enormous potential for economic benefits through smart spending for example on improving the energy performance of buildings, better water resource management and adapting cities to the impacts of climate change.*"

This linkage between economy and sustainable investment is described by circular economy, equated of "cradle to cradle" from a socioeconomic perspective. We should see waste as a resource and that applies to all kind of actions taken.

Apart from political challenges there are technological needs, both improvement of existing and development of new technologies. Denmark aim for a 50% integration of wind power and Kåberger [3] explains how wind power has increased more than predicted worldwide. Solar PV is also increasing and intermittent energy requires smart technologies for maximum utilization. Energy storage is so far limited but integrated complex systems of networks, demand response and energy efficiency will help in using renewable energy as a source.

Lastly, imagine a person switching off the lamp remotely from a smart phone, a household where air conditioning is tuned down automatically during high peaks and a neighbourhood prosuming energy from a wind turbine. These are parts of a smart city where energy is used efficiently. Response to electricity prices affect the demand side of energy and smart technologies along with integrated information systems are needed to control the consumption.

1.1 Background

As a part of a Master program in Sustainable Energy Systems at Chalmers University of Technology Sweden a final thesis is conducted with focus on energy systems. The thesis reflects parts of what is learned from the Master program and contains topics as Energy Market, energy technologies and environmental related concerns. The cooperation with E.ON was initiated together with the examiner and supervisor who are currently working with E.ON. From 2011 E.ON is taking part of a sustainable city project in Hyllie, Sweden. The goal of Hyllie is to make a climate smart city area with smart energy solutions and technologies. Demand response, targeting a market based electricity system, is a fairly new concept only tried out in a small extent around the world. The background of this thesis is the need of research and investigation of demand response in the Nordic Energy Market.

1.2 Aim of the thesis

The aim of this thesis is to analyze and investigate values for stakeholders and actors participating in a demand response electricity system. In order to find the potential values, all actors and their role in the system must be defined and identified. Customers are one of the main actors and one part of the report is dedicated to find incentives and models for customer participation. Optimal solutions in terms of business models will be investigated and defined for the main stakeholders participating in the current energy market. This part focuses on finding solutions to integrate stakeholders in an efficient and cost economic way. In summary, the aim is to find incentives and values for all parts affected by implementation of demand response in the Nordic Energy System.

1.3 Method

The method behind this work is literary study and analysis of existing information from i.e. companies, organizations and authorities. The information gained is used to create understanding of the requirements for a demand response system, which is then used to develop business models aiming to combine the different stakeholders involved in a demand response system. Calculations are performed to find cost saving potential for residential customers by reducing or shifting parts of the household appliances. This data was taken from the Swedish energy authority, Energimyndigheten, and reflects the consumption from 81 average apartment families in Sweden.

2 Hyllie and the current Electricity Market

This chapter introduces the future city area of Hyllie, the energy targets and the vision for this sustainable city. It also explains the current Energy Market situation and the actors involved. Finally, the Swedish regulations for the energy system are described.

2.1 Hyllie

An introduction of Hyllie and what is planned for the area.

2.1.1 Background and vision of Hyllie

Hyllie is a city district of Malmö constituting an area of 900 ha and 32000 citizens and is located in the southern part of Malmö, Sweden. The ambition for Hyllie is to make it a climate smart city and to act as a model for sustainable cities in Sweden as well as for the rest of the world. A climate contract was signed in February 2011 by the municipality of Malmö, VA SYD and E.ON. Hyllie has an important role to play in order for Malmö to reach their environmental targets. The area is now undergoing construction and planning and the result will be a sustainable city. Hyllie will consist of residential apartments, houses and business facilities such as Malmö Arena, Malmö fare-hall and Emporia shopping mall. Finally, 9000 apartments and equally amount of working places are planned until 2030. The recreational area around the city is carefully planned for the inhabitants and a big park will surround the place [4]. Smart grids and smart energy solutions will make the inhabitant able to control, steer and measure their energy consumption. The inhabitants of Hyllie will also act as prosumers that will not only consume but also produce their energy and thereby have the oportunity to utilize it or even sell it. It is important to consider possible future changes and development that might occur. This may be changes in environmental policies, building constructions or energy targets. Well-planned bike and pedestrian lanes in combination with car-pooling possibilities will make it easy and comfortable for people to act and live green. Besides the environmental aspects there should be a sustainable economy focus.

2.1.2 How to make a Smart City

Energy technology, participating inhabitants, policy instruments and smart home management systems are some of the factors of creating a sustainable city. The interaction between technology and peoples' behaviour is important. All energy in Hyllie is planned to be renewable and/or recycled until 2020 and have a high degree of self-sufficiency. Efficient resource structures for transport infrastructure and land use are some key questions in the holistic perspective. Interaction between sewage, waste and water is also important to make an efficient energy flow. Household waste is recycled and food waste is turned into biogas. Electricity, gas, heating and cooling are to be carefully planned and integrated together with smart infrastructure. The buildings should use little energy but also to be compatible with the energy systems planned in Hyllie. A main part of the energy used in Hyllie shall be locally produced from renewable energy sources like wind and solar power [5]. Intermittent energy sources require smart energy systems. By shifting consumption when energy is produced or by storing electricity maximum utilization of intermittent energy sources can be achieved. As can be seen, there are many actors, stakeholders and instances involved in such a system.

2.2 Electricity Market

The electricity market consists of many different actors having an important role in the energy systems. The main actors and their role are defined below. Further on the process of market trading is described.

2.2.1 Market Actors

Deregulation of the electricity markets introduced new entities in the electricity market place. Different entities exist across market structures and on a broad level the following actors can be identified according to *figure 1*.

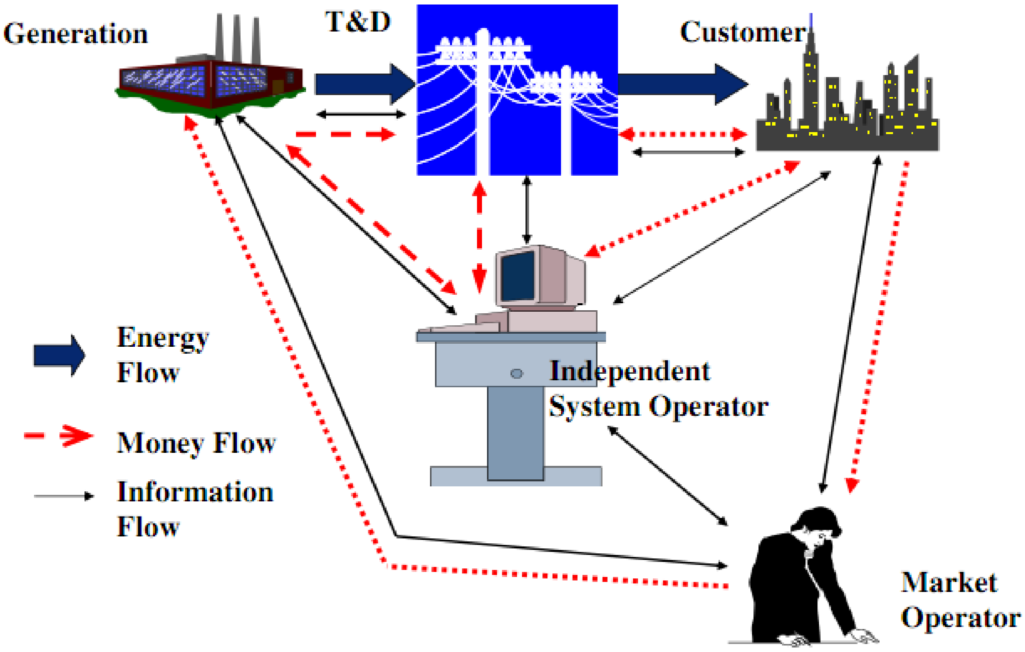

Figure 1. The Nordic Electricity Market [6]

*Generating companies (Gencos).*The generators produce and sell electrical energy. A generating company can own a single generating unit (power plant) or a group of generating units, which then is referred to as independent power producers (IPP). They can also contribute to regulation, voltage control and reserve capacity. These services can be sold to the system operator who needs to maintain the quality and security of the electricity supply [7].

Transmission Companies (Transcos). The transmission companies coordinate, control and monitor the transmission network. They own transmission assets such as cables, lines, transformers and reactive compensation devices and they operate this equipment according to the instructions of the independent system operator ISO [7]. Their main responsibility is to transfer the electricity from the generators to the consumers and enable transmission wires to be available for all entities in the system. They are also responsible for development the transmission system in given areas in order to ensure long-term ability of the system to meet reasonable demands for the transmission of electricity [8].

Distribution Companies (Discos). The distribution companies own and operate the local distribution network in an area. They can have monopolies, sell electrical energy to all consumers connected to their network or they can be responsible only for operating maintaining and developing the distribution network and grid stability, integration of renewable energy sources at the distribution level and regional load balancing [9].

Retailers. Retailers do not own any large physical assets. They buy electrical energy on the wholesale market and sell it to consumers who cannot participate or wish to participate in the wholesale market. Some retailers are subsidiaries of generation or distribution companies. The customers of each retailer can be connected to different Discos [7].

Market operator (MO). The market operator runs the market settlement system. It matches the bids and offers which are submitted from buyers and sellers and determines the market price based on certain criteria according to the market structure. The MO monitors the delivery of energy and forwards payments from buyers to sellers [7].

Independent system operator (ISO). The ISO controls, coordinates and monitors the operation of the electric power system. It has the prime responsibility of ensuring the security and reliability of the power system. It is called independent as it does not participate in the electricity market trading. The system has to be operated in a fair way that does not treat one market participant better than another [7]. The ISO can provide supply of emergency reserves or reactive power from other entities in the system in order to preserve the system reliability and security. In the Swedish power system the ISO owns the transmission network and composes one entity with the TSO, namely the ISO/TSO (Svenska Kraftnät).

Regulator. The regulator is the governmental body entrusted with the responsibility to ensure a fair and efficient operation of the electricity sector. It sets the prices of the services and products that can be provided by the entities having monopolies [6]. It also establish rules for the electricity market and investigate cases in which market power may be misused [7].

Customers. A customer is an entity that consumes electricity. Small consumers are connected to the distribution system and they buy electricity from a retailer. Large consumers can, on the other hand, either buy electricity directly from the electricity market by bidding for purchase, or from a Genco [7].

Prosumers. A prosumer is a new entity concept that consumes but also can produce and store electricity [10]. Prosumers will be able to own and operate small or large parts of the power grid, transport electricity and they will obtain economic optimization according to their energy utilization [11].

Aggregators. Aggregators can offer services to aggregate energy production from different sources. In their services local aggregation of power demand and power supply from customers/prosumers can be included [8].

2.2.2 Market Trading

The electricity trading is divided in three different periods. Each period consists of different types of markets. The first period, *Forward/ Futures Market* takes place between a few years ahead to a few days ahead. During this period the different actors sign contracts that define the quantity and the price of the electricity that will be purchased. The second period constitutes of the *Day-ahead Energy Market*, the *Intra-day Adjustment Market* and the *Regulating Power Market*, *figure 2*. In the *Day-ahead Energy Market (Elspot)* the production schedule for the following day is determined, the trade is agreed and the price is set. *The Intra-day Adjustment Market (Elbas)* takes place during the day of delivery and help to reschedule generation and consumption. Prices in the *Intra-day Market* are set based on the first-come first-served principle. The *Regulating Power Market* ensures the balance between supply and demand during the delivery hour. After the operation hour the ex-post trading takes place. During that period the balance responsible party (BRP) makes the financial adjustments for the energy that finally delivered [12] [13] .

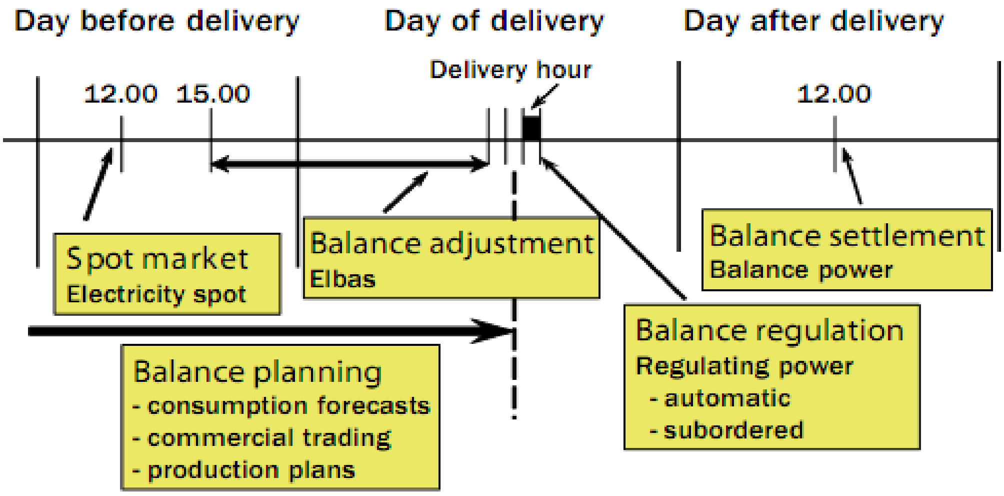

Figure 2. Time table for Market Trading **[12]**

2.3 Regulations - Ongoing transformations in the Swedish energy market

A directive applied in the European Union (EU) 2003 forced all member countries to open up their transmission networks under common regulations and to offer supply choices to their customers in 2007. Varieties in transmission capacities in different countries make outcomes vary, however transparency in electricity market pricing and supply increase. Support from organizations like European Transmission System Operators benefits this development. Nordpool is the first integrated international electricity market and consists of Sweden, Denmark, Norway and Finland. Nordpool allows hourly spot trading between the four countries and consumers can choose supplier as long as the transmission capacity allows [14].

According to the Swedish association Svensk Energi there are possibilities for the Nordic countries electricity production to be fossil free in 2030. In order to reach these goals it is necessary that the climate ambition for Europe as well as for Sweden goes hand in hand with the development in the rest of the world. Discussions go that global targets need to be determined for global common prices on carbon dioxide emissions. By switching from fossil fuels to electricity in i.e. the transport sector, energy efficiency will become significant and lower the total energy use. Hence, increased export of electricity from the Nordic countries to the rest of EU may lower the net emission in the region. Svensk Energi in cooperation with technology companies has defined a few tools to reach the goals. Some of the tools are reinforcement of the electricity grid to integrate more intermittency and to allow more export of electricity and to reduce losses. More efficient licensing processes to increase incentives for renewable production and support for development and research in alternative energy production are needed [15].

The Swedish energy market is a complex system with frameworks regulated by politics. Currently Sweden faces trends of more environmental legislations, increased security of supply combined with inquires for low energy prices. Production and power grids are closely coupled and changes on one affect the other and vise versa. A fundamental question about how to develop a business model for demand response is how the market looks like and on what level the solution should be found. Solutions can be found either on a market level or on physical levels like administering aggregated reserve capacity. Finland, as an example, relies mostly on the market based system to cover capacity demand and has very little reserves. Another concept is options-market for regulating power where power reductions can be traded with almost the same terms as for consumption power. This market is partly implemented in Norway where Statnett via the options-market invest in peak reserves at the producers. Sweden has a model for this type of reserve capacity market but it is not meant to be managed by Svenska Kraftnät as the aim is to use it only in case of a market collapse. The price setting is significantly high. There are discussions of what market makes the most important to increase demand response systems. Elbas, which is the Swedish hourly price market, and the regulating market require shorter response time from customer then as for the spot market. From this it can be argued that the spot market may have the largest potential for increased demand response. However, all markets are coupled and there need to be a parallel development within them all.

Implementation of demand response will make demand side flexible and hence stabilize the pricing. Pricing today is set by the production price of the most expensive technology on the margin but in reality the price may increase depending on demand. This implies that the most expensive technology may not have its total fixed cost covered and incentives for investing are small. A flexible mechanism may avoid this scenario as the demand side is better balanced. The price may exceed the marginal cost which lead to higher incentives for the producers and increased trust for customers on the market [16].

Sweden is since November 2011 divided into four electricity market zones with the aim to make a more fare electricity price and was a step towards the integrated energy market in the Nordic countries. This regulation was initiated at EU level in compliance with other Nordic countries to increase the benefit of the international market [17]. Regulation allows producers to connect to the grid as long as no special limitations take place. The DSO will charge producer the cost for connecting and is also responsible for the measuring of production and consumption at all connection points. The DSO hence sends this hourly measured data to the producer, retailer and TSO.

Future regulations for the Swedish energy market will in a high degree coincide with regulations set on EU level and discussions goes how to integrate markets on international level. Targets and processes in Sweden are and will therefore be based on decisions made on EU level [17].

2.3.1 Future scenario for energy production and consumption

Energimyndigheten made some predictions about future energy production and consumption in Sweden. Renewable energy production is predicted to increase until 2030 and a reason for that prediction is the fulfillment of electricity certificate system targets. Nuclear power is predicted to increase from 64 TWh 2007 to 73 TWh 2030. The combination of increased power production and a slightly increase in energy use will make Sweden a large net exporter of energy. The industrial energy use foresees an increase, mostly in biofuels but also in electricity. The reason is increased industrial production. The transition from oil and electricity heaters in residential buildings to other heating technologies make energy use decrease from 151 TWh 2007 to 133 TWh 2030. Energimyndigheten also made some sensitivity scenarios, for increase in economic growth and in fossil fuel prices. In case of a high economic growth, electricity use in Sweden will increase and the net export from Sweden to neighbor countries will not be that high. In case of higher prices of fossil fuels the electricity production will become more expensive and the electricity prices will increase. Hence the net electricity export will increase compared to the first case. It can be seen that high prices for fossil fuel benefit the use of renewable energy sources, contribute to development of energy efficient technologies and lead to a decreased net use of energy [18].

3 Demand Side Management and Demand Response

The electric power system of today requires a good balance of demand and supply, a smooth and stable delivery and environmentally friendly produced electricity to avoid climate change. Security of supply and a rising demand are two factors impelling demand side management and demand response which in general can be described as a wide concept for reducing and/or shifting energy demand. Reducing consumption by i.e. increasing efficiency, results in reduction in energy production which leads to less environmental impacts. Shifting implies to reallocate the energy use from high peak to low peak consumption hours. The following chapters will give a deeper understanding of the concepts.

3.1 Demand Side Management

Demand side management is an overall term expressed by different definitions and concept. According to IEEE

“Demand Side Management is a portfolio of measures to improve the energy system at the side of consumption. It ranges from improving energy efficiency by using better materials, over smart energy tariffs with incentives for certain consumption patterns, up to sophisticated real-time control of distributed energy resources”[19].

On the other hand, the U.S. Department of Energy relates Demand Side Management to response from price signals.

"Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.”[20].

These two definitions diverge slightly as the second definition focuses on response to peak time pricing while the first one also include efficiency measurement. This is where demand response comes into the picture.

3.2 Demand Response

“Demand response can be defined as the changes in electricity usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time”[21].

Demand Response is being more and more essential for the market and for the energy system. Shifting energy from peak hours to off-peak hours and hence distribute the load is one way to manage the demand side. These peaks are both costly to handle and a threat to the climate since marginal production technologies can be expensive and are usually fossil based. Shifting load curves can be done by demand response and there are plenty of customer participating programs for this purpose. These programs are divided in different categories depending on the purpose and market structure in place. Essential for these programs to work is smart metering devices that are placed inside participants’ buildings to measure consumption and to communicate on-time price of electricity. These devices use network communication systems to allow participants to control their consumption or load via smart phones or computers.

3.3 Demand Response Programs

There are different models for demand response programs: direct load control and price response control are two defined options. Load control enables customers to sign a contract about the reduction that could be controlled automatically without any further action from them. Price response control requires a higher degree of customer participation but that degree depends on the model used as explained further below. If the customers choose to be more involved there are models for manual response. A drawback with manual response is the lack of control when the customer leaves home for work or that the customer fall into patterns and thereby a lack of flexibility occurs. On the other hand there are reduced costs for technology by using manual response methods.

Different types of demand response programs are either implemented, at test level or at concept level. The international demand response programs raised below are examples of models discussed in USA. The Swedish models are concepts but defined to fit the existing Swedish market.

3.4 International Examples

These are some programs discussed on international level. The hierarchy used is shown in *figure 3*. DR programs are divided into incentive and price based programs. The first one has also two subcategories of classical and market based programs.

3.4.1 Incentive based programs, IBP

These programs do not use electricity prices to control consumption. Instead customers agree on reducing a certain amount of their load during critical events and are paid for that. There are two options to control the load. First it could be the utility that steers the load and makes actions when needed, second it could be the customers who make actions themselves in case of an event. Incentive based programs are divided into two categories, classical programs and market based programs.

3.4.1.1 Classical Programs

Classical programs give the customer a payment or discount rate for participating, the customers are thereby not paid for their performance.

Direct load control, DLC

Direct load control programs imply that the customer agree on giving control to the utility to switch off some devices in critical events. The shut off may take place a short time after the customer receives the signal. These devices can be heat pumps, HVAC systems, hot water boilers etc. The control prerequisites are determined from the beginning and the number of events for the customers is limited according to the contract. Customer gain is a discount on electricity price. The program is suitable for private customers as well as small commercial participants.

Interruptible/Curtailable load program, ILP

This program let the customer receive payment or discount rates for participating. The customer is asked to reduce their load to a predefined value. It they do not reduce there could be some kind of penalty depending on the contract used.

3.4.1.2 Market based programs

In the market based programs, customers save money according to their performance, i.e. the more they reduce or shift the more payment/saving they earn.

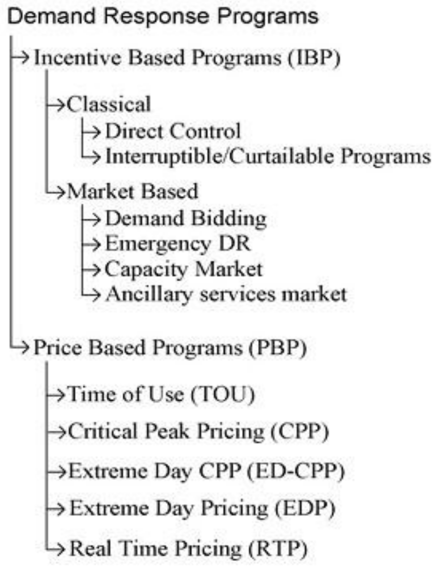

Figure 3. International DR programs

Demand Bidding

This program, sometimes called buyback program, is suitable for large consumers bidding on the wholesale market. The customer bid on how much reduction can be done in the next consuming period and the bid is accepted if it is lower than the market price. The customers gain money according to their performance but they will receive a penalty if the reduction they bid on is not achieved.

Emergency DR programs

In contrast to demand bidding programs, participants get incentives to reduce a certain load during emergency events and no bidding is applied.

Capacity Market programs

These programs are based on that the customer reduces their load according to a predefined amount of reduction when system contingencies occur. The reduction call comes 24 hours ahead and the customer may get a penalty if they do not reduce according to the defined amount.

Ancillary service market programs

Customers are here bidding on load reduction on the spot market as an operating reserve. When the bid is accepted the customers are paid the spot price for being on standby. If they reduce their load according to the bid, when they are asked to, they will get paid for their reduction according to the spot market price.

3.4.2 Price based programs, PBP

Price based programs are designed to lower consumption in high critical events or as a continuing incentive to reduce overall demand. Price based programs are based on dynamic pricing and the price is set according to the real time electricity price. The aim is to reduce the peak demand during specific hours and the method is to have high electricity prices during peak hours and lower prices during off-peak hours that make these programs steering towards the market.

Time of use tariffs, TOU

These tariffs are built on a model where the price varies within a predetermined time interval that is defined as high or low peak hours. The customer knows beforehand what the price will be in a certain hour or time. In comparison to real time pricing, this model has lower accuracy. This means that the actual supply and demand will not be reflected in the same way. Time tariffs can also be combined with a separate price for high peak load consumption, this would somewhat compensate for the drawbacks of inaccurate pricing compared to RTP. The simplest rate of TOU is to have two price levels, one peak price and one off peak price.

Critical Peak Pricing, CPP

CPP uses a higher electricity price during peak hours. This price is pre-determined and communicated to the customer some time ahead the event. CPP prices are used in a limited number of days or hours per year.

Extreme Day Pricing, EDP

EDP is similar to CPP and has higher electricity prices during peak events. However, it differs from CPP since the price is valid for the whole event day of 24 hours.

Extreme Day CPP, ED-CPP

This program is similar to EDP as it has high price on extreme peak days. In comparison, the off-peak price is fixed and not fluctuating as for EDP [21].

Real time pricing, RTP

This program makes the customer pay a real time price for their electricity. The price varies in time which creates an economic incentive to shift the demand. Customers receive price information a day-ahead or an hour-ahead depending on the market. An important aspect to consider is when to inform the customer about the price, if it is too near the actual time of use it could be difficult for the customers to act in time [16]. Many economists argue that RTP programs are the most efficient ones and that policymakers should focus on this type of programs.

3.5 Swedish Examples

There are larger and larger constraints on the Nordic electricity network and there are doubts of how the demand side can me managed properly with the market system existing today. Without a price-based demand response there are risks that the power production will not be enough to cover the demand. Elforsk identified a few concept models for demand response programs. The models aim to approach a market-based system for reserve capacity and effect problems. Three models were developed for private customers and two for industrial and business customers. The main criteria for development of these models were set as

Effect: the model should give incentives for customers to reduce their consumption at certain critical events.
Economy : the models should generate financial benefits for all actors involved.
Simplicity: the models should be easily used and understood.

The first criterion excludes the use of normal tariffs since it does not give incentives to reduce consumption at extraordinary high peak hours but only shift between general peak hours. The second and third criteria are essential for a sustainable market model. Spot pricing and critical peak pricing (CPP) are used for the private customer models as well as a variety of direct effect reducing methods. The five concept models described by Elforsk do not require any major changes in regulation but an extended investment and implementation of technologies are required. Conclusions made by Elforsk are that the models are expected to affect the power consumption positively [16].

3.5.1 Fixed price with right of return

Many electricity customers in Sweden choose to have a contract with a fixed price for the whole year, and fewer choose contracts that are based on spot price calculated on monthly basis or template pricing. However, the most efficient model out of a socioeconomic point of view is when customers receive real time spot market prices. Elforsk suggests a program, fixed price with the right of return, where the customers have a fixed price for a certain amount of power as variations up or down are paid in spot prices. The customers subscribe a certain amount of electricity distributed per season or month. This model is barely tried for household customers since the complexity is rather high. This type of contract implies that the customer pays the spot price on their margin which will be an incentive for them to lower their electricity use. Benefits with this type of contract are the reduced price risks while a drawback is the very many price signals communicated to the customer. An idea would be to send certain signals in extreme cases when the price exceeds normal prices, for example by sending an SMS. This type of contract implies that the customer meets the spot price on the margin and will hence have incentives to respond to the price signals without taking too many risks.

3.5.2 Dynamic time tariffs

Dynamic time tariff or Critical Peak Pricing, CPP, is a model where the customer has a fixed price for their electricity during all times except on critical events. During these critical events, the price goes up very much which make an incentive for the customer to reduce consumption. The customer will be notified before the event occurs and can thereafter make a decision on how to act. The name dynamic time tariff means that the tariff is dependent on the situation and therefore dynamic. A benefit of CPP is the clear signals of extraordinary critical event. On the other hand it does not provide information of demand and supply in less critical periods [16]. This model has been tried out within Elforsk's Marked Design Program [22] where the customers contracted reduced their load consumption by 50% on average, during peak hours [16].

3.5.3 Remote control of household customers

Soft control of customers where tried out in the 80´s and some programs are still running. Remote control of household customers may be possible with the new systems of smart grids, smart metering and remote communication of spot prices.

3.5.4 Aggregating reserve capacity

This new actor of aggregator provides a service where reserve capacities are aggregated and used for reserve effect. An estimated amount of reserve effect in Sweden is about 1000 MW. This business model let the customer sign a contract directly with the aggregator using spot prices. Subsidies may be given to the aggregator to cover parts of the fixed costs. Economies of scale may be advantageous for actors already having an operation centre but the question of who to act as aggregator is still discussed.

3.5.5 Repayment of power

This model is tried out for larger customers. The customers specify what repayment is required to lower its power use. If the price is lower than the spot price the retailer can repurchase power reduction from the customer instead of buying power from the market.

3.6 Actors involved in Demand Response and their Incentives

The customers are the most important actors since they have to respond to the signals, either automatically with assistance from the retailer or manually by themselves. Different type of models requires different degree of customer participation and apart from their smaller bills there may be risks for reduced comfort. An American study shows that participation for climate purposes also makes out a small incentive. In the same time the main reason for cancelling a demand response program is a too small economic saving [23].

Retailers are the second important group of actors and the incentive for them should be the reduction of risks, which are defined as variations in output. Take-and-pay contracts give raise to both price and volume risks but with DR these risks are reduced as demand decrease. An interesting aspect is when the retailer is contracted with the balancing company. The retailer in this case acts as a reseller and the risk for this actor is very small and hence it would contribute to very little incentive for this kind of actor.

The third group of actors are the grid operators. There are two main incentives for grid operators for an increased demand response. One incentive is the reduced cost for subscription to the overlay networks due to reduced power output, i.e. the cost the grid owner pay for connection to the regional or national grid. However, in Sweden this cost is around 200 SEK/kW and is normally allocated to the end customer and therefore the saving for reduced subscription cost may not always benefit the grid owner. Another incentive is the saving from reduced reinforcement of the grid. As less power is needed to be transferred because of the management of the load locally there will be no need for increasing the capacity of the network [16].

3.7 Demand Response Benefits and Costs

There are both benefits and costs associated to the different actors in a demand response program. These benefits and costs are important to consider when planning for DR implementation.

3.7.1 Benefits

According to Dr. Al-badi, University of Waterloo, the benefits for demand response can be categorized into four groups; participants, market-wide, reliability and market performance, and are listed in *table 1* below. These are not certain actors but general areas where benefits are found.

Participants are both private and commercial customers contracted for a demand response program. Their savings come when reducing or shifting the overall electricity consumption and especially when the price is high. They may also save money without reducing energy use if their consumption is less than average when contracted. If consumption is shifted to off peak periods, the customer may also use more energy with no additional cost.

Market-wide benefits refer to common aspects of the society. The electricity costs decrease when utilization of energy producing facilities is more efficient. Expensive production equipments used for peak hours could be avoided and lower the overall price of electricity. Market-wide benefits are also associated to infrastructure and reinforcement of the grid.

Reliability concerns the increased security of delivered electricity and benefits all market actors. The operator will have more resources to use in order to maintain the power system’s reliability.

The last benefit mentioned here is the improved market performance that will arise specifically from market-based programs. The opportunity for customers to choose retailers and demand response programs give market values. Another benefit is the reduced price volatility that occurs as more cheap electricity is produced rather than the expensive marginal electricity. An important fact is that price increase exponentially when approaching maximum production. There have been discussions that a 5 % reduced consumption made 50% price reduction in the California electricity crisis [21].

Table 1. Benefits associated to four different sectors

Participant	***Market-wide***	***Reliability***	***Market Performance***
Incentive payment Bill savings	Price reduction Capacity increase Avoided infrastructure cost	Reduced outages Customer participation Diversified resources	Reduced market power Customer options Reduced price volatility

3.7.2 Costs

Costs associated to actors are important to be defined and should be considered carefully when choosing DR programs. Table 2 below shows participants and program owner´s initial and running costs associated to the program implementation. The initial cost for participants consists of equipment that needs to be installed. This may be smart meters, smart thermostats and peak load controllers etc. These technologies are normally paid by the customer but installation could be done by the program owner. Some running costs raised here consider large customers like industries. Running costs are associated with inconvenience for the customer to reduce their level of comfort and is measured in effort rather than economic values. Initial costs for the program owner consists of metering and communication equipment, billing system and education and information for the customers contracted. Information is a crucial step for sustainable customer participation. The running costs are administrative costs, marketing, incentive payment and evaluation. The billing system needs to be upgraded and the market needs to be developed to attract more customers [21].

Table 2. Costs associated with the implementation of DR programs

Participants	***Program owner***
Initial	Initial
Enabling technology	Metering and communication
Response plan	Billing system
	Customer education
Running	Running
Inconvenience	Administration
Lost business	Marketing
Rescheduling	Incentive payment
Onsite generation	Evaluation

4 Demand Response Systems

Demand Response Systems refer to communication and information technology needed for the implementation of Demand Response. This chapter gives an overview of different communication models and network standards for remote control of home energy management.

4.1 Automated Demand Response and Standards for Smart Grids

Automatic demand response is a model where the customer sets up predefined actions that automatically initiate when an event occurs. The model can be based on smart systems with integrated software that allows automated demand response. Automated Demand Response, ADR, provides information and communication technologies that enable extended energy management performance. It uses semi or full automated techniques and procedures combined with DR programs to achieve balance between power production and consumption[24].

One of the main elements in implementing demand response and use its maximum potential is automation. Automated demand response systems are needed to reduce the operating costs of DR programs and at the same time to increase DR resources availability. Automation can reduce the response time and also the effort that consumers put in achieving demand response. Load reduction can become more predictable and quicker load adjustments for balancing supply and demand will be enabled. As it is the only way for different market entities to communicate with each other, some standardization is needed [25].

Various benefits can be provided to stakeholders if standardization in ADR is adopted. First of all implementation of DR programs and Distributed Energy Resources will become easier. Standardization promotes technology innovation and assures interoperability. Technology costs will be lowered as smart equipment vendors will minimize design and innovation costs. With ADR standards, system development would be quicker and integration and installation costs could stay in low levels resulting in more effective DR. Market players will also be benefited as they will use DR programs more successfully. Standards will also reduce capital, operation and maintenance costs as different enterprises will follow common rules. For example control companies e.g. DSO will integrate the communication system in their control systems for minimum cost [26]. The creation of more flexible software and end-to-end technologies will be enhanced because of the open communication protocols and interfaces, and these end use technologies will be easier integrated. Consumers can choose between many services and products among new energy markets and control equipments without thinking of possible incompatibilities.

For future smart energy systems with low energy consumption and efficient use of energy, new home energy systems to control energy use have to be developed. Smart meters and smart grids put the customer in focus enabling remote control of its own consumption. This remote control requires communication between the household electronic equipment and the customer’s control device, i.e. a smart phone or a pad. For these devices to communicate and in order to apply the system in any household and to any household electronic device, common standards are needed [25]. The OSI model described below is a conceptual model for computer communication in seven different layers. All layers are needed for an end-to-end communication transmission and provide different services. Standards are applied in all layers of the model and some of the layers and corresponding technologies are discussed below [27].

4.2 OSI Model

A communication protocol, also called technical specification standard, is a system for communication and message formats for information exchange in telecom and internet networks. The protocol contains rules for exchange of information and define syntax, semantics and synchronization of communication and can be used for both hardware and software technologies. Protocols define the way a message is received and processed and make a close analogue to programming language, as there must be a standard in order to communicate. The protocol must be agreed on between the users and can for better use be converted into technical standards.

An example of a framework like this is the OSI model which is a conceptual data communication model in seven layers, *figure 4*. The model is well known and developed by the international standard organization, ISO. The different layers provide certain duties that are independent of the technologies used below or above a certain layer. The different layers contain various protocols and here, three important layers are discussed more in detail, the application layer, the network layer and the link layer [27].

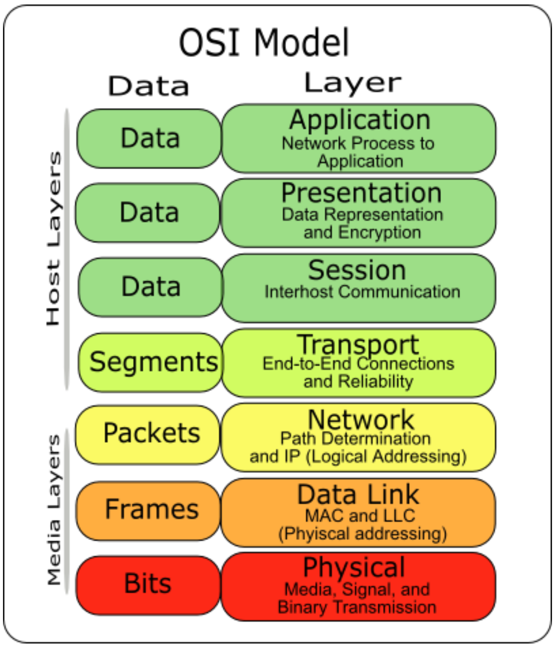

Figure 4. The OSI Model [27]

4.3 Application Layer

The application layer is used both by the host and the receiving device for communication between them and the application layer protocol implemented for each of them must match each other. These protocols specify what type of message is sent from the host to the receiver [28]. Some models in the application layer is exemplified below, i.e. communication between the home technologies and the grid.

4.3.1 OpenADR

OpenADR is an open global communication data model that enables system operators and electricity providers to automatically exchange DR signals with each other and their customers over any existing IP-based communications network by using a common language. OpenADR can directly be embedded in DR systems which give the opportunity for consumers to better manage their energy consumption and to maximize the benefit.

OpenADR is an emerging standard for smart grid systems. It standardizes message formats used for Auto-DR. Dynamic price and reliability signals can then be delivered in a uniform and interoperable way among customer systems and between wholesale and retail systems. OpenADR communicates over the internet and use web services. Large data packages can be transmitted [29].

As can be seen in *figure 5*, a Demand Response Automation Server, DRAS, is used as a facilitator of customer's response to the demand by using different DR programs. Different market entities like aggregators but also other stakeholders like software and hardware manufacturers can use the DRAS and automate parts of DR programs.

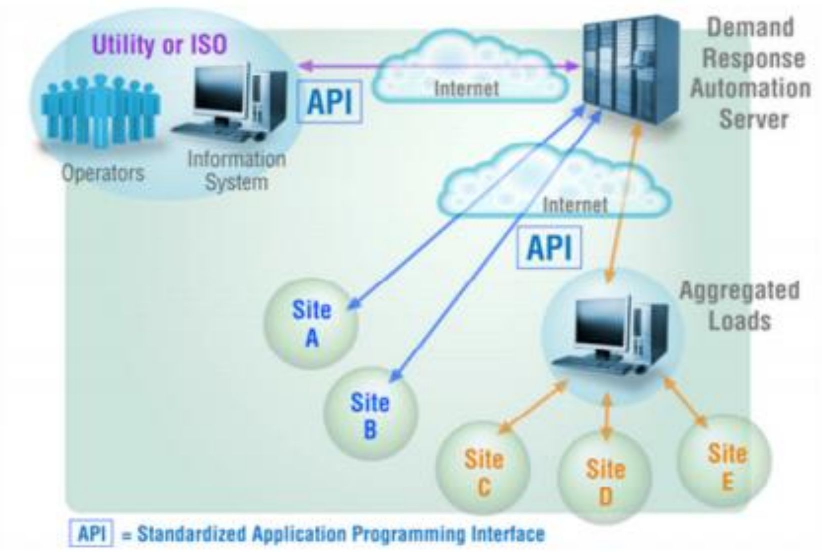

Figure 5. OpenADR communication architecture [26]

4.3.2 Smart Energy Profile, SEP

Smart energy profile, SEP, is a public application profile used for smart energy technologies. It is created in order to develop an interoperable protocol used for the connection of smart energy devices between the buildings and the grid. The SEP 2.0 is an agreement between the Wi-Fi Alliance, ZigBee Alliance, HomePlug Alliance and HomeGrid Alliance. It runs over a Transmission Control Protocol / Internet Protocol, TCP / IP, and it is media access control, MAC, and physical layer, PHY, agnostic [30].

SEP 2.0 protocol supports connectivity to the Smart Grid and includes Home Energy Management functions [31]. It defines the way that devices should proceed in order to deliver a set of functions such as metering and DR load control. These functions can be used by the consumers to manage their home energy consumption and/or it can enable their participation in demand side management done by utilities. For example, a SEP 2.0 compliant application used in a tablet or smart phone can get information about the hourly energy consumption in the customer’s house. Also a utility can send price signals to smart appliances so they can reduce the energy consumption in high peak hours [30].

The main difference between SEP 2.0 and OpenADR is that SEP 2.0 standardizes device communications in response to market signals once they have been received by a gateway, while OpenADR standardizes information exchange between utilities and energy management control systems [29].

4.3.3 REST

REST stands for Representational State Transfer. Rest is a hybrid style derived from several network-based architectures [32]. It is a set of architectural principles that can help in the design of Web services that center on system’s resources. It also embodies the way that resource states are addressed and transferred over HTTP by different clients written in various languages. REST is a ruling Web API model used by mainstream Web 2.0 service providers like Yahoo, Google, and Facebook [33]. An application programming interface, API, is a protocol that it is used as an interface by software components to communicate with each other.

4.4 Data Link Layer

The data link layer, *figure 6,* is used by communicating devices to exchange data over a common local media in the physical network where this media can be copper cables or optical fiber. An example of a standard using the data link layer is the ZigBee where the data link layer enables communication between different ZigBee devices. Z-wave is another standard for remote control via e.g smartphones.

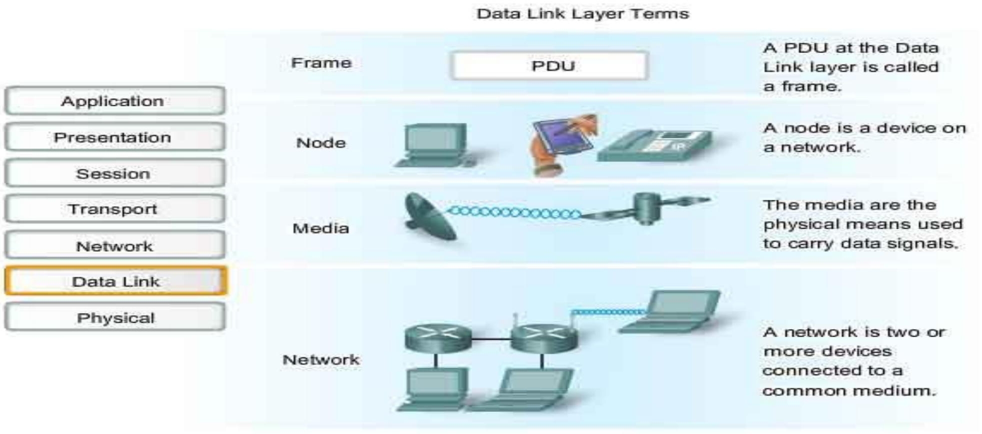

Figure 6. The Data Link Layer [34]

4.4.1 ZigBee

Zigbee is a low-cost and low-power wireless mesh network standard under development for smart technology communication. The standard is based upon IEEE 802.15.4 standard for WPANs (Wireless Personal Area Networks) [35]. A ZigBee device is a physical object equipped with a radio receiver. The objects could be simple technologies such a light switch, a remote control or a thermostat. The network layer makes individual ZigBee devices to communicate. A ZigBee network consists of a coordinator, a router and an end device. The coordinator controls the network so that other unwarranted technologies do not interact with the system. The router enables the network to come around obstacles, and the end device receives and reads the message sent [36]. All technologies compatible with ZigBee are ZigBee certified and there are hundreds of companies that are members of the ZigBee Alliance [37]. Zigbee can be used as an alternative to WiFi (802.11) or Bluetooth [35]. Technologies using ZigBee is reported to be successful in communicating load control by pricing [38].

4.4.2 Z-Wave

Z-wave is a wireless communication protocol used for smart home applications like light commercial areas using low power radio receiver. The protocol is compatible with low latency communication for small packages unlike WiFi and IEEE 801.11 based systems designed for high bandwidth data flow. Z-wave can be connected to many different technical devices in a home, the window shades, lamps and thermostats. Any Z-wave enabled device can be connected to the network. Those that are not connected could be adapted by a Z-wave accessory module to join the network. Remote control from a computer or smart phone can be done from any distance [39].

4.5 Network Layer

The network layer provides services to exchange data over the network between end devices and enable end systems that are connected to different networks to communicate to each other via a common router [40]. An example raised below is the internet protocol that uses the network layer.

4.5.1 Internet Protocol, IP

ADR consists of different technologies communicating between energy consumption control applications. Technical standards enable companies to develop technologies that can communicate with technologies from other producers. One example is the internet where a worldwide internet protocol, IP, enabled internet users to communicate with a countless of technologies and applications. Internet Protocol is a network layer protocol that delivers packages from the source host to the destination host based on the IP address [41]. In order to connect different networks we need network nodes, for example a gateway. Some companies argue why to develop a new gateway when most homes already have one, the internet. By using the existing gateway much money is saved, both for the companies and for the customer. This could be an incentive for companies to focus on residential homes as many companies focus on industrial customers since that area is more developed. Smart thermostats and intelligent metering could be developed for internet connectivity and Comverge sees IP-based devices as an evolution to develop load control systems [42].

4.6 Technologies for Demand Response Systems

Demand response requires new smart technologies to facilitate load control and make DR more profitable for the users. Three important new smart technologies that can facilitate load control are Advanced Meter Infrastructure, AMI, Building Automation Systems, BASs, and embedded control systems. AMI include smart metering connected with a local network and many of them support Real Time Pricing. BASs is planned for the next generation of smart buildings that typically use wireline communication like Ethernet [38].

4.6.1 AMI

Advanced metering infrastructure, AMI, consists of state-of-the-art hardware and software technology to send information between customer and the energy system. A two way communication enable the customer to receive information about in-time prices and consumption and then to control consumption remotely [43]. AMI can provide communication infrastructure for future demand response projects. AMI refers to the full system of metering, control and communication between the customer and the service provider, *figure 7*. It can be seen as an analogy of how a Supervisory Control and Data Acquisition, SCADA, system provides digital communications for substations in the electricity network [38]. The costs for implementation of AMI include costs for software, hardware, network infrastructure, network management software, installation costs, meter data management and information technology. AMI system security can be vulnerable according to FERC and for that virtualization and remote attestation is needed [44].

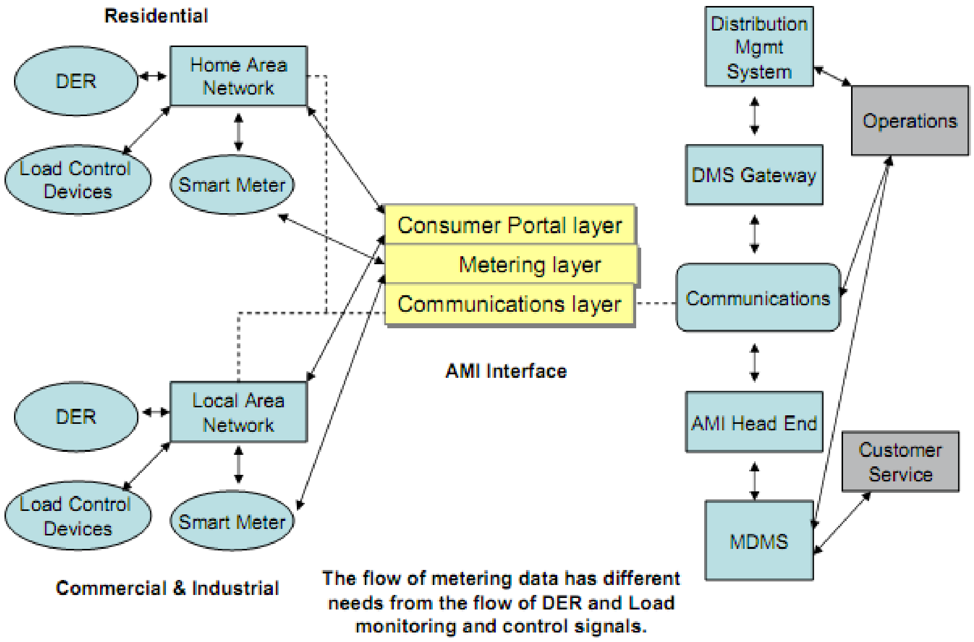

Figure 7. Overview of AMI [43]

4.6.2 BAS

BAS is used mainly for controlling actuators like door locks, sensors e.g. motion detectors and networked computers. The BAS technology can be divided in two groups. The first one can play a role in emergency monitoring for fires, smoke or break in detection. It can also be used to control appliances like dimmers. The second one aims at machinery control but also includes more sophisticated features such as movement sensing [38]. Open communication standards facilitate the integration of heating, ventilation, air conditioning control applications in BASs. A BAS is composed of hardware and software. BAS use internet protocols and open standards as BACnet and LonWorks.

4.6.2.1 BACnet

BACnet is a Data Communication Protocol for Building Automation and Control Networks developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, ASHRAE, [45]. BACnet standardizes the presentation of data and processes in a device by using object oriented approaches. It provides standard services for data access in a device and various interfaces to accommodate small, medium and large systems. Because of its characteristics a BACnet system can accommodate devices from different manufacturers that can operate with each other with no additional integration. Hence a BACnet system offers considerable savings in proprietary systems but also in installation and maintenance costs and resources [46].

4.6.2.2 LonWorks

LonWorks, Local Operation Network, is a networking platform that was developed to address the problem of the incompatibility between nodes coming from different companies and developers in a traditional network [47]. It is an open standard that enables the devices to exchange information on the network over different communication channels like Ethernet or power line [48]. The LonWorks platform can be used in advanced metering application, DR systems, lighting and HVAC controls.

4.7 Embedded Systems

Embedded systems are computer systems that are designed to control certain functions of complete devices that usually include mechanical parts and hardware. They are microprocessor systems that cannot be programmed by the user. Embedded systems for example in washing machines are used to control the power for the motors, the temperature levels and the wash cycles. New solutions can be available based on networked embedded control devices. Appliances can be controlled and or automatically react to fluctuating electricity prices. The monitoring of the appliances can be wireless or wire-line based on different standards that will be used [49].

5 Future Vision - Market and Power System

The following chapter describes possible scenarios for the aggregator's role in the Swedish electricity market. Three business models are compared with advantages and drawbacks.

5.1 Current System Situation

Figure 8 shows the connection links between different stakeholders in the current energy system. The electricity is mainly produced in large power plants and transferred to the consumer (one way flow) through the transmission and distribution grid (dashed line). The retailers purchase energy in the market and resell it to the customers. The DSO is responsible for the metering of the customer's power consumption and for reporting that to the retailers in the end of its month. The consumers receive a bill from the retailer for the electricity that they consumed and one bill from the DSO for the distribution services provided.

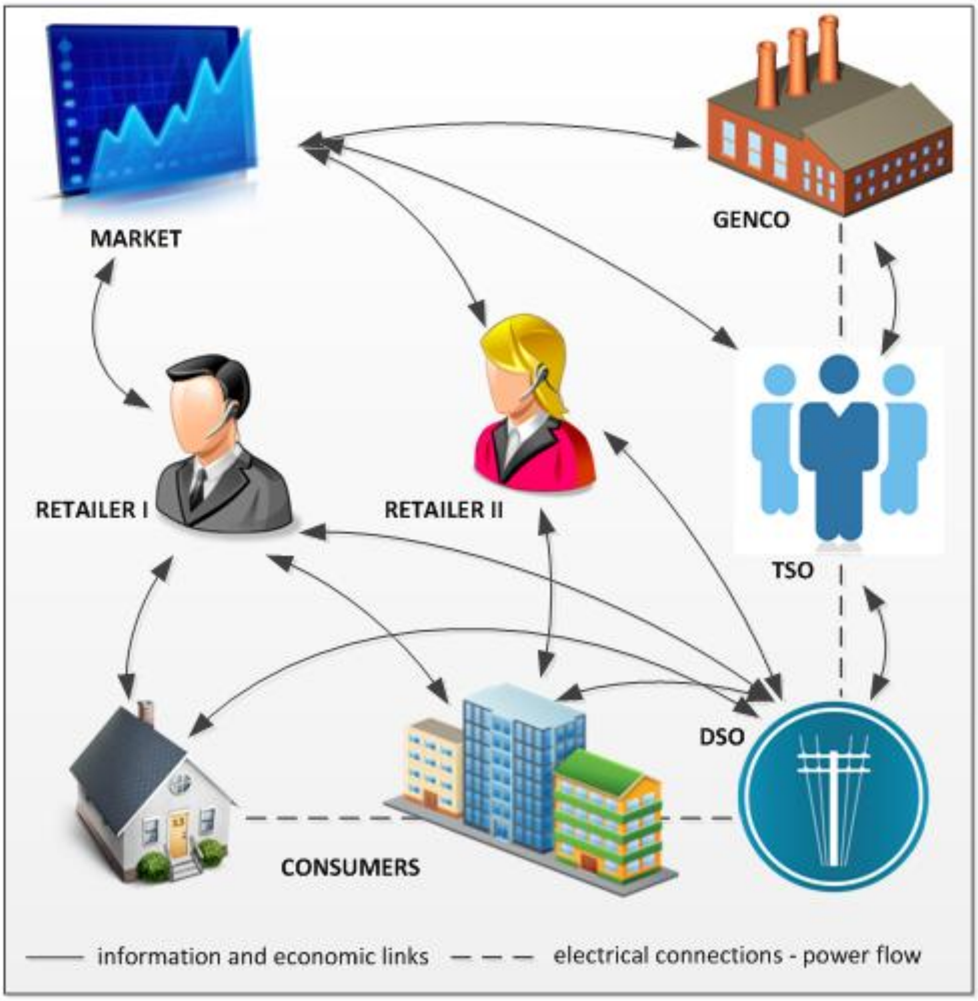

Figure 8 Current Situation of the Swedish Electricity Market

5.2 New Market Entities

In order for Demand Response to be more easily enabled, new markets concepts should be introduced. New market actors will play a key role in how Demand Response will affect the power system. One new market entity as mentioned in chapter 2.2.1 is the aggregator. Aggregators will help their customers to manage their consumption or production of electricity in order to save money without reducing their comfort.

Aggregation of Demand Response already exists in the industrial sector. This subchapter will focus on DR aggregation in the commercial and residential sectors where the potential of DR is large. The new concept of aggregators will be defined and their relationships with prosumers and other market participants will be analyzed.

5.2.1 Aggregator

An aggregator can be defined as a company which helps electricity consumers to take part in DR activities. It acts as an intermediary between electricity end-users, who provide distributed energy resources, DER, and those power system participants who wants to get an advantage from these services. Distributed energy resources can refer to demand response, DR, distributed generation, DG, and energy storage.

The aggregator can take different roles in the system depending on the system structure. The aggregator can for example be an external independent service company or the role as aggregator could be taken by the DSO or even the retailer. The choice is discussed for different types of business models and some different options are raised below.

The purpose of the aggregators is to give smaller consumers or prosumers the ability to participate more efficiently in the electricity markets. The prosumers' costs are larger than their income if they participate individually in the markets in order to sell their produced energy. On the other hand small and medium sized consumers are not affected from the wholesale market prices as retailers provide them with contracts in which the rates do not vary in time [50]. *Figure 9, 10* and *11* shows the position for aggregators in different business models.

5.3 Business Models for the Aggregator's role

As the aggregator is a new concept it should be examined who would be more beneficial to play this role. An aggregator can be a completely new entity or a transformed power system or market participant.

Tables 3, 4, 5 summarize the roles of the three different market participants that have the potential of becoming aggregators and their current and future objectives. They also include the benefits and the disadvantages that the three business models presented have.

5.3.1 Business Model I: The DSO as Aggregator

One participant who could act as an aggregator is the DSO. DSOs have the advantage to act as monopolies in certain areas and they are the ones that install smart metering technologies at consumers. Hence, DSO could easily have the necessary information about their consumers' consumption or production and treat it in a way that could enable DR. On the other hand DSOs have no possibility to participate in the Swedish power market after its liberalization. Even if they tried to carry out load control in order to operate the network in a more efficient way that would encroach on market based load control [50]. This obstacle can be avoided with the creation of a subsidiary company that have close relationships with the DSO and can participate in the markets.

The changes in relationships between the different stakeholders are presented in *figure 9*. The red lines represent new established information or economic links and relations that have been changed. The customers in this case purchase electricity as they have done before through the retailers but now the DSO provides them with DR services. The DR results can be sold in the market as a negative consumption. This can be done by the DSO or by a subsidiary to the DSO company because of the regulatory issues. The ability of the DSOs to enable DR can be used by the ISO in order to maintain the security of the system more efficiently.

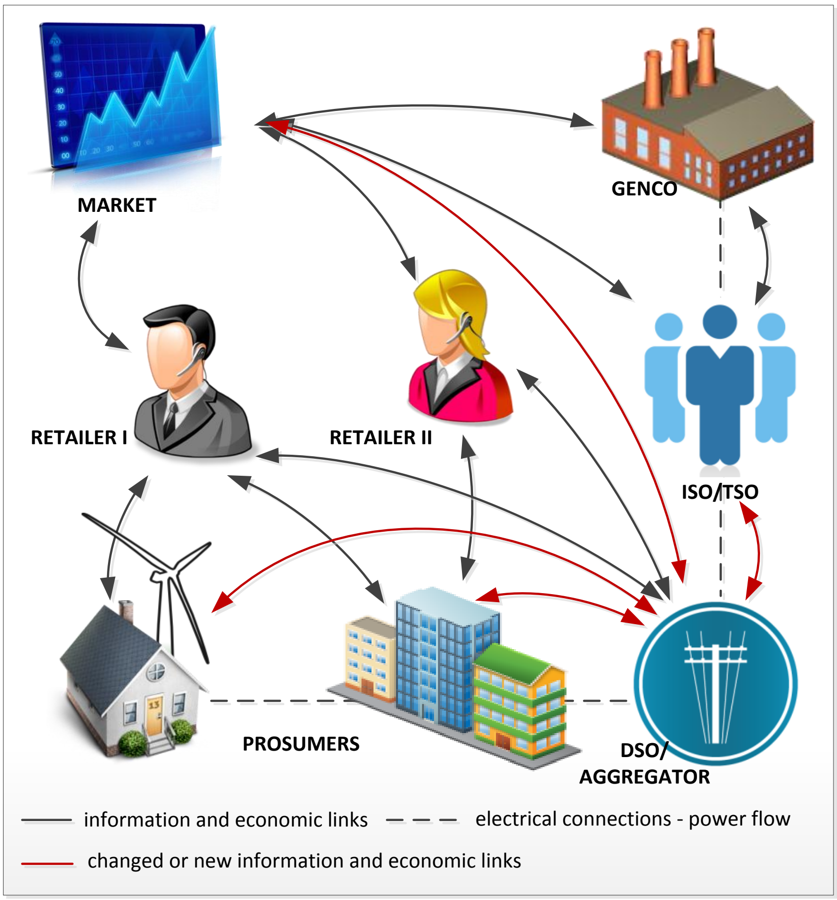

Figure 9 Business Model I: The DSO as Aggregator

Table 3. Summary of Business Model I

Business Model I
DSO’s Current Role
• Monopoly for the distribution of electricity to consumers in a given geographical area. • Responsible for network operation, power quality, maintenance, building new local grids and grid connections to other grids. • Network operation and development function separated from sale of electrical energy. • Responsible for measurement of distributed electricity. Report to retailers, balance responsible parties and to ISO for billing, settlement and as basis for physical power trade.
DSO’s Current Objective
• Maximize regulated profit.
DSO’s Future Objective
• Maximize regulated and unregulated profit by enabling demand response.
Advantages
• One DSO per area reduces complications. • Retailers continue with their current role. • Smart meters are already installed from DSOs. • Costs don’t have to be distributed to different actors but go only to the DSO. • DSOs have already their customers’ consumption patterns. • The distribution grid will be operated more efficiently as the DSO will aggregate DR in a way that will benefit the power distribution. • The DSO has already established relations with the ISO and consumers.
Drawbacks
• No participation in the market if the current law system will not change or subsidiary companies will be created. • Allocation of the investments costs to customers will be difficult as the existing distribution fee/tariffs are very low. • DSO may have difficulties in giving discount offers for multiple services as they currently are responsible for distribution only. • New relationships between DSO and the market • New regulations needed. DSO participation in the market

5.3.2 Business Model II: The Retailer as Aggregator

Another option is for the retailers to start acting as aggregators, *figure 10*. Retailers have already close connections to their customers as well as with the markets.

Retailers who offer real time prices are similar to aggregators. Demand system installations on customers' side can enable automatic response to price signals. Until now retailers do not own these types of systems that can give them the ability to implement demand response. Another advantage of this business model is the limitation of balance calculation problems when the retailer is identical to his customer. The main advantage of this model is its simplicity. Consumers consumption is directly included in the retailers consumption balance. Then this load reduction can be traded in the wholesale market [50].

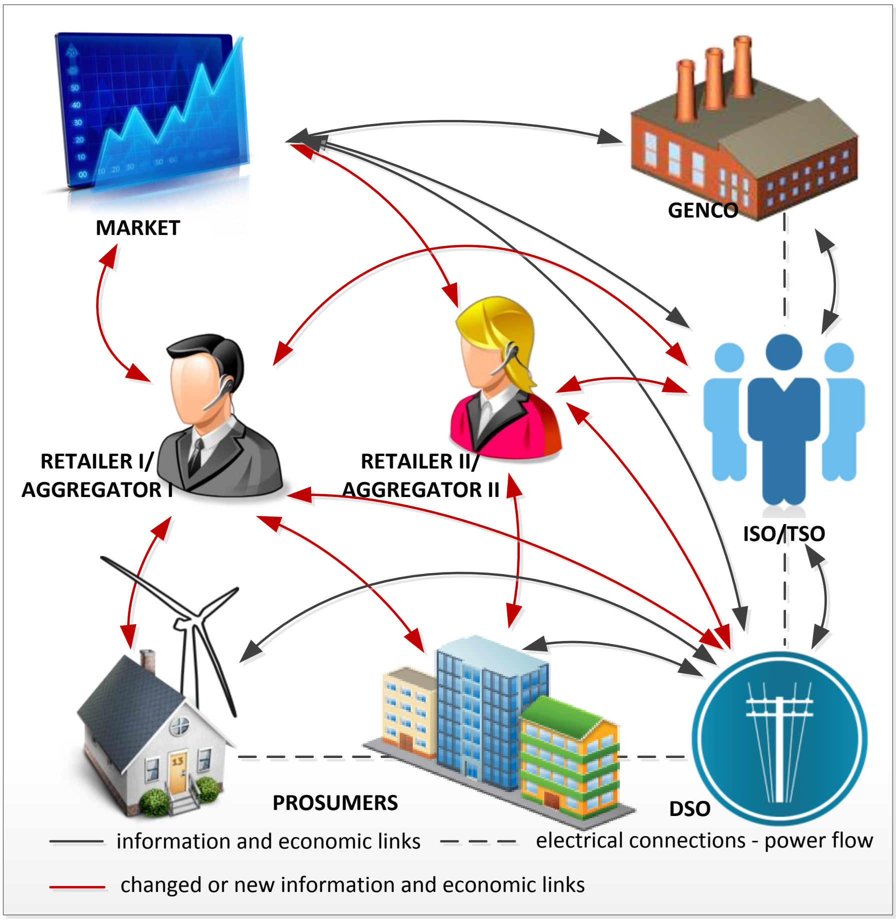

Figure 10. Business Model II: The Retailer as Aggregator

For this model to be adapted many changes in relations between different actors are necessary. First of all the retailers will need to have direct access to the consumption’s metering. The customers will have to sign new contracts that will be based in DR programs available and their connection to the retailers will be continuous as they will receive signals for prices and other DR events. The aggregator should have a close collaboration with the TSO/ISO and DSO as the DR results can vary in minutes or seconds basis which dramatically can affect the power system.

Table 4. Summary of Business Model II

Business Model II
Retailer’s Current Role
• Buys electrical energy on wholesale market and resells this energy to consumers in competition with other electricity suppliers. (Its consumers do not have to be connected to the network of same distribution company • Retailers do not own any large physical assets. • The electricity supplier is in most cases also balance responsible (BRP)
Retailer’s Current Objective
• To maximize profit by taking the advantage of the difference between wholesale and retail prices.
Retailer’s Future Objective
• In addition to the current objective, to maximize profit from the aggregation of power reduction or production that can be sold in the power market.
Advantages
• Retailers have connection with the market already. • Balance calculation problems are reduced. • Retailers can give discount offers for multiple services. • Only one unit for buying and selling, reduced complexity for customers • Costs for installing technologies will be distributed among retailers and not become a huge single initial cost for only one provider.
Drawbacks
• Transformation of the regulations and current laws. • Establish new relationship between Retailer, ISO/ TSO and DSO • Many retailers on the market imply many aggregators. This makes it complicated when technologies should be shared between apartments in a building. (Residents in block apartments can have different retailers)

5.3.3 Business Model III: A Service Company as Aggregator

The last business case is when aggregators act as service companies to retailers, *figure 11*. Such companies would get paid according to the service contract that they will have with retailers but they could not get direct benefits from their activities. The services provided could be load control, DR aggregation, scheduling optimization and forecasting. The effects of load control are summed up in the consumption balances of the different retailers that will have the ability to sell power according to aggregators’ suggestions. The service companies should assure that they will try to achieve maximum DR in order to benefit the customers, the retailers and also to contribute to the power system’s reliability. The latter signifies that the service company should create a relationship to the ISO/TSO and DSO.

The main advantages in this model are that the aggregator is not limited from the retailers' contracts. That means that the contracted customers can switch supplier without changing aggregators and also that the contracts between aggregators and customers can last longer. On the other hand, if customer's are switching between retailers there must be service contracts between the aggregators and the new retailer [50].

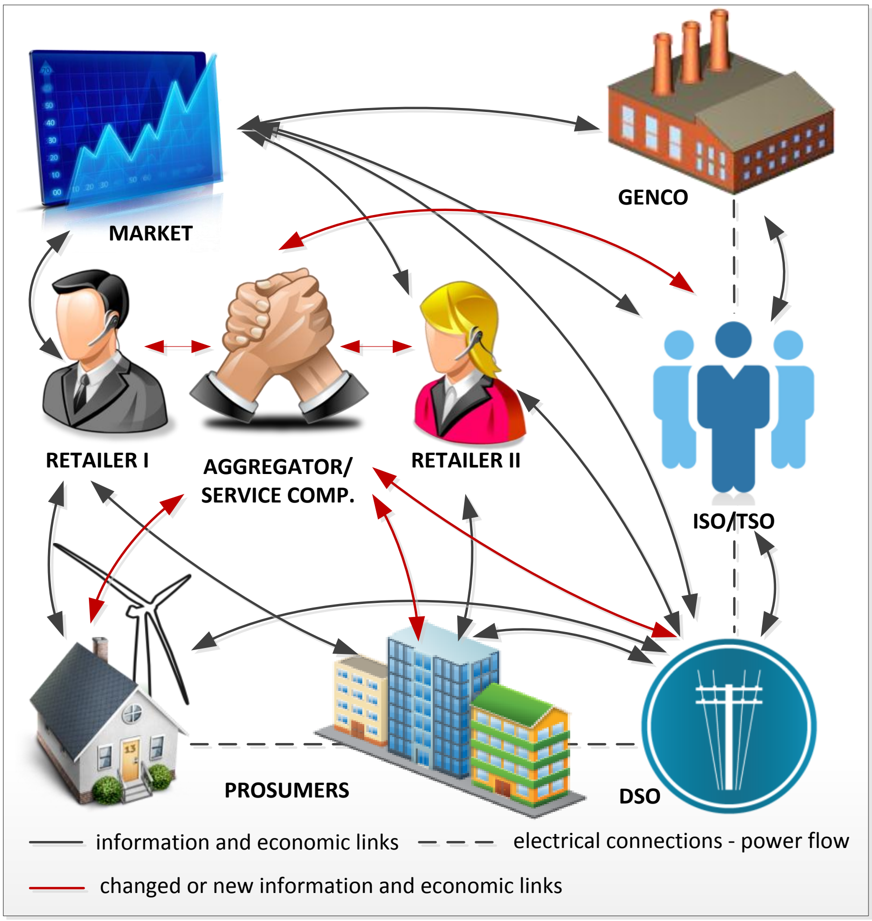

Figure 11. Business Model III: A Service Company as Aggregator

It seems that the more service companies the more complex the system becomes. That is because of the more connections – contracts needed between the service companies, the retailers and the customers. The existence of more than one service companies in a local system does not reduce the complexity when it comes to the ownership, operation and maintenance of the Demand Response Systems compare to the case where retailers also act as aggregators. Hence, if this business model is implemented it would be more sustainable if the service company acts as monopoly in a certain geographical area, in the same way that DSOs act now.

Table 5. Summary of Business Model II

Business model III
Service company’s Current Role
• It does not exist in the Nordic system currently
Service company’s Current Objective
• It does not exist in the Nordic system currently
Retailer’s Future Objective
• To maximize profit from the service contracts that signs with as many different retailers as possible.
Advantages
• The service company is not limited from the retailer’s contract with the customers • Contracts can last longer • Customers can choose from different aggregators that contribute to a more competitive market.
Drawbacks
• The service company should have service contract with different retailers. The system will become more complicated if many companies are introduced. • Customers have to sign one more contract and receive on extra bill. • The service company does not receive direct benefit from their activities, so maybe will not try to maximize the DR effect

5.4 Business Models and Technology needed

Figure 12 shows the different actors of the power system and the technology needed in order to enable DR and more specifically automated DR. The figure can be divided in two parts. The upper part illustrates the connection of the participants via an OpenADR system. The DRAS receives market prices, forecasts and other event signals. This information is combined with DR programs and new signals are sent to the lower part participants which can be the aggregators, large or small consumers. The signals can be received to the client servers that will commit consumption reduction according to preprogrammed arrangements. Also the signals coming from the DRAS can be utilized by BMS systems or installed gateways at the customers side that use OpenADR communication standards. Inside the buildings the devices’ communication can be based in SEP and communication technologies like Zigbee, Wifi etc. The customer is the one that chooses what DR program to be used and type of DR e.g. fully automated, semi automated. The customers remotely receive information about events and on time prices and thereby make a decision on how to act.

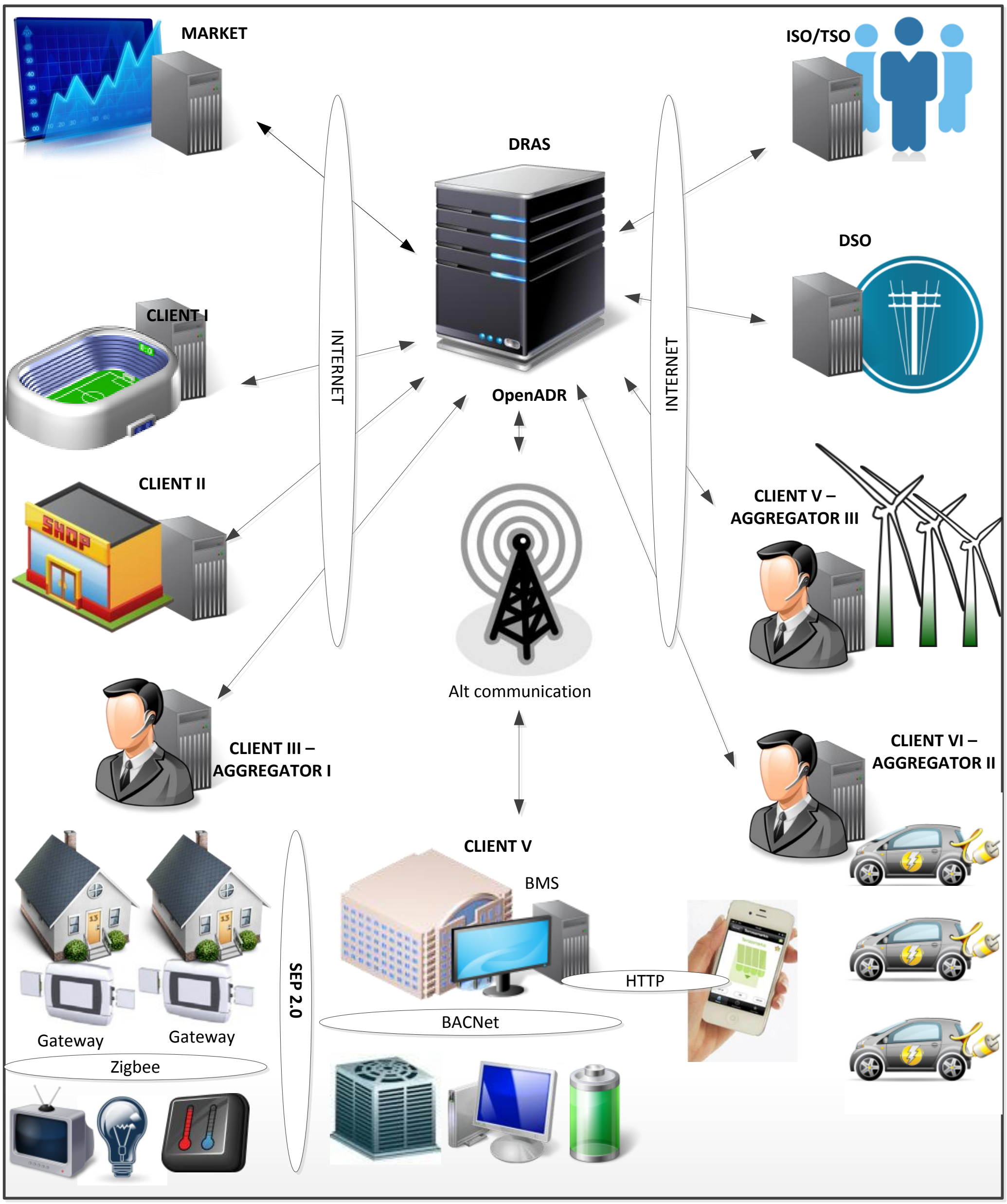

Figure 12. Demand Response System in a city perspective

6 Cost Saving Potential for residential customers

In a Demand Response energy system there are possibilities for customers to decrease their energy costs by shifting their load to less costly hours, i.e. into off-peak hours and/or reducing their consumption. This chapter aims at giving a brief idea of the cost saving potential for Swedish electricity customers. As this thesis focuses on state-of-art demand response systems and as no physical data from Hyllie yet are available, the calculations below are based on a few assumptions.

6.1 Assumptions and factors

The main assumptions, and probably the most critical, are the assumptions about people's behaviour and their response to price signals in a Demand Response energy system. In the calculations made, three scenarios are investigated for three different levels of reduction in demand. Consumption patterns for different household categories are analyzed from load curves supplied by the Swedish Energy Agency, Energimyndigheten. Depending on category, assumptions are made differently. Some devices cannot be shifted more than a few hours while other activities can be shifted between days. The minimum and maximum hourly spot prices for one day is assumed to be 0,3 SEK/kWh and 0,6 SEK/kWh respectively, hence the price difference ΔP equals 0,3. The average electricity price, $P_{average}$, is assumed to be 0,45 SEK/kWh. The assumption is made after analysing price development from NordPool Spot Market.

The calculations are based on average Swedish family household apartments with residents of 26-64 years old, as this constellation is assumed to make up the largest share of people living in cities. Houses are less common in inner cities and that is why houses are not counted for. Family means couples with children/child or single person with children/child and the mean living area is 76 square meters. No residential heating or tap water heating is considered since fully district-heating utility is assumed. Freezers of horizontal type are not included, only vertical ones. Data is based on 81 different apartments in Sweden.

The mean annual consumption for 26-64 years old residents in family apartments is 3710 kWh/year, *figure 13*. The mean annual load is 3139 Watt and the maximum load during the measured period reaches 9770 watt, *figure 14*.

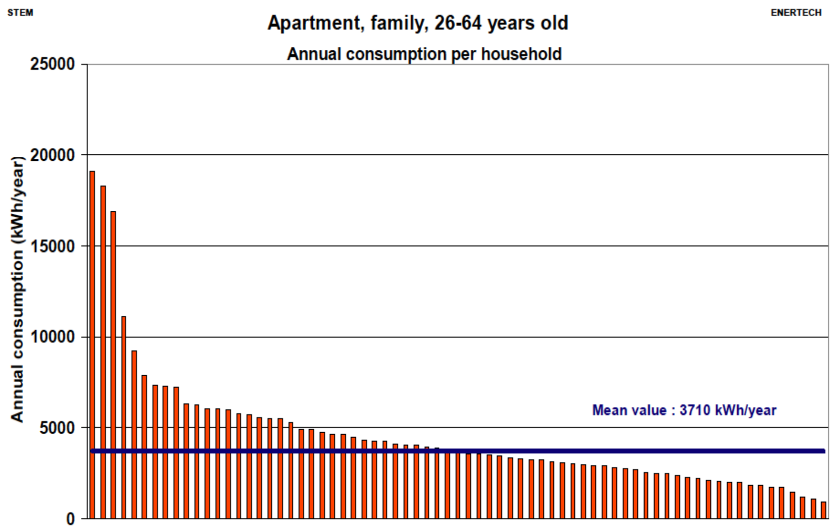

Figure 13. Annual mean consumption, family apartment (kWh/year)

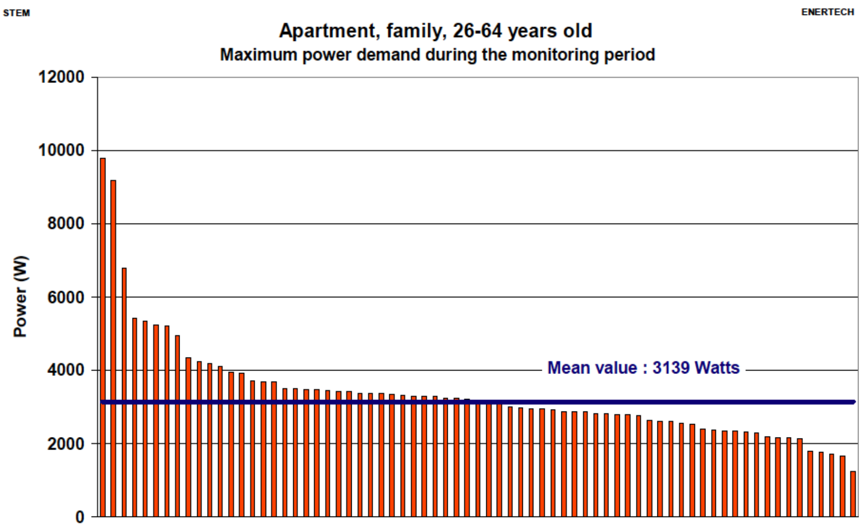

Figure 14. Annual mean load, family apartment (Watt)

The load duration curve in *figure 15* below shows the distribution of power demand over the year. An average maximum power demand of 295 Watt is reached during 20% of a year. 558 Watt is required during 80% of the year. If 558 Watt is required during 80% of the year, one can argue that the remaining peak power demand has reduction potential and hence this is the targeted area.

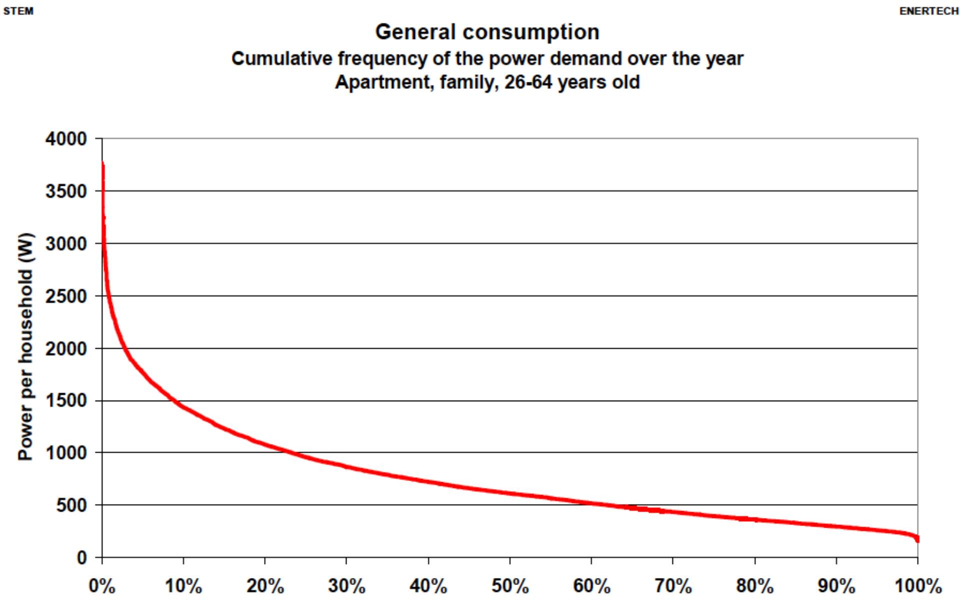

Figure 15: Load duration curve, family apartment

The average hourly load distributed on type of appliances is shown in *figure 16* below. This data is used to estimate and assume saving potential using demand response. It can be seen that the peak consumption occurs between 17:00 to 23:00. Parts of this consumption e.g. dishwashing, laundry and drying can be shifted to off-peak hours between 00:00 to 07:00. Lighting is assumed not to be shifted but reduced. Cooking is not shifted nor reduced and therefore not calculated for. Cold appliances have a limited shifting potential since it is heavily dependent on the time shifted, i.e. it can only be shifted a couple of hours, however the fluctuation in demand over a few hours is very small. Audiovisual and TV sites are not assumed to be shifted but consumption from stand-by mode can be limited.

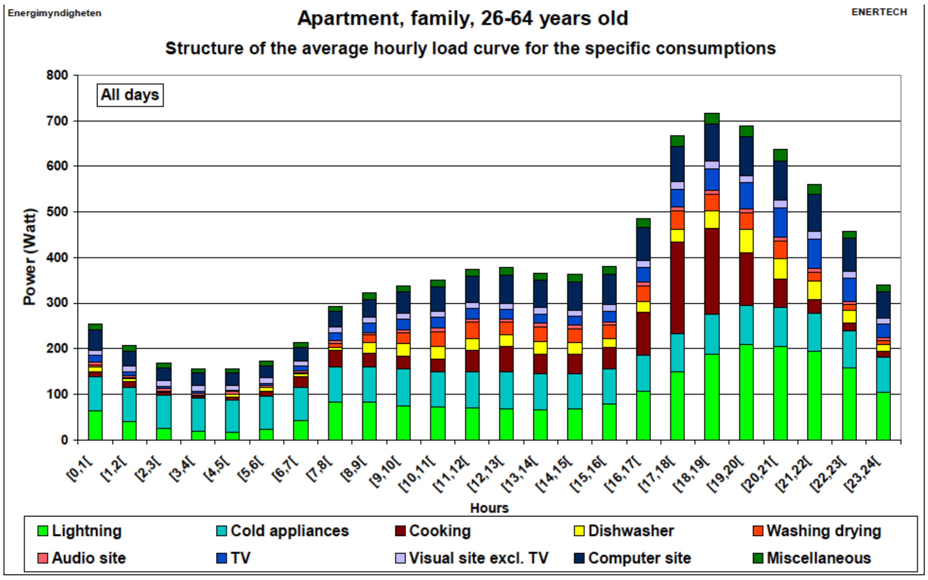

Figure 16: Average hourly load curve, family apartments

The relative contribution from apartment loads is shown in *figure 17*. Lighting, cold appliances and computer sites make up the largest share. The largest possible saving for households is made from reducing and/or shifting these activities. For each activity different reduction potential is assumed. To have an overall view of this potential the relative contribution from the different loads, the loads curves and the load duration curves should be taken into account. These can be combined with the price fluctuations in order to see how demand response can become more beneficial for the customer.

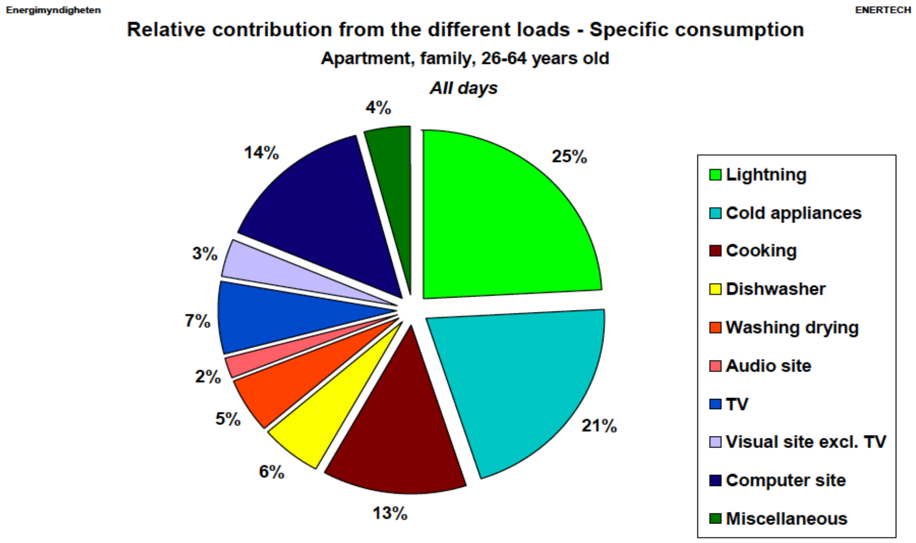

Figure 17: Relative contribution from different loads, family apartments

6.2 Cost Saving Calculations

The cost reduction from shifting parts of the energy consumption during peak price hours equals the amount of shifted consumption during peak hours (SC), times the difference between the peak and the off-peak electricity price (ΔP), *equation 1*.

$$\textit{Cost Reduction} = SC * \Delta P$$

Equation 1. Cost reduction from shifting processes.

If energy consumption will not be shifted but reduced then the cost saving equals the reduced power consumption times the electricity price. Reduction of standby-mode consumption is considered to be a continuous process and hence an average electricity price, $P_{average}$, is used for this type of appliances, *equation 2*. Consumption reduction from appliances that are temporary reduced during peak events are calculated by using an average peak electricity price, P_{max} , *equation 3*. This applies to i.e. lighting.

$$\textit{Cost Reduction} = RC * P_{average}$$

Equation 2. Cost reduction for continuous reduced processes.

$$\mathit{Cost\ Reduction} = RC * P_{max}$$

Equation 3. Cost reduction for temporary reduced processes.

6.2.1 Lighting

Lighting is a service that cannot be shifted but reduced. Switching off or dimming down the light at certain hours is one way of reducing energy consumption from lighting. The cost saving potential by switching off or dimming the light are calculated for three scenarios reflecting 10%, 20% and 30% peak hour reduction and are calculated from the average consumption of 691 kWh/year, *figure 18*. The calculations are based on *equation 3* and the maximum price, P_{max}, is used as the reduction will occur during peak hours.

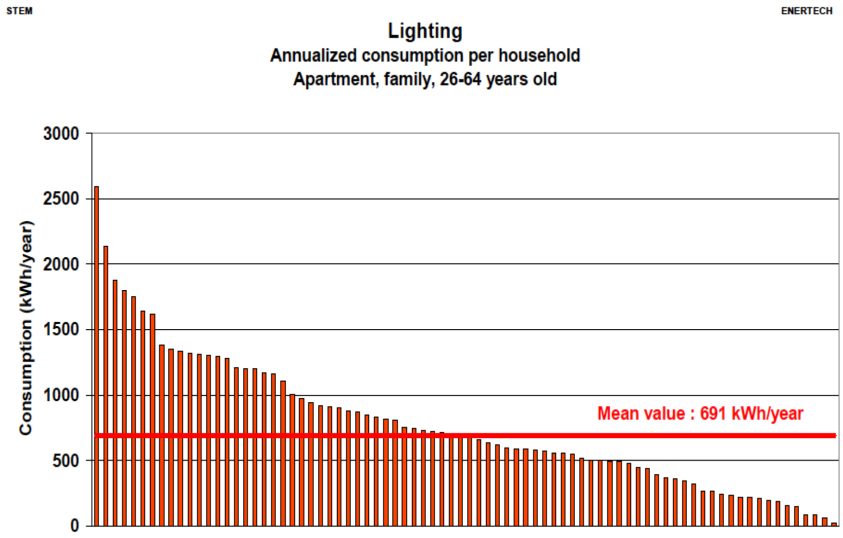

Figure 18. Annual consumption from lighting per household and year

Results from reducing lighting is shown in *table 6.*

Table 6. Saving potential from reduced lighting.

Consumption Reduction								
	Consumption	**Reduction percentage**			**Price max**	**Cost reduction**		
	kWh/year	**10%**	**20%**	**30%**	**SEK/kWh**	**SEK/year**		
Lighting	691	69,1	138,2	207,3	0,6	41,46	82,92	124,38

6.2.2 Refrigerators and vertical freezers

The annual mean load for refrigerators and vertical freezers is 259 kWh/year and 421 kWh/year respectively. The daily consumption for both refrigerators and freezers is very stable, *figure 19*, and it does not make any sense to use pre-cooling in cold devices in this case since pre-cooling only can be done in a limited time before the actual use. The load difference between two hours in a row that pre-cooling can be used is very small, around 5-6 Watt, thus the saving potential is negligible and is therefore not calculated in this thesis.

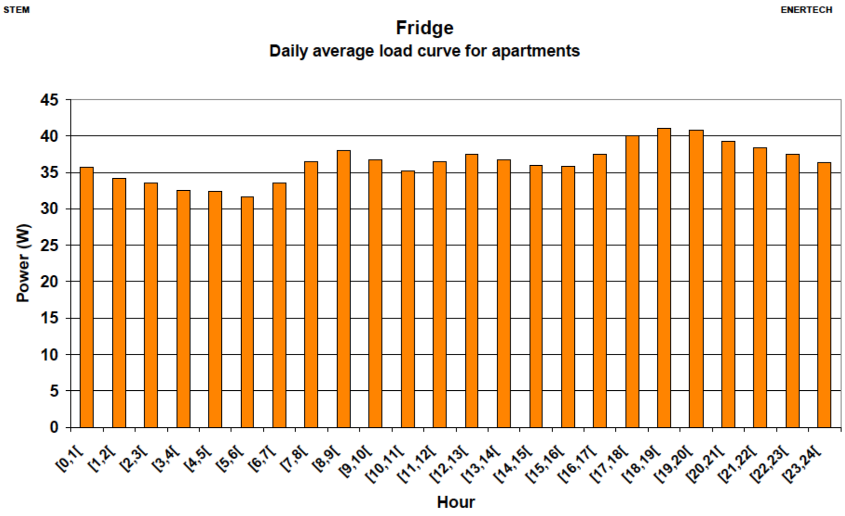

Figure 19: Daily average load curve for refrigerators

6.2.3 Laundry – Washing & Drying

Common laundries are normally found in apartment blocks. Washing and drying machines are therefore rarer in apartments. The annual cloth washing machines energy consumption for a family apartment is 167kWh/year, *figure 20*. Consumption depends on numbers of washing cycles and temperatures.

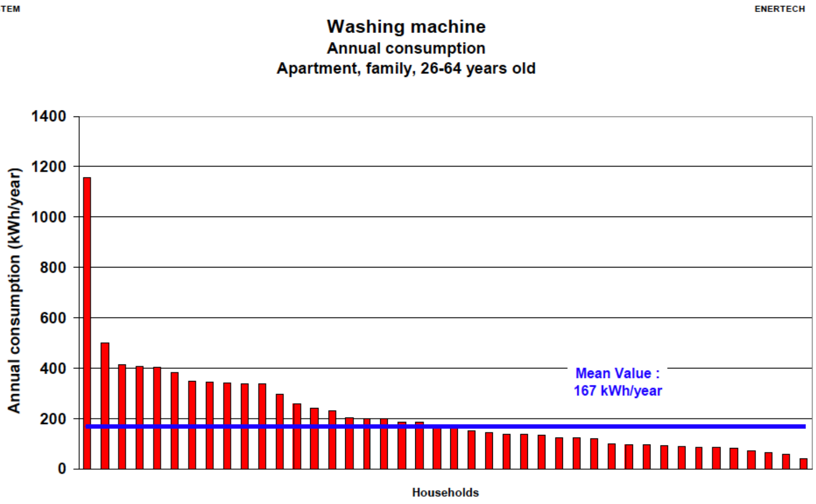

Figure 20. Annual consumption from washing machines (kWh/year)

Dryers are, on the other hand, more commonly used for residents living in apartments than in houses. One explanation could be that houses have possibilities to dry their clothing outdoor summertime or that they have more space for cloth lines. Average yearly consumption from drying is 243 kWh/year, *figure 21*.

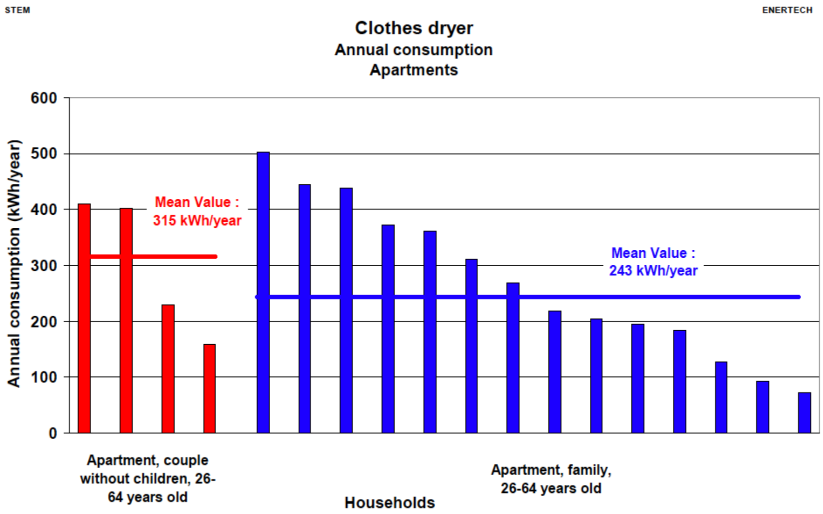

Figure 21. Annual consumption from clothes dryers (kWh/year)

The shifting possibilities for washing and drying are calculated by making three scenarios where the shifting possibilities are assumed to be 20%, 35% and 50% respectively. The yearly saving from shifting laundry activities can be seen in table 7.

Table 7. Saving potential from shifting laundry activities

Consumption Shifting								
	Consumption	Shifting percentage			ΔP	Cost reduction		
	KWh/year	20%	35%	50%	SEK/KWh	SEK/year		
Washing machines	167	33,4	58,45	83,5	0,3	10,02	17,535	25,05
Dryers	243	48,6	85,05	121,5	0,3	14,58	25,515	36,45

6.2.4 Audiovisual Site - TV

Audiovisual sites in Swedish households consists of all kind of equipment connected to the TV. This is DVD players, hi-fi, home cinema, surrounds systems etc. The annual mean consumption from audiovisual site and TV is 309 kWh/year, *figure 22*, and 139 kWh/year respectively, *figure 23*.

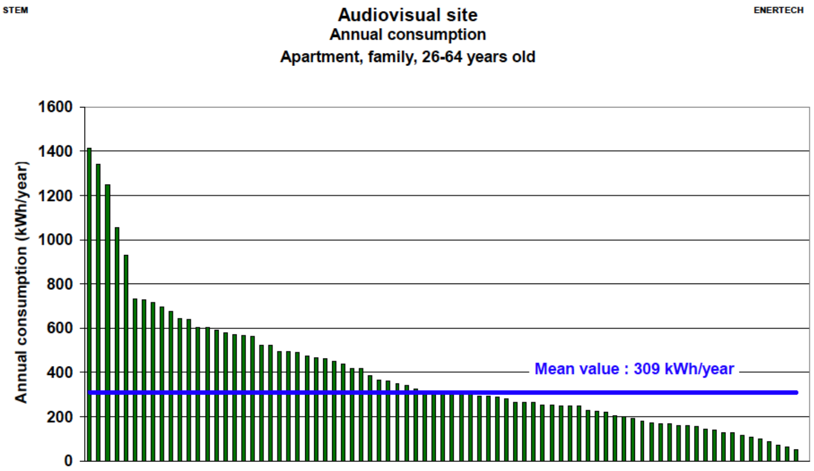

Figure 22. Consumption from audiovisual sites for family apartments (kWh/year)

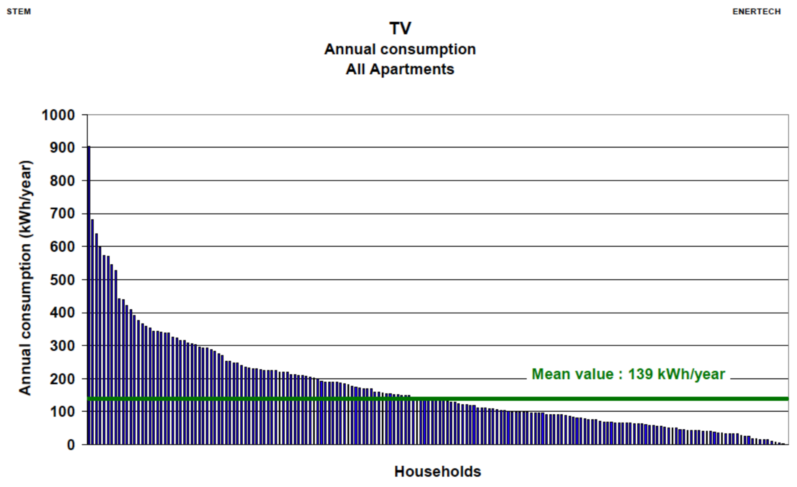

Figure 23. Consumption from TV sites for family apartments

Stand-by consumption time makes out a significantly part of the total consumption time and one of the keys in saving potential for this category is to turn the devices into an OFF mode. The time share of ON, stand-by and OFF modes is illustrated in *figures 24 and 25 below*. Audiovisual sites are in stand-by mode 60,5 % of the year and TVs are 31% of the year.

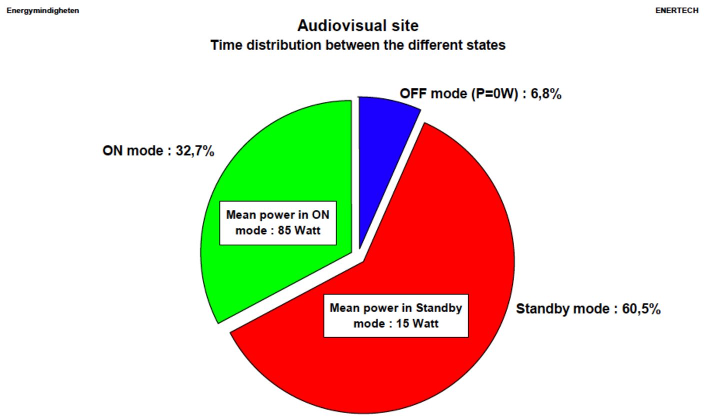

Figure 24. Time distribution between different modes for audiovisual site.

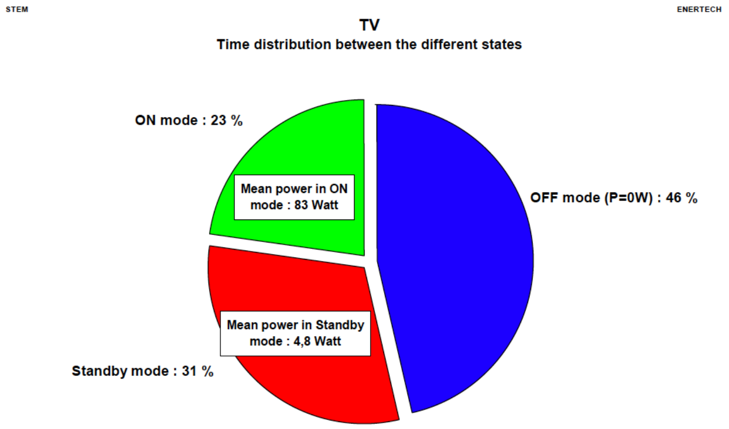

Figure 25. Time distribution between different modes for TV

The saving potential from changing from stand-by to OFF-mode is shown in *table 8*. For calculating the cost reduction potential from switching the devices from stand-by to OFF-mode the average price ,$P_{average}$, is used as the reduction will not only occur in peak price hours.

Table 8. Saving potential from changing from stand-by to OFF-mode

Consumption Reduction						
	Reduction percentage	**Year**	**Mean power in standby mode**	**Reduced energy consumption**	**Price**	**Cost reduction**
	%	Hours	Watt	kWh/year	SEK/KWh	SEK/year
Audiovisual site	60,5	8760	15,00	79,50	0,45	35,77
TV	31,0	8760	4,80	13,03	0,45	5,87

6.2.5 Computer Site

Computer site consist of equipment used in working places and may be printers, modems and monitors. The mean consumption in family apartments is 287 kWh/year, *figure 26*.

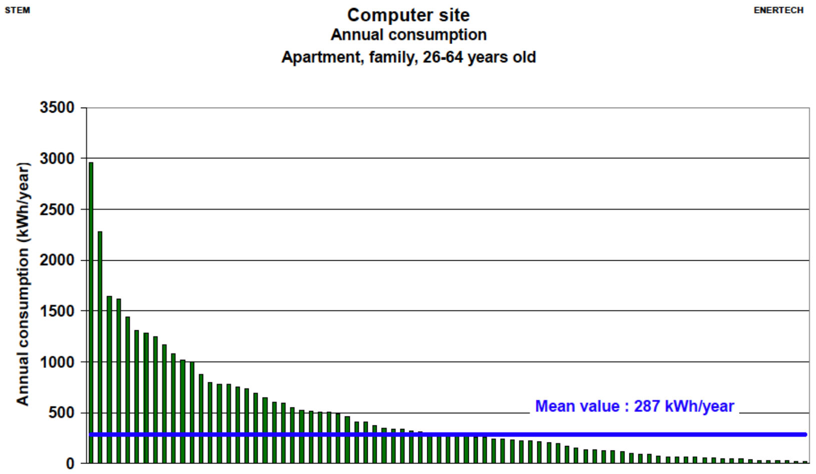

Figure 26. Annual consumption from computer site.

Savings are done by switching computer sites from standby to OFF-mode. The standby mode makes up 56% time of the year, *figure 27*, and equals 4906 hours. Mean power drawn from standby mode is 14 Watt.

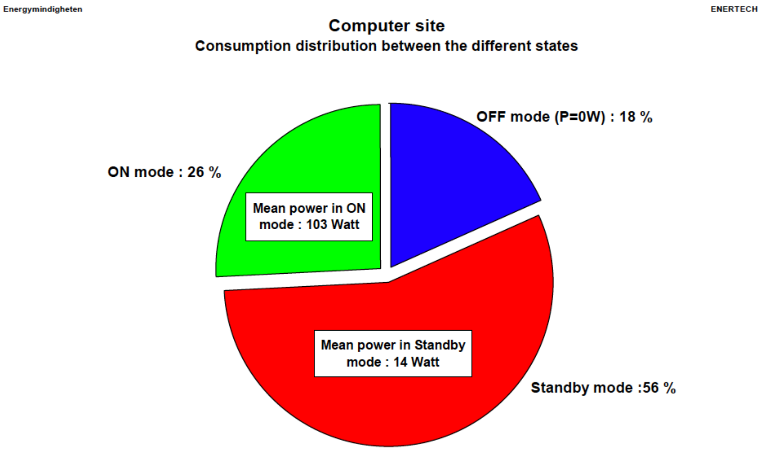

Figure 27. Time distribution between different modes for computer site.

Table 9 shows the saving potential from changing from stand-by to OFF-mode for computer site.

Table 9. Saving potential from changing from stand-by to OFF-mode

	Consumption Reduction					
	Reduction percentage	**Year**	**Mean power in standby mode**	**Reduced energy consumption**	**Price**	**Cost reduction**
	%	Hours	Watt	kWh/year	SEK/KWh	SEK/year
Computer site	56,0	8760	14,00	68,68	0,45	30,91

6.2.6 Dishwasher

Dishwashers in family apartment consume 214 kWh/year as a mean value, *figure 28*. This consumption is heavily dependent on number of persons in the household. The load curve in *figure 29* shows that the fluctuation in energy consumption is high hence there is a shifting potential. The calculations are based on peak hour reductions of 20%, 35% and 50%.

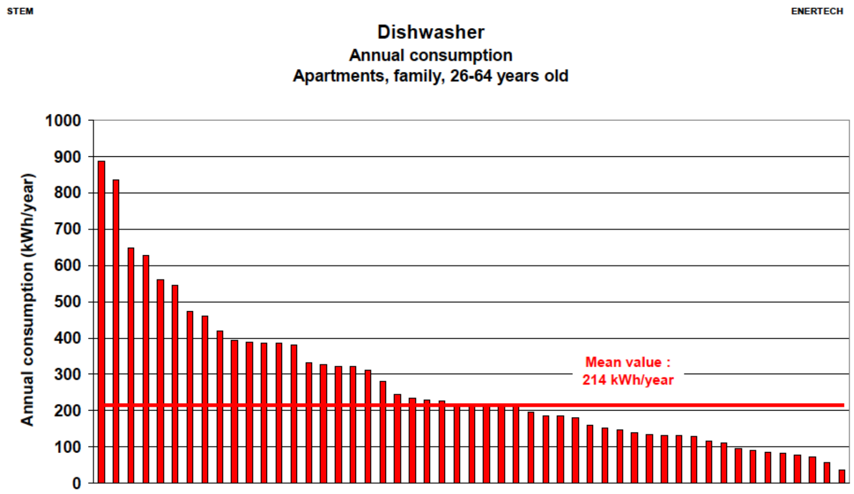

Figure 28. Annual consumption from dishwashers

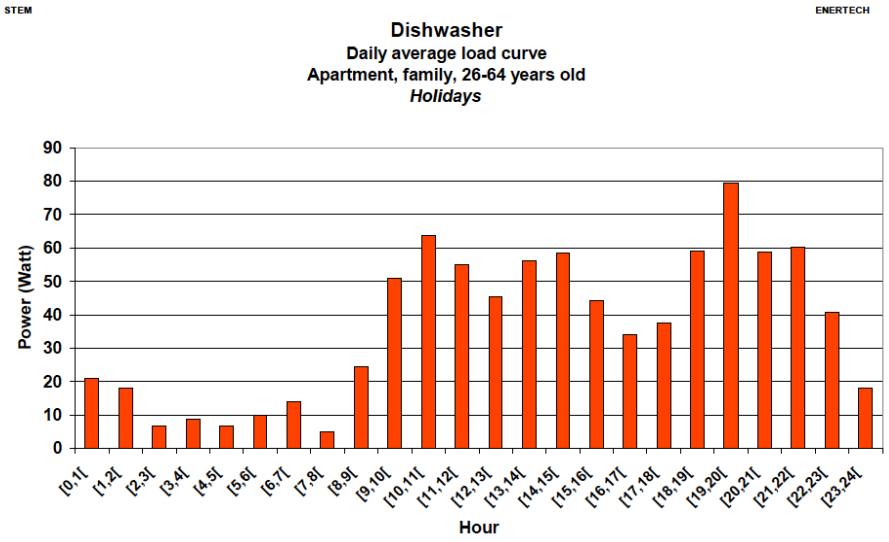

Figure 29. Daily load curve from dishwashers

Table 10 gives the potential from shifting dishwashing from peak to off-peak hours.

Table 10. Saving potential from shifting dishwashing

Consumption Shifting								
	Consumption	**Shifting percentage**			**ΔP**	**Cost reduction**		
	KWh/year	**20%**	**35%**	**50%**	**SEK/KWh**	**SEK/year**		
Dishwashers	214	42,8	74,9	107	0,3	12,84	22,47	32,1

6.3 Technology costs

The cost of implementing DR can vary a lot as it depends on the type of technology that will be used. According to E.ON, a Building Management System for a residential block of 50 apartments costs from 0,3 to 1,5 MSEK. This means that if the cost is distributed to the residents, each apartment should be charged 6000 to 30000 SEK. A rough cost estimation for a Home Energy Management System is about 2000 to 15000 SEK per apartment [51].

On the other hand, commercial standalone automation and energy management solutions based on commercial standards like ZigBee and OpenADR do exist in the market at prices from 2000 to 3500 SEK [52] . Wireless controlled switches can vary from 250 to 900 SEK [53] . The cost would increase if every appliance, such as light bulbs, need to be connected to these switches. Although there are companies that reduced the integration cost of ZigBee chips in LED lamps from 600 SEK to 15 SEK [54]. This type of technology development can make the technologies more affordable for the households and enable fully automated demand response.

The graph in *figure 30* shows three different bars. The first one to the left gives the cost saving from one apartment. The blue pile reflects a small saving and the red a high saving. The values are scaled for a period of 10 years for a fair comparison with the cost of technologies. The technologies are assumed to have a life time of 10 years. The middle and right piles show the cost for smart home technologies divided per apartment. These costs are given by E.ON and are estimated costs for building and home energy management system that can be used in a smart city like Hyllie.

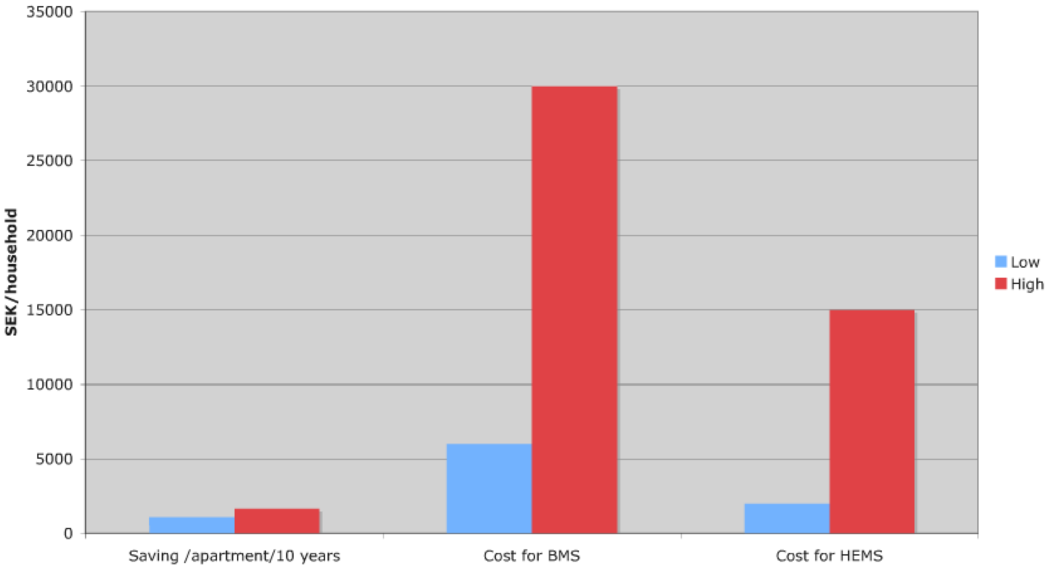

Figure 30. Cost and saving comparison.

7 Conclusions

The main questions raised in this thesis concern the values that exist for actors in a Demand Response energy system. The answers are investigated for each chapter and presented throughout the report, however a summary of the most important conclusions are discussed as followed.

Cities will play an important role in the future as 70-85% of the world population is predicted to live in cities. The largest part of emissions originates from cities, and smart energy systems will be required in order to manage the environmental impacts. Regulations in place are not always beneficial for a Demand Response implementation. There need to be incentives for actors to participate and the current market makes small incentives as of now.

Demand Response Programs are created to enable customers to participate. The values for customer are smaller energy bills due to reduced or shifted energy consumption, incentive payment for participating in the programs, greater awareness of their energy consumption and comfortable automated steering of their home appliances. Grid owners can enable a secure and stable electricity supply, which are their main objective as a company. Retailers have a reduced risk in variation of output and the market operators will have an improved market performance for the spot price based programs that are purchased via the electricity market. As peak production will be limited, energy producers may benefit from decreased technologies on the margin, which normally are both expensive and fossil based. The societal benefit from demand response is linked to a plethora of environmental issues. Less fossil based fuels will be used in energy production facilities as a result of more implementation of renewable energy sources. Less overall energy consumption creates safer supply of qualitative energy, less equipment and maintenance costs.

Automation of Demand Response Systems is the key issue when it comes to the implementation of Demand Response. Standardization is needed to reassure incomparability between the different technologies and reduce the costs. Open Standards can be used in order to develop an automated Demand Response System in a city perspective. New communication data models like OpenADR can be combined with smart energy technologies working in a house level and enable in that way the creation of a fully automated DR system.

Three different business models were analyzed in order to show how the aggregator can be introduced in the current power system. The aggregator is the actor that will enable Demand Response and help towards and automated DR System. As it is seen, new regulations are needed in each case as the concept of the aggregator is totally new. The new or transformed companies that will become aggregators have to collaborate properly with the power system participants. It should be argued that the aggregator should not operate as an additional actor but as an actor that will help the system to maintain stability and reliability. The way that aggregator's services can be sold and the distribution of the benefits should also be discussed.

Calculated results from saving potential for customer by reducing or shifting their energy consumption from peak hours are shown to be very small. The result from savings in means of money may not look too much for the single customer, but as discussed, a better implemented Demand Response and a developed smart grid may show other numbers, especially when looking from a system perspective. The home energy management technologies exemplified, BMS and HEMS are seen to be comparatively expensive and the cost for these definitely exceeds the saving they allow. The conclusion is that more R&D is needed within this topic in order to understand the full potential of Demand Response.

8 Discussion

Population increase and natural disasters put much pressure on reliable energy systems and therefore we need a price sensitive Demand Response to fulfil future need. The marginal difference between available effects and load drawn from the end-users is decreasing and the Swedish load reserve system is getting more strain. Elforsk 2006 writes in a report that flexible Demand Response, i.e. response from signals in critical events, probably is the most crucial part for a sustainable power system [16].

Targets for Hyllie require 100% renewable and recycled energy production. Renewable technologies are also associated to green house gas emission, if not to the energy production so to the production of the actual technology. Reducing energy consumption will hence reduce emissions from this part of the chain. The thesis focus on value potentials but incentives should not only be cost saving, but also actions towards an environmentally sustainable living. Societal benefits from avoided emissions should also be included. These benefits cover human well-being due to fresh air, clean water, living ecosystems and a healthy population. The cost saving from these benefits are rarely taken into account but for sure there are connections.

Saving potential for residential customers focuses on residential family apartments only and does therefore not give a fair picture of the total potential available in a community. The consumption and hence savings depends heavily on the number of persons and family constellation in the household. Many assumptions are made for the calculations, which should be considered when looking at the numbers. A future vision includes a fully automated Demand Response System and it is difficult to forecast people’s behaviour and total energy and cost savings with no actual data available.

It seems like DR aggregation advantages the power system more than the end-customers when it comes to cost savings. That is mainly because the technology is still expensive and the electricity prices in Sweden are comparatively low. Another aspect is the benefit for the energy producing companies. Their costs may decrease a lot from avoiding peak production. Learning curves and economy of scale have impact on technology costs and effectiveness. These technologies are new on the market and little research is so far done in this field. Hence it should be further analyzed who are the main actors that should invest in Demand Response Systems.

Current and future regulation in the Swedish as well as in the Nordic Energy System will have an impact on the performance of Demand Response. Income from avoided emissions is another benefit if regulation and policies allow. Reforms and environmental policies will also affect the efficiency of Demand Response as taxes and tariffs may increase or decrease electricity production from different technologies. Green certificates, climate targets and political decisions are some examples that could increase Demand Response and hence result in less fossil and nuclear based power production. In order to successfully implement DR programs and systems it is important to try to foresee the future changes in the energy market. Global developments and political initiatives are factors that may change the benefits for such programs.

Choice of DR program is dependent on the aim of an increase in Demand Response. If the aim is to serve as reserve capacity for disruptions, models for direct load control managed by the system operator is preferred. If the aim is to make customers respond to market signals, price models may be more effective. Another question is whether to control the critical peak events only, or to continuously move towards the market. The first one may be easier to handle since fewer and more important signals are sent to the customers.

Electricity prices are forecasted to increase and this may benefit the outcome from Demand Response [55]. Customers’ response, development and implementation of variable electricity pricing and hourly metering is a requirement for Demand Response. Today around 30% of the Swedish population is contracted with variable pricing but that is not necessarily hourly pricing [56]. Hourly pricing has only been available in Sweden since October 2012. A well working demand response requires customers to use hourly pricing, at least for price based DR programs.

Computer security and personal integrity is something that should be developed in parallel to Demand Response Systems and Smart Grids. IT-hackers may be able to track people’s consumption and hence make a house break in when consumption is low and the house owner is away. Demand Response Systems are built on technological communication schemes and wireless solutions. Remote controlling must be reliable and safe for the users.

Well known organisations like IEEE and Open Smart Grids are important sources for information about communication and interoperability. However, they should be considered with caution and not constitute basis for regulation formation within the EU [57].

9 References

1. International Energy Agency (IEA) , N.E.R. *Nordic Energy Technology Perspectives, Pathways to a Carbon Neutral Energy Future*. 2013.
2. Potocnik, J. *7th European Conferenece on Sustainable Cities and Towns,European Commission for the Environment*. 2013.
3. Kåberger, T. *Chalmers Energy Conference, The role of energy efficiency*. 2013.
4. *Den hållbara staden byggs i Hyllie*. E.ON Homepage 23-05-2103]; Available from: http://www.eon.se/om-eon/Om-energi/Hyllie/.
5. Homepage, E.O. *Fakta om Hyllie och energilösningen* Available from: http://www.eon.se/upload/eon-se-2-0/dokument/om_eon/om_energi/sustaninable-city/Fakta-om-smarta-nat-i-Hyllie.pdf.
6. Tuan, L., *Basic Economic Concepts and Market Operation Market Operation*, 2012, Chalmers.
7. Kirschen D., S.G., *Fundamentals of Power System Economics*. 2004, England: John Wiley & Sons Ltd.
8. *DIRECTIVE 2009/72/EC*, 2009, THE EUROPEAN PARLIAMENT AND THE COUNCIL. p. L211/55.
9. *Roles and Responsibilities of Actors involved in the Smart Grids Deployment*, E. Deliverable, Editor 2011, EU Commission Task Force for Smart Grids
10. Shandurkova, I., *A Prosumer Oriented Energy Market, Developments and future outlooks for Smart Grid oriented energy markets*, 2012: Halden.
11. Grijalva S., *Prosumer-Based Smart Grid Architecture Enables a Flat, Sustainable Electricity Industry*, 2011.
12. Kraftnät, S., *The Swedish Electricity Market and the Role of Svenska Kraftnät* 2007, Svenska Kraftnät
13. *The power market - how does it work*. Available from: http://www.nordpoolspot.com/How-does-it-work/.
14. *Pricing Electricity for Sustainability Climate Change and Canada's Electricity Sector* 2010, Sustainable Prosperity: Ottawa.
15. Kellberg, C. *Framtiden måste bli klimatneutral och energieffektiv*. Available from: http://svenskenergi.episerverhotell.net/sv/Om-el/Miljo-och-klimat/Klimatneutral-framtid/.
16. Damsgaard, N., *Affärsmodeller för ökad efterfrågerespons på elmarknaden* 2006, Elforsk rapport 06:16
17. Kleregård, A.-C. *Trots stora kommande förändringar på elmarknaden - både skratt och allvar på regionmöte i Lysekil*. Available from: http://www.svenskenergi.se/Pressrum/Nyheter/Trots-stora-kommande-

forandringar-pa-elmarknaden---bade-skratt-och-allvar-pa-regionmote-i-Lysekil/.

18. Energimyndigheten, *Långsiktsprognos 2012, En konsekvensanalys av gällande styrmedel inom energi- och klimatområdet*.

19. Palensky P., D.D., *Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads*. 2011.

20. Hedrick, K., *Demand Side Management: Why utility-directed load management programs make more sense than ever before.*, Landis and Gyr.

21. Al-Badi, M.H., *A summary of demand response in electricity markets*, 2008, Department of Electrical and Computer Engineering, University of Waterloo. p. 1989–1996.

22. Jaakko Karas, P.S. *The Increasing Scope and Authority for Power Exchanges*. Elforsk rapport 13:57 2013; Available from: http://srv128.bluerange.se/Documents/Market%20Design/projects/ER_13_57.pdf.

23. S., R., *Preliminary Results of the EEI / PLMA 2002 Demand Response Benchmarking Survey* 2003 Edison Electric Institute

24. PG&E. *Automated Demand Response Program*. Available from: http://www.pge.com/mybusiness/energysavingsrebates/demandresponse/adrp/.

25. Lawrence Berkeley National Laboratory, A., *OPEN AUTOMATED DEMAND RESPONSE COMMUNICATIONS SPECIFICATION (Version 1.0)*. 2009.

26. Center, D.R.R., Open Automated Demand Response.

27. LLC, G.K.T., *The OSI Model: Understanding the Seven Layers of Computer Networks*, E.R.S.o.W. Papers, Editor.

28. Highteck.net, *Application Layer ISO OSI Functionality and Protocols*.

29. Alliance, O. *Leading Utilities Embrace OpenADR 2.0*. Available from: http://www.openadr.org/index.php?option=com_content&view=article&id=68:leading-utilities-embrace-openadr-2-0&catid=21:press-releases&Itemid=121.

30. Saksena, M. *Smart Energy Profile (SEP) 2.0 Uncovered*. 2011; Available from: http://www.eetimes.com/design/smart-energy-design/4229848/SEP--Smart-Energy-Profile--2-0-Uncovered.

31. Instruments, T., *Smart Energy Profile Solutions*.

32. Fielding, R.T., *Architectural Styles and the Design of Network-based Software Architectures*, 2000, UNIVERSITY OF CALIFORNIA, IRVINE.

33. IBM. *RESTful Web services: The basics*. Available from: http://www.ibm.com/developerworks/webservices/library/ws-restful/.

34. Highteck.net, *DataLink Layer*.

35. Egan, D., *The emergence of ZigBee in building automation and industrial control.* 2005.

36. Han, D.-M. *Smart home energy management system using IEEE 802.15.4 and zigbee*. 2010; Available from: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5606276.

37. Corporation, D.-K., *ZigBee's Smart Energy 2.0 Profile Brings New Capabilities and Design Challenges.*

38. Michael LeMay, R.N., George Gross, Carl A. Gunter, *An integrated erchitechture for demand response communication and control*, 2008, University of Illinois Urbana-Champaign.

39. Alliance, Z.-W. *Z-Wave: The New Standard in Wireless Remote Control*. Available from: http://www.z-wave.com/modules/AboutZ-Wave/.

40. Highteck.net, *OSI Network Layer*.

41. Gont, F., *Security Assessment of the internet Protocol*, 2008, CPNI.

42. Tweed, K., *Comverge Leverages Broadband for Residential Demand Response*.

43. Laboratory, N.E.T., *Advanced Metering Infrastructure*, 2008, Office of Electricity Delivery and Energy Reliability, U.S. Department of Energy.

44. Institute, E.P.R., *Advanced Metering Infrastructure (AMI).* 2007.

45. American Society of Heating, R.a.A.-C.E.A., *Official Website of ASHRAE SSPC 135.*

46. Automation, R.T., *BACnet® Overview, An Application Layer Protocol for Building Automation.*

47. Echelon. *LonWorks*. Available from: http://www.echelon.com/technology/lonworks/.

48. Automation, R.T. *LONWORKS OVERVIEW, A Plan for Product Enhancement*. Available from: http://www.rtaautomation.com/lonworks/.

49. Heath, S., *Embedded Systems Design*. 2003: Newnes.

50. Jussi Ikäheimo, C.E., Seppo Kärkkäinen, *DER Aggregator business: the Finnish case*, 2010.

51. Lilienberg, D., *Project Manager E.ON*, 2013.

52. Inc, U.D. *ISY994i Series*. 2013.

53. S, G.T. *Home Automation and the 'Internet of Things'*. 2012.

54. John, J.S. *Marvell Builds the Smarts Into Networked LEDs*. 2013; Available from: https://www.greentechmedia.com/articles/read/marvell-builds-the-smarts-into-networked-leds.

55. Krögerström, L. *Professorn: Elpriset måste mångdubblas*. 2013.

56. Centralbyrån, S. *Priser på elenergi och på överföring av el (nättariffer)*. Available from: http://www.scb.se/Pages/TableAndChart____92219.aspx.

57. Christer Bergerland, K.F., Olle Hansson, *Norra Djurgårdsstaden, Nya marknadsmodeller för engagerade kunder,* in *Elforsk rapport 11:66*2011.