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NATIONAL SCALE IMPACT OF THE STOCKHOLM ROYAL SEAPORT PROJECT

DEMAND RESPONSE AND LOAD-SHIFT FOR SWEDISH APARTMENT CUSTOMERS

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Abstract

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To meet the challenges of a fluctuating demand of electricity, the concept of a "Smart Grid" has been phrased. One of the most important goals of a Smart Grid is to enable end-consumers to participate more actively in the energy market. One way to do this is through "load-shifting" where consumption are moved from hours of high demand to hours of low demand. In Sweden, a Smart Grid project called the Stockholm Royal Seaport (SRS) project is currently taking place. The project have phrased a hypotheses regarding load-shifting called the "Active customer" scenario, in which a customer load-shifts 5-15 % of his electricity consumption. To facilitate this scenario, the SRS project uses an end-consumer price model for electricity, called the SRS price model.
This study investigates what impact the results from the SRS pilot project might have if implemented for private apartment end-consumers on a Swedish national scale. The study is divided into three parts. The first part investigates the challenges of a national scale implementation of private apartment end-consumer DR and the SRS price model. The second part investigates what the impact would be if the entire Swedish private apartment end-consumer sector where to act in accordance with the Active customer scenario. The third part consists of a sensitivity analysis. The challenges are deemed to be of a non-technical character, but rather of a marketing and communication nature.
The SRS price model is deemed to give a clear economic incentive for load-shift of private apartment end-consumer without electric heating. However, the incentive might be considered too weak with yearly savings of 48-165 SEK for a 15 % load-shift. The sensitivity analysis suggests that the cost savings are hard to influence. The impact of a fully implemented national private apartment end-consumer load-shift in accordance with the Active customer scenario and the SRS price model is small in comparison with other plausible demand developments.

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ABSTRACT

The Swedish electrical power system faces many challenges. Stricter environmental and economic demands require a more efficient use of both the transmission and distribution grids as well as the production capabilities. Since the Swedish national demand of electricity is fluctuating, the system has always been dimensioned to meet the periods of high demand, resulting in a low utilization of the system. To meet these challenges, the concept of a “Smart Grid” has been phrased. One of the most important goals of a Smart Grid is to enable end-consumers to participate more actively in the energy market. One way to do this is through “load-shifting” where consumption (or loads) are moved from hours of high demand (peak hours) to hours of low demand (off-peak hours). Load-shifting is a part of a set of intentional consumption modifications denoted “Demand Response” (DR) and is deemed to be one of the most important tools of the Smart Grid. In Sweden, a Smart Grid project called the Stockholm Royal Seaport (SRS) project is currently taking place. The project have phrased a hypotheses regarding load-shifting called the “Active customer” scenario, in which a customer load-shifts 5-15 % of his electricity consumption. To facilitate this scenario, the SRS project uses an end-consumer price model for electricity, called the SRS price model, as well as technological and market solutions not yet available on a national scale.

This study investigates what impact the results from the SRS pilot project might have if implemented for private apartment end-consumers on a Swedish national scale. The study is divided into three parts. The first part investigates the challenges of a national scale implementation of private apartment end-consumer DR and the SRS price model. The second part investigates what the impact would be if the entire Swedish private apartment end-consumer sector where to act in accordance with the Active customer scenario. The third part consists of a sensitivity analysis.

Four challenges for a national private apartment end-consumer load-shift implementation have been elicited. They are; the lack of easily moveable loads in a foreseeable future, the heterogeneous cost of distribution, the suggested price models low peak to off-peak price ratio and the comparatively small cost of electricity of the private apartment end-consumers. The SRS price model is deemed to give a clear economic incentive for load-shift of private apartment end-consumer without electric heating. However, the incentive might be considered too weak with yearly savings of 48-165 SEK for a 15 % load-shift, depending on apartment consumption. This corresponds to yearly savings of 124 to 429 million SEK for the entire customer segment. These challenges are deemed to be of a non-technical character, but rather of a marketing and communication nature.

The impact of a fully implemented national private apartment end-consumer load-shift in accordance with the Active customer scenario and the SRS price model is deemed to be beneficial from an overall power system point of view. However, the impact on the private apartment end-consumer national demand is small in comparison with other plausible system developments, such as energy demand reductions due to more efficient lighting solutions.

The sensitivity analysis of private apartment end-consumer cost savings when acting in accordance with the Active customer scenario indicates that the percentage savings may increase in the future when considering more volatile prices for electric energy or the implementation of a time differentiated energy tax.

Keywords: *Smart Grid, Demand Response, load-shift, price model, Stockholm Royal Seaport*

SAMMANFATTNING

Sveriges elkraftssystem står inför många utmaningar. Striktare miljömässiga och ekonomiska krav kräver ett mer effektivt utnyttjande av både transmissions- och distributionsnäten samt produktionskapaciteter. Eftersom Sveriges nationella efterfrågan på elkraft fluktuerar så har elkraftssystemet alltid varit överdimensionerat för att möta perioder av hög efterfrågan vilket resulterar i ett lågt utnyttjande av systemet. För att möta dessa utmaningar så har ett koncept om ett ”Smart Elnät” blivit myntat. Ett av de viktigaste målen med ett Smart Elnät är att tillåta slutkonsumenter att delta mer aktivt på energimarknaden. Ett sätt att åstadkomma detta är genom ”lastflyttning”, där konsumtion (last) flyttas från timmar med hög efterfrågan (hög-last timmar) till timmar med låg efterfrågan (låg-last timmar). Lastflyttning är en del av en uppsättning av avsiktliga konsumtionsmodifikationer kallade ”efterfrågestyrning” och anses vara en utav ett Smart Elnäts viktigaste verktyg. I Sverige så pågår för tillfället ett Smart Elnätsprojekt kallat Norra Djurgårdsstaden (NDS). Projektet har myntat en lastflyttningshypotes kallat ”Aktiv kund” scenariot där en kund antas lastflytta 5-15 % av sin konsumtion. För att underlätta denna lastflyttning så använder NDS en prismodell för slutkonsumenter, kallad NDS prismodell, samt tekniska och marknadsmässiga lösningar som inte är tillgängliga på en nationell skala än.

Denna studie undersöker vilken inverkan resultaten från NDS skulle ha om de var implementerade för privata lägenhetskunder på en nationell svensk skala. Studien är uppdelad i tre delar. Första delen undersöker utmaningarna för en implementering av efterfrågestyrning och NDS prismodell för privata lägenhetskunder på en nationell skala. Den andra delen undersöker vilken nationell inverkan ett fullt implementerad Aktiv kund scenario skulle få, givet att alla lägenhetskundskunder deltar. Den tredje delen består av en känslighetsanalys.

Fyra utmaningar för en implementering av lastflyttning och NDS prismodell för lägenhetskunder har identifierats. De är; brist på enkelt flyttbara laster, den heterogena kostnaden för distribution, den föreslagna prismodellens låga hög-last till låg-last prisration samt de jämförelsevis låga elkostnaderna för lägenhetskunder. NDS prismodell anses ge ett klart ekonomiskt incitament för lastflytting för lägenhetskunder utan elvärme. Incitamentet kan dock anses vara för litet med årliga besparingar på 48-165 SEK för en 15 % lastflytt, beroende på lägenhetskonsumtion. Detta motsvarar årliga besparingar på 124 till 429 miljoner SEK för hela kundsegmentet. Dessa utmaningar anses vara av en icke-teknisk karaktär, utan snarare av en marknadsföringsmässig och kommunikationsmässig natur.

Inverkan av en fullt implementerad lastflyttning för all privata lägenhetskunder som agerar i enlighet med Aktiv kund scenariot och NDS prismodell på en nationell skala bedöms som fördelaktig från ett översiktligt systemperspektiv. Inverkan är dock liten i jämförelse med andra troliga systemutvecklingar såsom minskad energiefterfrågan på grund av effektivare belysningslösningar.

Känslighetsanalysen av kostnadsbesparingarna för de privata lägenhetskonsumenterna som agerar i enlighet med Aktiv kund scenariot indikerar att de procentuella kostnadsbesparingarna kan komma att öka i framtiden om hänsyn tas till mer volatila energipriser eller en implementering av en tidsdifferentierad energiskatt.

Sökord: *Smart Elnät, efterfrågestyrning, lastflytt, prismodell, Norra Djurgårdsstaden*

TABLE OF CONTENTS

1. Introduction

In this introduction the background of this Master Thesis is presented followed by its objectives, methodology, limitations and disposition.

1.1 Background

This report is a collaboration between the Royal Institute of Technology (KTH) and the Swedish electricity distribution company Fortum Distribution. In this subchapter, the Master Thesis is put in context with the overall development of the Swedish electric power system, the "Smart Grid" concept and the Stockholm Royal Seaport project.

1.1.1 Challenges for the Swedish electrical power system

For a long time, Swedish authorities promoted the extensive use of electricity for heating and household appliances in private households as well as in industry. This was done in order to promote and encourage the electrification of Sweden through projects that often required large investments which made maximal participation of households and industry crucial. Due to a large amount of hydropower and (since 1964) nuclear power, Sweden benefited from relatively low electricity prices from production with low carbon-dioxide emissions (1).

The utilization of the electric power grid and the production linked to it is, however, not constant over a twenty-four hour period, nor over the duration of a full year or from year to year. High peaks in power demand are to be found during day time, especially at early mornings and early evenings when household residents are most active in the matter of cooking, cleaning and using electricity consuming appliances such as televisions, electric lighting and personal computers (2). Similarly, consumption is higher during the cold winter months than during the summer due to a high percentage of electric heating, specifically in houses. The demand for electric energy also fluctuates from year to year, mainly depending on weather conditions and the economic situation, since the Swedish economy is heavily influenced by electricity consuming basic industry such as paper and pulp, steel, chemical and engineering industry (3). This leads to two challenges for the electric power system. Firstly, the transmission and distribution grids need to be dimensioned to handle these periods of high demand. Secondly, adequate production needs to be available to meet the power demand during the same periods.

In order to avoid higher stress on the transmission and distribution grids, two principal solutions are to be found; reinforce the grids or utilize them more effectively. Since reinforcements of the grids are associated with high (sometimes unacceptable) economic and environmental costs, a more even utilization of the grids is desirable. The problem with meeting the increased need for peak production is somewhat more complicated.

In 1996, the Swedish electricity market was re-regulated, resulting in electricity being priced by marginal pricing instead of average pricing. This re-regulation was implemented to permit a more effective electricity market and to reduce the capacity reserve, which in a way reduced the system's ability to meet peak demand. Prior to the re-regulation, numerous production plants existed that was only used a few hours each year. These plants were carbon-emission intensive since they were often based on combustion generation that used oil or gas as fuel, but they were also expensive due to their low utilization factor. Just as the transmission and distribution grids were once over dimensioned, so were the electricity generation capabilities. It was believed that a marginal pricing of electricity would create incentives to reduce demand at high marginal prices and increase demand at low marginal prices, allowing the expensive plants with a low utilization factor to be closed. This would indirectly solve the problem with the stress on the grids at peak periods as well. (4)

Unfortunately, it has been shown that electricity demand is subject to low price elasticity; a given change in prices does not result in a proportional change in demand (5). In addition to this fact, price signals are not always transferred to end-consumers, which make an appropriate change in demand impossible. This unfortunate fact is due to the lack of time-differentiated electricity prices for end-consumers. Private end-consumers have traditionally been faced with a single, constant electricity price that does not vary during the course of a day, even though the prices sometimes vary from month to month, depending on the consumer's subscription (6).

1.1.2 The Smart Grid

To meet the above-mentioned challenges concerning the ineffective utilization of the grids and the time-varying aspects of electricity production and consumption, the concept of the "Smart Grid" has been phrased. There is unfortunately no one single definition of what a Smart Grid is. The concept usually refers to the drivers, technological solutions as well as market solutions that enable a more efficient utilization of the electrical power system as a whole (7). One of the most important goals for a Smart Grid implementation is to activate and enable end-consumers to participate more actively in the energy market. An active end-consumer could, for example, chose to postpone the use of a dishwasher or a tumble-dryer from times of high demand to times of low demand, allowing the power system to be utilized in a more even and therefore more stable manner and in the same time reducing his own costs. The behavior to move consumption (or loads) from hours of high demand (peak hours) to hours of low demand (off-peak hours) is called "load-shifting" (8). These sorts of intentional consumption modifications are denoted "Demand Response" (DR) and it is deemed to be one of the most important tools of the Smart Grid (9). Successfully implemented, load-shifting could reduce the need for new investments in distribution capacity, as well as in peak production plants (6).

1.1.3 The Stockholm Royal Seaport project

The Stockholm Royal Seaport (SRS) is an urban development project for a planned expansion of housing and business that are taking place in the district of Hjorthagen in Stockholm (10). Twelve thousand apartments alongside office space for thirty thousand workers are to be constructed until 2030 (11). The SRS project aims to show that cities can reduce carbon emissions as well as facilitate climate-friendly growth and it has been designated as one of 18 projects in the world supported by the Climate Positive Development Program, which is a part of the Clinton Climate Initiative (12). The main actors in the SRS Smart Grid are the electrical equipment manufacturer ABB, the Royal Institute of Technology (KTH) and the electricity distribution company Fortum Distribution.

A pre-study for the SRS project was performed in 2010 and 2011 (8) (13). In the pre-study, a market model that support a development towards an energy system with active consumers resulting in a more efficient use of the electric power system with less environmental impact are presented. This new market model; denoted the SRS price model, will be tested on voluntary households in the Royal Seaport area, starting fall 2012 (14).

The electricity price that the consumers face in Sweden consists of different components such as energy cost, taxes, retail price and a network tariff. The retail price originates from the demand and supply of electric energy available in the system and is therefore subject to a competitive market since the re-regulation of 1996 (4). The network tariff is related to the cost due to the transmission and distribution of the electricity from the producer to the consumer and is subject to a natural, but regulated monopoly (4). The SRS price model combines all of these costs into a single model. (14)

The aim with testing the new price model is to investigate its impact on energy consumption which has been defined in an “Active customer” scenario and corresponding hypotheses listed in the pre-study. The hypotheses state that an Active customer will move 5-15 % of his total electricity consumption from peak demand hours to off-peak demand hours. (8)

1.1.4 National scale impact of the Stockholm Royal Seaport project

Even though numerous pilot-studies have been undertaken, both internationally regarding Smart Grids in general as well as nationally focusing on the SRS project, few of these studies have examined the national scale impact of such solutions and models (15). In order to put these results into perspective, the need to extrapolate results to a larger scale is evident. Such an extrapolation needs to take into consideration the difference between demarcated pilot studies and “real-world conditions”. This Master Thesis will therefore focus on the national scale impact of DR and the SRS price model for electric energy to private apartment end-consumers.

1.2 Objectives

The objectives of this Master Thesis are to:

- Define and investigate the challenges of a Swedish national scale implementation of end-consumer DR and the SRS price model for electricity for private apartment end-consumers.
- Extrapolate the findings and implications from private apartment end-consumer DR and the SRS price model to a Swedish national scale.
- Develop an accompanying method for how a sensitivity analysis can be performed, given the before mentioned extrapolation of private apartment end-consumer DR and the SRS price model and taking into account possible future developments in the Swedish power system.

Given these objectives, the following research questions can be stated:

1. What are the challenges of a Swedish national scale implementation of end-consumer DR and the SRS price model for private apartment end-consumers?
2. What would be the results of a Swedish national scale implementation of end-consumer DR and the SRS price model for private apartment end-consumers?
3. How can an accompanying sensitivity analysis be performed, given the before-mentioned extrapolation of private apartment end-consumer DR and the SRS price model and taking into consideration possible future developments in the power system?

1.3 Method

An extensive data collection has been performed through reviews of earlier studies and meta-studies concerning the Swedish and Nordic electrical power system, national and international Smart Grid projects and the SRS project. Publicly available statistics regarding historical electricity prices and electricity consumption patterns are mainly gathered from Swedish authorities and Nordic companies.

Calculations of aggregated electricity consumption and end-consumer costs are based on publicly available data, if not otherwise stated. Calculations of theoretical, future scenarios are based on secondary data from earlier scenario studies concerning the development of the Swedish and Nordic power system.

A reference group was also used as a sounding board in the development of this Master Thesis, consisting of industry, academy and government experts as well as representatives of companies involved with the SRS project. The members of the reference group were:

Olle Hansson, Fortum
Erik Hjelm, Fortum
Christer Bergerland, Fortum
Annika Kühner, Electrolux
Anton Gustafsson, Interactive Institute
Lennart Söder, Royal School of Technology (KTH)
Anders Nilsson, Royal School of Technology (KTH)
Henrik Sandberg, Royal School of Technology (KTH)
Alessandra Parisio, Royal School of Technology (KTH)
Joakim Widén, Uppsala University
Cajsa Bartusch, Uppsala University
Christer Bäck, Swedish national grid (Svenska Kraftnät)
Lars Ström, Swedish Energy Market Inspectorate (Energimarknadsinspektionen)

1.4 Limitations

There are always difficulties attached to calculations based on historical figures as well as forecasts. To the best of the author’s knowledge, no previous studies have been made that extrapolate the results from Smart Grid pilot projects to national scales. The results presented in this Master Thesis should therefore, as for all calculations of this sort, be interpreted based on the conditions presented and the assumptions made.

1.5 Disposition

This Master Thesis is roughly structured according to the main research questions presented in section 1.2. In chapter two, important background information about the Swedish and Nordic electric power system is presented along with the price structure of the Swedish end-consumer price of electricity and information regarding the SRS project. Chapter three investigates the challenges associated with the extrapolation of results from the demarcated SRS pilot study to a Swedish national scale implementation of DR and the SRS price model. End-consumer costs and cost savings are presented as well. Chapter four outlines the extrapolation of the SRS price model and the Active customer scenario to a national scale. End-consumer composition is presented as well as an estimated aggregated load-shift. Chapter five describes a sensitivity-analysis of the national scale extrapolation. Future developments regarding the SRS price model Cost components and end-consumer prices are taking into consideration in the analysis as well as possible future developments of the Swedish national demand. The Master Thesis ends in chapter six with a discussion regarding the implications of a national scale implementation of the SRS price model and the suggested DR solutions.

2. Background

This chapter will present some important, fundamental aspects of the Swedish electric power system, the Swedish end-consumers cost of electricity and the SRS project. Firstly, in section 2.1, the physical structure of the Swedish electrical power system is presented along with the historical background of some of its important developments. Secondly, in section 2.2, the end-consumers' costs of electricity is explained, divided on the cost of energy, the cost of distribution and the costs of taxes and incentives. Thirdly, in section 2.3, the SRS project is presented along with a description of DR and load-shift, the SRS price model and the Active customer scenario.

2.1 The Swedish electrical power system

As a nation, Sweden consumes large amounts of electricity per capita in comparison with other nations, see figure 2.1 (16). The large per capita consumption is due to an electric energy intensive industry as well as high consumption of households due to a high percentage of electric heating and electric appliances (4). The paper and pulp industry in Sweden is the most electricity consuming sector with almost 40 % of the total industry consumption. Other large industrial users are the chemical industry, the engineering industry and the metal industry (17). Up until the 1990's, electricity demand in Sweden increased because of increased industry demand and a conversion of domestic oil fueled heating to electrical heating (4). Even though Sweden is still both a large producer and consumer of electricity, the national demand of electricity has stabilized during the last 20 years (17).

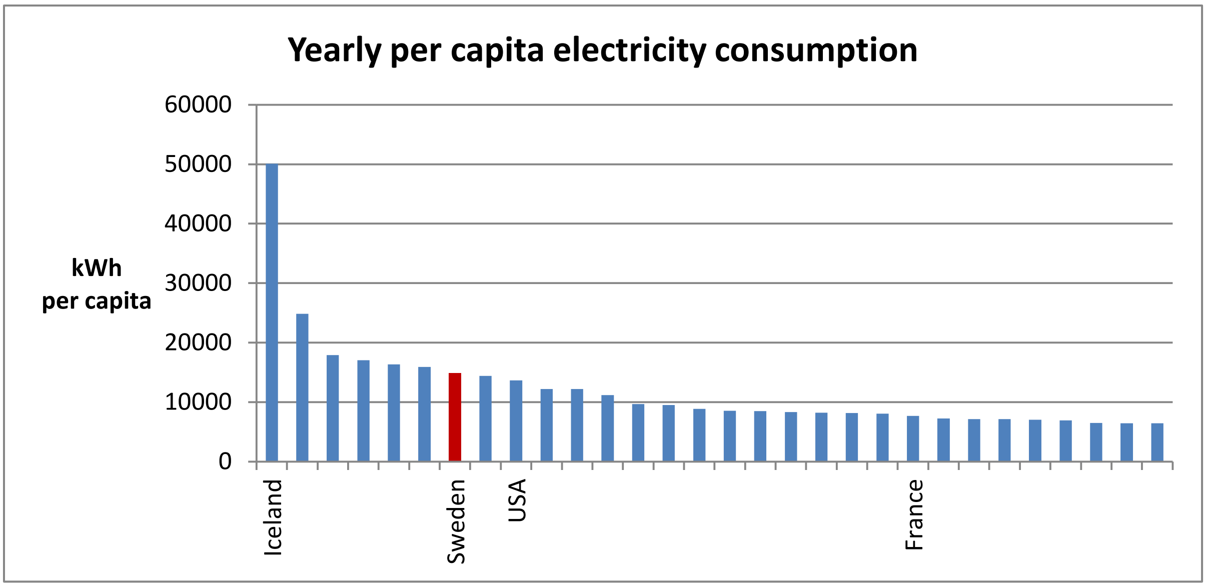

Figure 2.1. *The electricity consumption per capita in 2011 of the 30 nations with the highest per capita consumption. (based on* (16)*)*

The reason for Sweden's high per capita electricity consumption and the national configuration of industries has historical explanations. Until the 1960's, Sweden's electricity production came almost entirely from hydro electrical power plants. A state driven electrification campaign of industry and an expansion of the railroad system led to an extensive exploitation of Swedish rivers in order to meet the demand of electricity. The rivers most suitable for hydro power were often located in the northern parts of Sweden and because of that fact, an industry for power transmission over large distances was established, led by the company ASEA, now ABB. In the mid 1960's, public opinion opposed a further exploitation of the remaining rivers suited for hydro electrical power plants and instead Sweden started an electricity production expansion based on nuclear power plants. The nuclear power plants where located in the southern parts of the country to counterbalance the high demand for electricity of industry as well as of households and services in these regions. (1)

Due to the early expansion and focus on hydropower in the northern parts of the country in combination with the densely populated southern regions, Sweden's electrical power system has a distinct north to south architecture with substantial power production in the northern parts of the country while the majority of the consumption is located to the southern, more populated regions. Despite the expansion of nuclear power plants and combined heat and power plants in the southern regions, the Swedish national power flows still predominately goes from north to south. This has led to bottlenecks in the transmission capacity where not enough power can be transmitted during periods of high demand. (4)

The north to south architecture is to some aspect unique for Sweden within the Nordic power system. Norway, for instance has transmission bottlenecks in an east to west direction as well, resulting in a power system that is more fragmented than the Swedish power system. (4)

Sweden's history of centralized and high capacity electricity production with large-scale hydro electrical and nuclear power plants has influenced the construction of its transmission and distribution grids as well. The function of the transmission and distribution grids is to connect electricity producers with electricity consumers. (1)

The grids are divided on three hierarchical levels. On the highest level, there is the high voltage transmission grid. The transmission grid consists of approximately 15 000 km overhead power lines with a voltage of 220 kV and 400 kV connected by 150 transformers and switching stations. International transmission lines and cables are also included. The principal task of the transmission grid is to transmit electric power over large distances; from north to south and from the large southern nuclear power stations to population centers and industry users. (18)

Svenska Kraftnät (SvK) is a state-owned public utility that owns the Swedish transmission grid. SvK is also the Swedish transmission system operator (TSO) meaning that they, in addition to being the owner of the high voltage transmission grid, are responsible for the operation of the electrical power system. The TSO is responsible for the operational security of the entire power system and for maintaining the momentary balance between demand and supply as well as for maintaining and developing the transmission system in the long term and enhance efficient electricity markets. (19)

Connecting to the transmission grid is the regional distribution grids. The voltage from the transmission grid is transformed down to 40-130 kV for these grids. Certain energy intensive industries are connected to this voltage directly, while households and companies have an additional, local distribution grid between the regional distribution grid and their outlet. (18)

The local distribution grids have voltages from 30 kV down to 400 V and 230 V, which is the normal voltage of a Swedish household outlet. The lower voltages of 400 V and 230 V are usually used for underground cables. Unlike the transmission grid, the regional and local distribution grids are owned by private companies. These companies are usually distribution system operators (DSO's) as well, which are responsible for power quality and for measuring consumption and production of its customers. (18)

In 2011, there were approximately 170 grid owners in Sweden, the largest of which are Fortum, Vattenfall and E.ON (20).

These three grid owners own most of the regional distribution grids and more than 50 % of the local distribution grids. In addition to the three large grid owners, there are numerous smaller grid owners that are usually cooperatives or municipalities. A large market consolidation have taken place since the 1950's when over 1500 different grid owners operated in Sweden. (4)

2.2 The cost of electricity – cost components

Swedish private end-consumers of electricity are usually faced with two bills for electricity. One bill is received for the electric energy consumed, including all costs that are associated with the production of the electric energy including taxes and VAT and one bill is received for the transmission and distribution of the energy from the producer to the end-consumer, which also include VAT. The end-consumers Cost components of electricity are illustrated in figure 2.2.

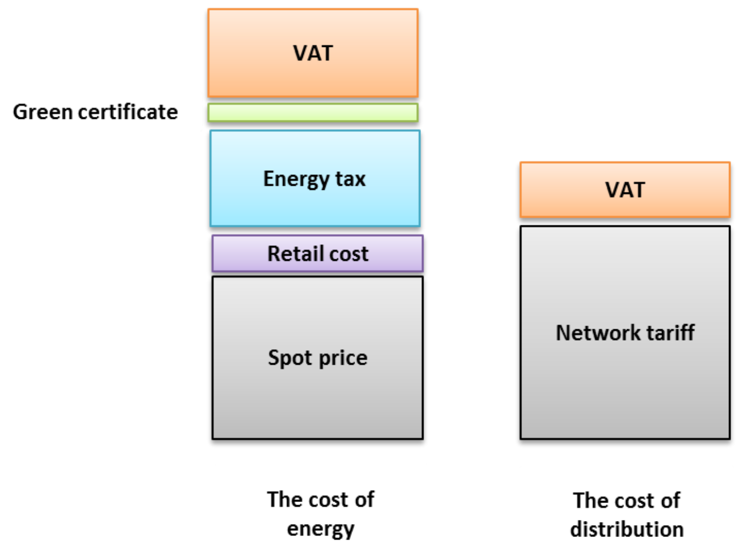

Figure 2.2. *Cost components of electricity that a Swedish end-consumer is subject to. (Based on* (21)*)*

In this section, the Cost components of private apartment end-consumers are presented, along with information regarding their pricing.

2.2.1 The cost of energy

The end-consumer cost of electric energy is based on the market price of electricity, called the Spot price, and the retail cost, see figure 2.3.

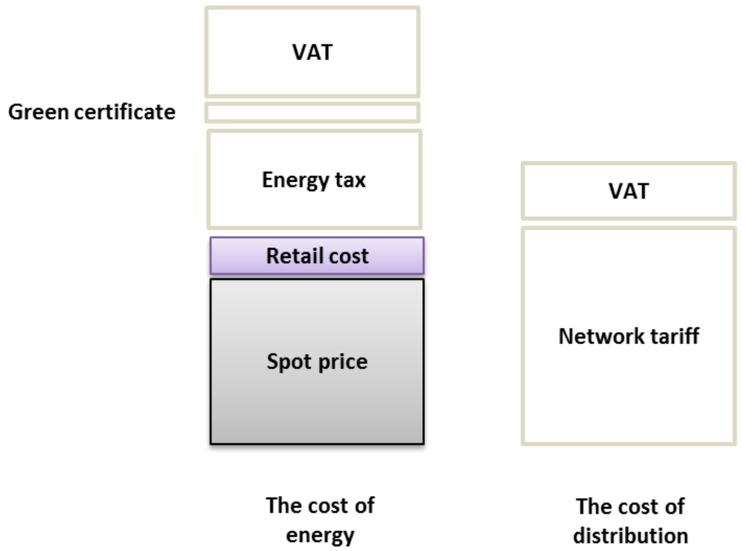

Figure 2.3. *The cost of electric energy that a Swedish end-consumer is subject to. (Based on* (21)*)*

Originally, electricity pricing in Sweden was influenced by the governments' demand on return from the largest producer of electric energy Vattenfall which was, and still is, state-owned. The governments' influence in combination with the oligopolistic nature of the market resulted in a price cap as well as prevented the prices to become too low. However, Swedish electricity producers implicitly acted in accordance with marginal pricing during this period, resulting in prices that did not differ much from those that would exist given full competition. (4)

In 1991, Norway's electricity market was reregulated to one using marginal pricing and in 1996 Sweden followed (4). The common electricity market operator Nord Pool was created with Sweden's and Norway's TSO's; SvK and Statnett as owners (4). Some years later, Denmark and Finland followed and their respective TSO, Energinet.dk and Fingrid became part owners of Nord Pool as well. Thus a common Nordic electricity market was created (22).

On Nord Pool's day-ahead electricity market Nord Pool Elspot, electric energy is traded on an hourly basis and by marginal pricing, meaning that the most expensive MWh produced each hour decides the price for all electricity bought and sold that hour. The selling bids of the sellers and the buying bids of the buyers are submitted to the market at 12.00 CET (Central European Time) the day before the delivery. These bids generates a demand curve and a supply curve which is used to determine a price cross where the marginal, balancing price of electricity each hour is set. As of 2013, there are roughly 360 buyers and sellers operating on Nord Pool Elspot. (23)

A demand and supply curve is illustrated in figure 2.4. The steepness of the demand curve indicates the relative price inelasticity of the electricity demand.

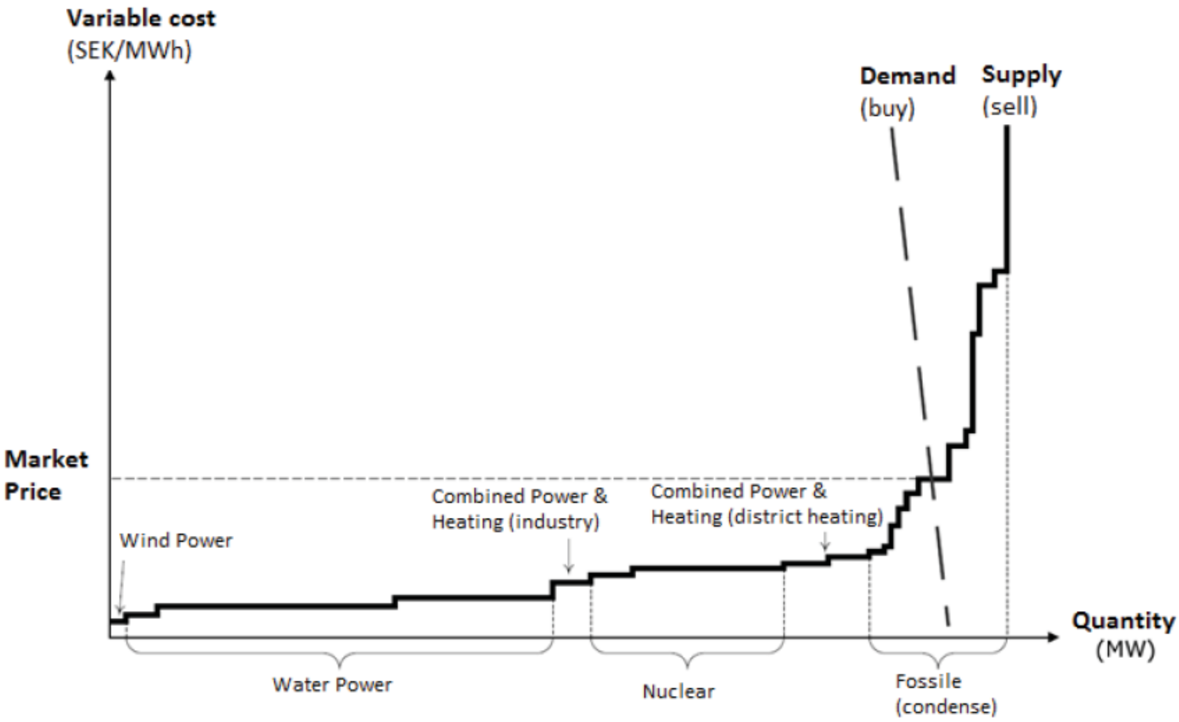

Figure 2.4. *Demand and supply curve for Nord Pool Elspot. Common marginal production prices for different types of production are included. (based on* (24)*)*

If a seller or a buyer discovers that his production or consumption is not coherent with that of the bids he has submitted to Nord Pool Elspot, the difference can be negated by buying or selling the needed energy on a secondary, intra-day market called Nord Pool Elbas. This additional intra-day market becomes more important when the consumption and production becomes increasingly harder to predict, as can be the case with a higher percentage of wind power in the power system for example. (25)

Due to the north to south architecture of the Swedish electric power system described in section 2.1, the transmission grid is sometimes incapable to transmit enough electric energy from producers to consumers in accordance with the trading on Nord Pool Elspot, resulting in transmission bottlenecks (26). As a way to mitigate these difficulties and create fair market incentives for consumers, producers and grid operators, Sweden was divided into four different price areas in 2011, see figure 2.5 (27).

Figure 2.5. *Sweden's price areas and the Swedish transmission grid.* (28)

Since the introduction of the price areas, Sweden now has different electricity spot prices depending on where in the country the electric energy is consumed. If the transmission capacity between two price areas is maxed out, the importing price area will suffer higher prices. Norway is divided in up to five different price areas, Denmark is divided into two price areas while Finland only has one. (26)

Most of Sweden's hydro-electrical production is located in price area one (SE1) and two (SE2) while the nuclear power production are located to the southern price area three (SE3) (29). The electricity prices are generally higher in the price areas SE3 and SE4 in the event of a transmission bottleneck (30).

Since the reregulation, the market for electric energy is open for competition and each end-consumer can chose which producer to buy electricity from. However, most end-consumers are too small to trade directly with the market on an hourly basis and therefore use retailers as providers of electricity subscriptions. The subscriptions are usually fixed, meaning that the end-consumer pays the same price for a kWh regardless of when it is consumed within the subscription period. This price is based on the electricity spot price added with the risk premium and profit margin of the retailer. In reality, the retailers compete by hedging and billing services as well as making forecasts of consumer consumption since the majority of the energy is priced and sold through Nord Pool Elspot. (19)

Retailers or trading companies trades financial products such as futures and forwards on a financial market and thus hedging themselves from price fluctuations. By this design, the incentive to reduce consumption during hours of high prices is all but eliminated since it is only the retailer or the trader who is affected by the consequences of unpredictable prices. Possible losses are of course intermediated to the end-consumer in the form of more expensive subscriptions in the future, but not before after the fact. This leads to a situation where the end-consumers have no direct but an indirect incentive to reduce their consumption. (19)

2.2.2 The cost of distribution

The end-consumer cost of distribution is based on the network tariff, see figure 2.6.

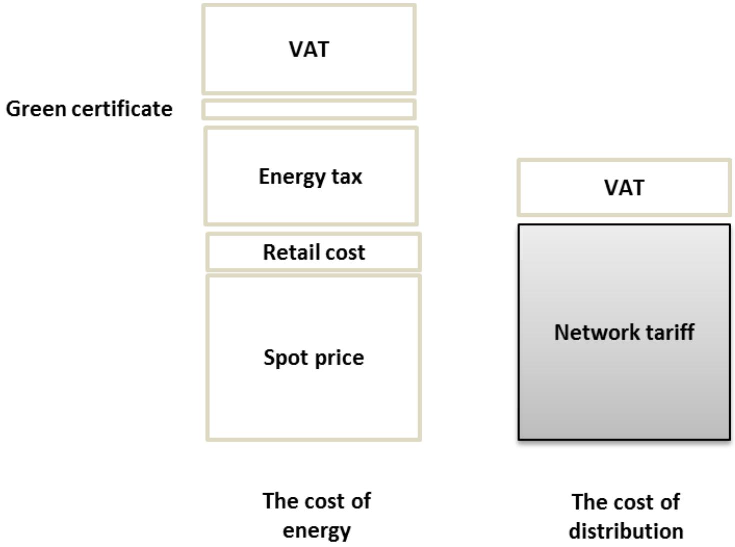

Figure 2.6. *The cost of distribution that a Swedish end-consumer is subject to. (Based on* (21)*)*

While the cost of electric energy can readily by subject to an open market with competing actors, the same is not efficient with the cost of the distribution of electric energy. The transmission and distribution grids are capital intensive forms of infrastructure and competing entities for the services they provide would be far from socioeconomically viable. Therefore, the distribution grid owners operate under a regulated monopoly. (4)

In order to prevent the grid owners to make unreasonable profits due to their monopolistic position, they are subject to regulations and audits by a state regulator called the Swedish Energy Market Inspectorate (EI). EI sets revenue caps for the operation of the grids in advance in four year intervals. (31)

Grid owners are often DSO's, which are responsible for power reliability and for measuring consumption and production of its customers. If the power reliability does not meet the requirements, the revenue cap can be lowered in the following four year interval. The distribution grid owners are responsible for the maintenance and development of their respective grids, just as SvK is responsible for the transmission grid. Distribution losses in the distribution grids are compensated by the DSO which are also responsible for a fair and equal market, meaning that they have to treat all customers in their respective grids equal in regard of distribution subscriptions and billing. (32)

Since the distribution of electric energy operates under a natural monopoly, the end-consumer cannot influence the cost of distribution. The cost of distribution, in the form of a network tariff, usually depend on a fixed cost based on the fuse size of the customer, which limits the maximum power output and thereby the dimensioning of the grid, as well as a variable cost based on the amount of energy distributed, which in turn influence the losses in the grid. (33)

2.2.3 Taxes and incentives

The end-consumers cost of taxes and incentives origin from both the cost of energy and the cost of distribution, see figure 2.7.

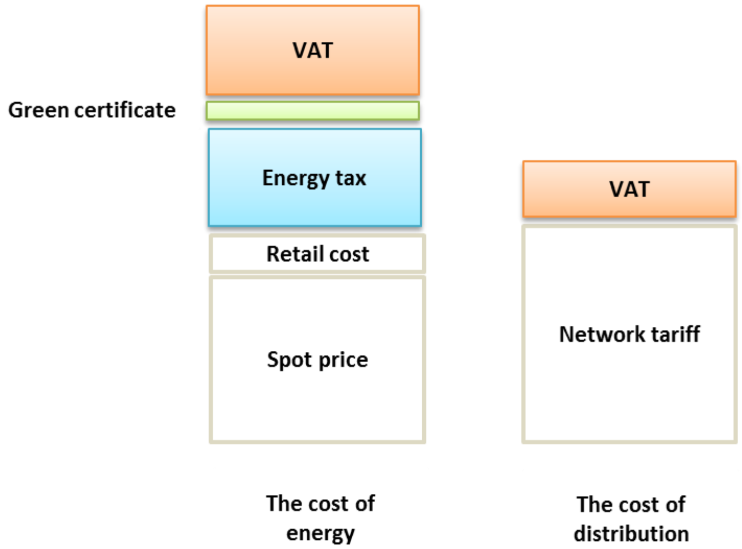

Figure 2.7. *The cost of taxes and incentives that a Swedish end-consumer is subject to. (Based on* (21)*)*

There are numerous taxes and incentives that influence the end-consumers cost of electricity. The most important ones are the value added tax (VAT), the energy tax and the green certificates.

The green certificate system was introduced in Sweden in 2003 to encourage electricity production from newly developed renewable energy production. The system dictates that a certain percentage of the energy production must stem from renewable production and the percentage changes every year. A producer of renewable energy receives one green certificate for every MWh he produces which he then can sell to other actors that have an obligation to account for a certain percentage of renewable production each year. The actors with an obligation to account for green certificates are for example retailers and energy intensive industry users. This creates an artificial market that gives incentives to increase the production of renewable energy up to a certain level. Since the certificates are traded on an open market, where the prices are determined by the total production of electric energy in relation to the production that stems from renewable production, the price of the certificates may fluctuate. (4)

However, the tally of the certificates is done ones a year so the instant price of the certificate does not have the same importance as that of the electricity spot price. In 2012, Norway joined the system allowing the renewable production to be located at the most economically beneficial location possible. For the year 2013, the quota that needs to be reached is 13,5 %. This percentage will shift every year until the year 2035, when the system seizes to exist. (34)

Since the green certificate needs to be purchased by the retailers themselves, the cost can be said to actually be a part of the cost of energy.

The energy tax is a consumer tax that for 2012 was set to 29 öre/kWh. The tax is paid by the end-consumer regardless of when the electricity is consumed and the magnitude of the tax is increased from year to year. VAT is paid by the end-consumer on the retail price that includes the spot price of electricity, the green certificate, the retail fee and the energy tax as well as on the distribution costs. (35)

There are many additional taxes that affects the end-consumer price of electricity such as property taxes for production facilities, emission taxes on sulfur dioxide and other emissions but these are seen as included in the spot price of electricity (35). The green certificate are separated from these taxes as it operates under a market system with supply and demand and is therefore indirectly priced by the government rather than directly, as is the case of other taxes (4).

2.3 The Stockholm Royal Seaport project

The SRS project is an urban development project that will evaluate numerous different technological solutions as well as market solutions linked to the Smart Grid concept. Many of these solutions intend to encourage a more effective use of the electrical power systems. (12)

To evaluate these proposed solutions, the electricity consumption of a number of test apartments will be monitored. (8)

These apartments will be equipped with energy saving functions such as sensors that can detect the movements of the inhabitants as well as predefined energy saving settings that programs the entire apartment according to the usage of the apartment. The apartments will also be fitted with appliances denoted “smart machines” that can react on the fluctuating prices of electric energy by turning themselves on during the most beneficial time periods. The usage of these appliances is of the nature that a load-shift of its consumption has a small impact on consumer comfort. Therefore, the smart machines are white goods such as washing machines, tumble dryers and dishwashers. (36)

2.3.1 Demand response and load-shift

One goal with the SRS project is to investigate how private apartment end-consumers can be influenced to move their electricity consumption from hours of high demand to hours of low demand through load-shift (8). Load-shifting has the potential to both reduce the need for new investments in distribution capacity resulting in lower distribution costs, as well as in production capacity resulting in lower electricity prices (6). The load-shifting of the private apartment end-consumers within the SRS project will be facilitated by the technological solutions presented in section 2.3 such as smart machines.

2.3.2 The SRS price model

Within the SRS project, an end-consumer price model will be tested on selected test apartments. This price model; denoted the “SRS price model” is designed to enable end-consumer DR and encourage load-shift from pre-defined peak hours to pre-defined off-peak hours. The SRS price model Cost components are presented in table 2.1.

Table 2.1. *Cost components of the SRS price model.* (37)

Abbreviation	**Cost component**	**1 November - 31 March**	**1 April - 30 October**	**Unit**
S_p	Energy	Spot price	Spot price	SEK/kWh
Nt_h	Network tariff, peak hours	0,90	0,49	SEK/kWh
Nt_h	Network tariff, off-peak hours	0,30	0,24	SEK/kWh
Rf	Retail fee	0,10	0,10	SEK/kWh
Gc	Green certificate	0,032	0,032	SEK/kWh
Et	Energy tax	0,29	0,29	SEK/kWh
VAT	Value Added Tax	25	25	%

The price model will thereby combine price components that both stem from the monopolistic distribution market with price components from the open market of electric energy as well as the different taxes and incentives presented in the previous section. (36)

2.3.3 The Active customer scenario

In order to evaluate whether the SRS price model can influence end-consumers electricity consumption, hypotheses and test scenarios are needed. Within the SRS project, a pre-study has developed and defined an Active customer scenario that states that an end-consumer will;

"Move 5 and 15 % of daily energy consumption from peak to off-peak" (8)

The defined scenario describes a load-shift where the total electricity consumption of the end-consumer is constant, even though the consumption pattern is modified.

3. CHALLENGES OF A NATIONAL SCALE IMPLEMENTATION OF DEMAND RESPONSE AND THE SRS PRICE MODEL

This chapter will treat fundamental challenges that may arise during a national scale implementation of the SRS price model and end-consumer DR in Swedish private apartments. The chapter is divided into two separate parts beginning in section 3.1 with an examination of the SRS price model that was presented in section 2.3.2, focusing on the economic end-consumer incentives that the distribution cost component is likely to generate in combination with the varying price of electric energy and the legislated taxes. Thereafter, a gap analysis of the different technical and sociotechnical challenges associated with a national scale implementation of end –consumer DR and the SRS price model is presented in section 3.2. The chapter ends with a summary in section 3.3.

3.1 THE SRS PRICE MODEL INCENTIVES

The composition of the SRS price model is presented in section 2.3.2. Since the price model combines the costs of energy and distribution as well as taxes and incentives, a closer examination of the incentives created by this price model is in order. Variations of the price model have been analyzed in earlier studies but these have not investigated the consistency of the SRS price models different Cost components (15) (38). The price model has been updated since the earlier studies as well (37). Since the stated objective with the price model is to encourage end-consumers to be more responsive to price signals and thus reducing consumption during periods of high prices, an analysis of the economic incentives a potential consumer will be faced with is presented in this section (8).

Since the 1st of October 2011, Sweden is divided geographically into four price zones to manage increasing transmission capacity restrictions, as described in section 2.2.1 (17). In order to be consistent with the following calculations, the prices of price zone three (SE3) is used for all calculation in this study post this date. Price zone three was chosen since it has the highest population by far with seven of Sweden's ten largest cities, including Stockholm and Gothenburg.

3.1.1 INTERNAL CONSISTENCY

To investigate how the different Cost components of the SRS price model interact, the components respective incentives are analyzed. The distribution cost component is fixed before-hand and is therefore constructed in order to always give the incentive to reduce demand during the pre-defined peak-hours; 08.00 – 20.00 during all weekdays as well as 08.00-20.00 during weekends in the winter season (37). The energy cost component is based on the fluctuating price of electricity and is ever-varying as it is dependent of the open Nord Pool Elspot electricity spot market (4). This arrangement could potentially lead to periods where the cost components yields conflicting incentives which will therefore cancel each other out or worse; give an undesirable incentive such as promoting consumption during hours of high demand.

By comparing the average peak period spot price of electricity with the average off-peak period spot price during a weekday, an incentive measurement can be constructed. If the average peak price is higher than the average off-peak price, the incentive is said to be correct, the reverse scenario is said to be incorrect, see equation 3.1 below.

$$(average\ spot\ price, weekday\ 08.00 - 20.00) -$$
$$(average\ spot\ price, weekday\ 20.00 - 08.00) = incentive \qquad \text{(Eq. 3.1)}$$

$$incentive > 0\ \rightarrow correct\ incentive$$
$$incentive < 0\ \rightarrow incorrect\ incentive$$

The incentive represents only intra-day incentives, that is; the difference between peak and off-peak prices within a 24 hour period during a weekday. Weekends have not been taken into consideration for the sake of simplicity and since the demand for electricity is usually higher during weekdays than weekends (2). Table 3.1 summarizes the cases where the incentive of the distribution cost component of the SRS price model is not consistent with the incentive created by the ever-changing cost of energy.

Table 3.1. *Frequency of energy cost incentive non-consistent with the distribution cost incentive. (Based on* (39)*)*

Year	# of week-days	# of incorrect incentives	% of incorrect incentives
2010	261	6	2,3
2011	260	3	1,15
2012	260	3	1,15

The tariff component seems to be overall consistent with the varying price of electricity. The days of incorrect incentives follow no particular pattern regarding seasonality, suggesting that the seasonal variability of the energy price does not affect the intra-day variability to any significant degree. The results suggest that the SRS price model will most often create a correct and coherent incentive that will encourage the consumers to move their consumption from the peak hours 08.00-20.00 to the off-peak hours 20.00-08.00 during weekdays.

3.1.2 Short term economic incentives

The SRS price models distribution cost component should be able to create a correct incentive regardless of the electricity spot price since the time-varying price of electricity may not always coincide with the distribution cost components peak and off-peak periods, as presented in section 3.1.1. A comparison of the average hourly end-consumer prices generated by the SRS price model during the summer seasons of 2010-2012 is presented in figure 3.1. The prices includes the energy spot price, the distribution cost network tariff, retail costs, green certificate and energy tax as well as VAT as defined in section 2.3.2.

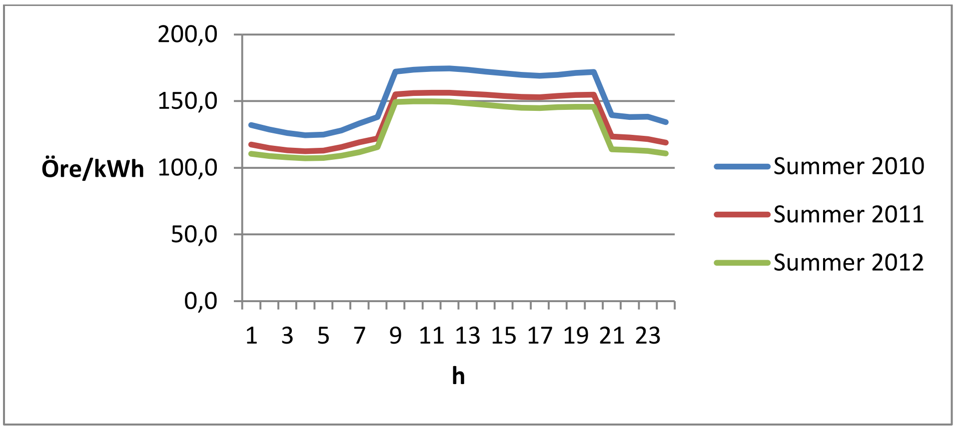

Figure 3.1. *Hourly average prices per kWh produced by the SRS-model during a weekday in the summer season (April 1 to October 31). The prices includes the energy spot price, the distribution cost network tariff, retail costs, green certificate and energy tax as well as VAT as defined in section 2.3.2. (Based on* (39) *and* (37)*)*

Apparently, the distribution cost components network tariff has a significant impact on the total price of electricity, indicating that the end-consumer will always be given a clear incentive to shift his consumption from the pre-defined peak hours to the pre-defined off-peak hours. The incentive will clearly be higher than if only the varying energy spot price were to be used.

Compared to the average energy spot-prices during the summer season, the influence of the distribution cost components network tariff can appear to be quite large. This is due to the fact that the SRS price model does not have any fixed tariff component, something that is customary in ordinary distribution subscriptions, see section 2.2.2 (20). The lack of a fixed tariff component results in higher variable prices in order for the price model to be revenue-neutral from a DSO's point of view. In figure 3.2, the corresponding costs for the winter season are illustrated; note the difference of scale of the y-axis.

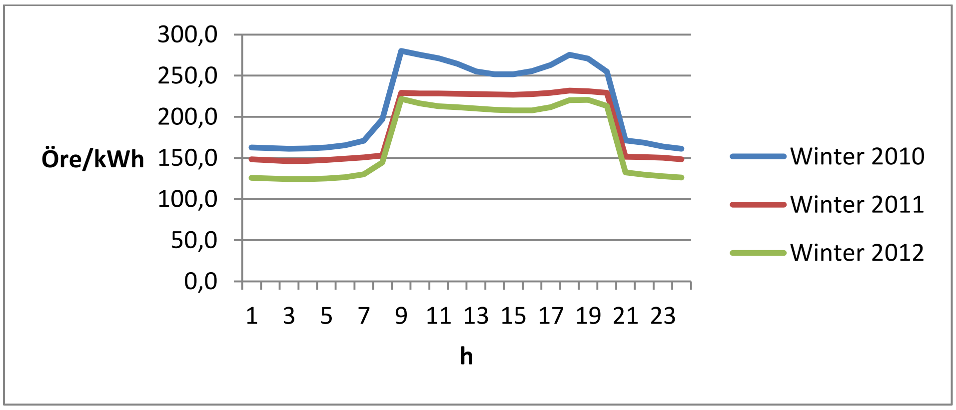

Figure 3.2. *Hourly average cost per kWh produced by the SRS-model during a weekday in the winter season (November 1 to March 31). The prices includes the energy spot price, the distribution cost network tariff, retail costs, green certificate and energy tax as well as VAT as defined in section 2.3.2. (Based on* (39) *and* (37)*)*

The distribution cost component is quite distinctive in the winter season as well. The SRS price models total average peak to off-peak price ratio is not above 1:2 for any year or any season. The peak to off-peak price ratio is an important measurement as earlier studies have shown that higher ratios usually encourage greater peak hour consumption reduction (15). This correlation, that higher peak to off-peak price ratios increases peak hour reduction, is sometimes suggested to be linear, as presented in figure 3.3. Thereby, no known “tipping point”, at which an increased peak to off-peak price ratio results in a dramatic change in load-shift, may exist (5). However, in a state of the art meta-study undertaken within the SRS project it was suggested that a peak to off-peak price ratio of at least three should be used in order to encourage peak demand reduction if no enabling technology, such as smart machines, is used (15).

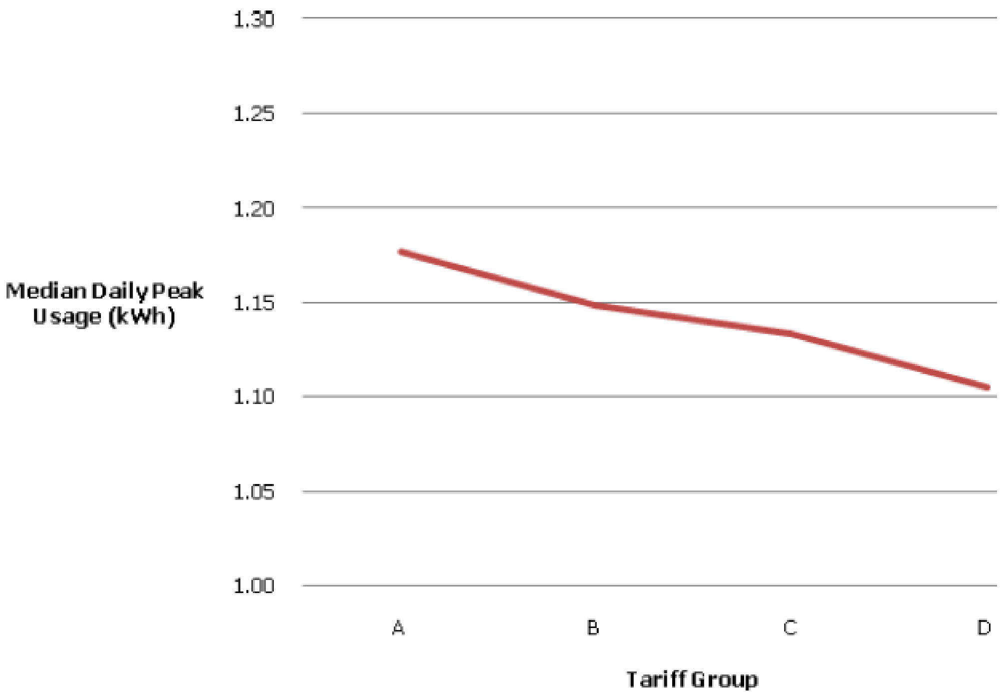

Figure 3.3. *Higher peak to off-peak price ratios implies lower peak hour consumption. Ratios are increasingly higher for the different tariff groups along the x axis, from 1,43 to 3,04. (5)*

3.1.3 LONG TERM ECONOMIC INCENTIVES

New end-consumer electricity price models may have winners and losers. As the conditions changes, so do the cost distribution among customers and the revenue for the distribution grid owners (38). The aims with the SRS price model should be that an implementation should be revenue neutral from a grid operator point of view and be non-discriminatory from a customer’s point of view (38). However, if a consumer choses to act in accordance with the price model incentives, savings should be made. To estimate how a potential consumption load-shift of a customer using the SRS price model would affect the costs of that customer, the proposed Active costumer scenario has been used, which was established during the SRS pre-study, see section 2.3.3. This section will investigate how different customer types using the SRS price model would benefit by acting in accordance with the Active customer scenario by applying load-shift to their consumption.

3.1.3.1 Type apartments

To calculate the long term economic incentives that may be generated by the SRS price model, five type apartments have been used. Apartment electricity consumption in the form of load curves for the five type apartments stem from a study by the Swedish Energy Agency which are a result of the empirical measuring of a total of 187 apartments between the years 2005-2008 (2).

The five used type apartments from the study are defined by the number of apartment residents and the age of those residents. Most apartments in Sweden are heated by district heating so electricity consumption for heating is not included (40). Consumption excluding heating is denoted “specific” consumption. The type apartments are; singles below and above the age of 64, couples below and above the age of 64 and families (2). The hourly load curves for the apartments are divided on usage as well as on day of the week. An example of the load curve for a single below the age of 64 during a weekday is presented in figure 3.4. The electricity consumption of the apartment in the figure is divided on hour of consumption (x-axis) and usage (y-axis). Electricity use for heating purposes is excluded.

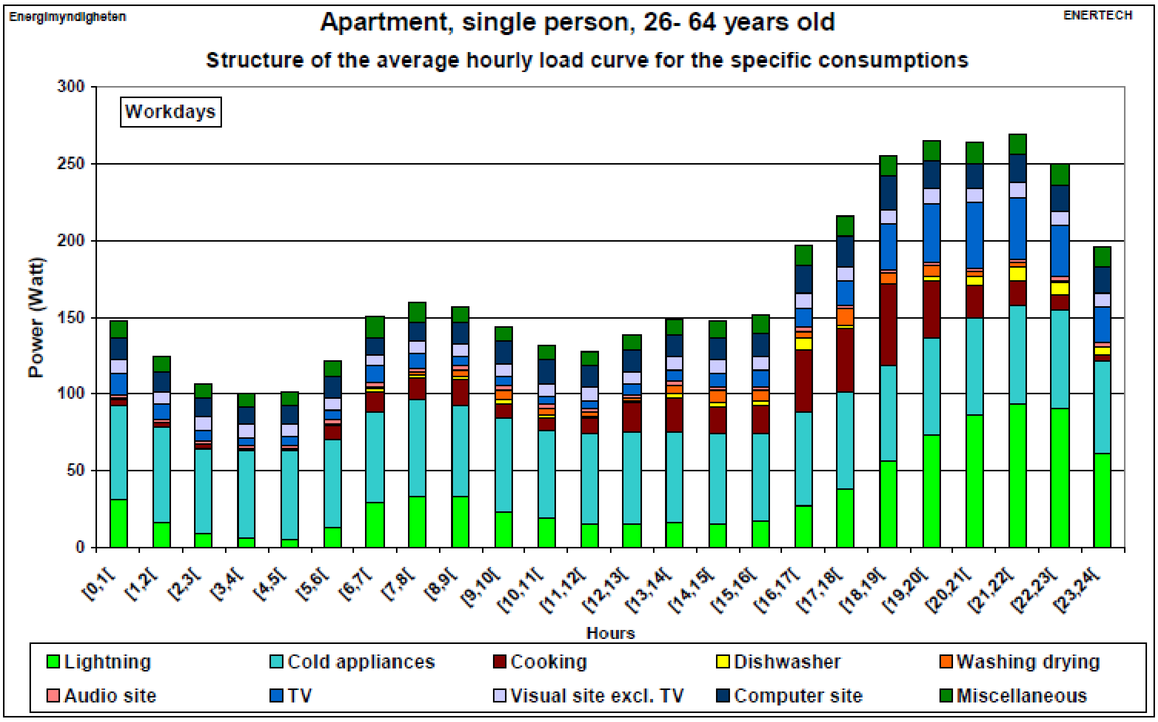

Figure 2.115: Structure of the average hourly load curve for the specific consumption– Apartments – Workdays

Figure 3.4. *Consumption for a single apartment inhabitant below the age of 64 during a weekday, excluding usage for heating purposes. Consumption is divided on usage.* (2)

Seasonality effects on the consumption of electricity used for lighting, cooking, audio-visual site, televisions and cold appliances are included, all of which are highly seasonal (2). For these usages, the consumption for the specific usage is modified by multiplication of a weighting factor for each week, see figure 3.5 for an example of the weighting factors for lighting.

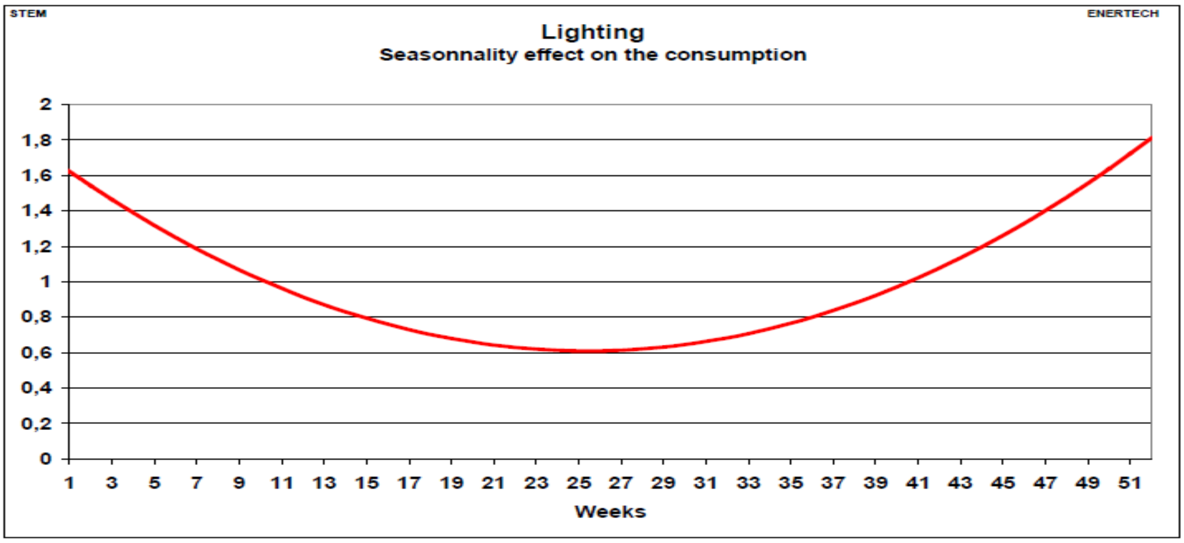

Figure 2.345: Lighting – Seasonality effect on the consumption

Figure 3.5. *Weighing factor for electricity consumption used for lighting purposes.* (2)

3.1.3.2 The Active customer scenario

Before calculating the theoretical costs and cost savings of the different type apartments, a closer examination of the assumed load-shift is in order. The Active customer scenario, presented in section 2.3.3, is defined in the pre-study as that a customer will;

"Move 5 and 15 % of daily energy consumption from peak to off-peak" (8)

Since the current proposed SRS price model defines all weekend hours as off-peak hours between the 1st of October and the 31st of March, the calculation of the proposed load-shift is not straightforward. Three different interpretations of the load-shift are presented below; two interpretations from earlier studies and one interpretation that will be applied to calculations in this study.

Load-shift method 1

An earlier study within the SRS project interpreted the load-shift in the following manner (15):

1. 5 or 15 % of the load of each peak hour is extracted from the corresponding peak hour.
2. The total extracted load from the peak hours during one day is added up.
3. The total extracted peak load is distributed evenly over all off-peak hours during that same day.

This method was used before the SRS price model defined weekends as off-peak hours between the 1st of October and the 31st of March (15). Due to this fact, the calculations could be performed day by day, by simply moving the load from the peak hours to the off-peak hours within a 24 hour period. However, the total load-shifted does not necessarily add up to exactly 5 or 15 % of the specific days' total consumption. It is more likely that more than 5 or 15 % of the specific days' total consumption is moved, since the consumption is usually higher during peak hours.

Load-shift method 2

Another study performed by Fortum Distribution which focused on the pricing of the distribution cost network tariff component only, suggested a fixed load-shift of 484 kWh per year of an apartment with a yearly consumption of 3443 kWh, equaling roughly 14 % of the total yearly load (38). The price model that was used distinguished between weekdays and weekends and the amount of load-shifted was based on an analysis of appliances which usage could be easily adjustable. Rather than calculating a load-shift explicitly before calculating the cost savings, the following method was applied to calculate the yearly cost savings (38):

1. The peak price was subtracted with the off-peak price, resulting in a price difference.
2. The price difference was multiplied with the total load-shifted load of 484 kWh.

Calculating cost savings by this method does not consider seasonality effects but rather assumes that the same proportion of consumption can be moved throughout the year. This approach also implicitly allows consumption to be moved from peak hours during weekdays to off-peak hours during weekends. Such an approach has its merits, since some consumption, i.e. dishwashing and clothes washing and drying may be assumed to be held off until the weekends.

Load-shift method 3 (proposed and applied in this study)

In this study, the following approach has been proposed and applied to calculate the load-shift:

1. 5 or 15 % of the load of each peak hour is extracted from the corresponding peak hour.
2. The total extracted load from all peak hours during one week is added up.
3. The total extracted peak load during one week is distributed evenly over all off-peak hours during that same week.

This will allow consumption to be moved from weekdays to weekends but not between seasons or between weeks. The load that can be shifted is also dependent of the specific week consumption, allowing higher amounts of load-shift in weeks of high consumption and lower amounts of load-shift in weeks of low consumption. For a summary of the price models from earlier studies mentioned in this section, see appendix A.

3.1.3.3 Estimated costs and savings

By using the specific consumption of the five different type apartments presented in section 3.1.3.1, the SRS price model presented in section 2.3.2 and historical spot prices of electricity from 2010-2012 (39), the annual costs for apartment customers can be calculated. By updating the consumption patterns with a 5 to 15 % load-shift according to the interpretation of the Active customer scenario described in section 3.1.3.2, the costs can also be calculated for customers who choose to change their consumption patterns. The cost *P* for a kWh consumed at the hour *h* is calculated by:

$$P_h = (Sp_h + Nt_h + Rf + Gc + Et) * (1 + \frac{VAT}{100}) \qquad \text{(Eq. 3.1)}$$

The cost components of the SRS price model presented in section 2.3.2 are specified again in table 3.3. The magnitude of the energy cost component *Sp* and the distribution cost network tariff component *Nt* varies according to the hour of consumption.

Table 3.3. *Cost components of the current SRS price model.* (37)

Abbreviation	Cost component	1 November - 31 March	1 April - 30 October	Unit
S_p	Energy	Spot price	Spot price	SEK/kWh
Nt_h	Network tariff, peak hours	0,90	0,49	SEK/kWh
Nt_h	Network tariff, off-peak hours	0,30	0,24	SEK/kWh
Rf	Retail fee	0,10	0,10	SEK/kWh
Gc	Green certificate	0,032	0,032	SEK/kWh
Et	Energy tax	0,29	0,29	SEK/kWh
VAT	Value Added Tax	25	25	%

The costs for the five different type apartment customers using the SRS price model for the years 2010-2012 are presented in tables 3.4 to 3.6. Spot prices for price area three (SE3) from Nord Pool has been used for all calculations (39). The other components are assumed to be fixed, even though the cost for green certificates and energy tax varies from year to year. However, these components are hard to influence by the retail company Fortum who design the price model. The tables present the costs of a customer that use the SRS price model without altering his consumption (no LS), load-shift 5 % (5 % LS) or 15 % (15 % LS) of his consumption from peak to off-peak hours in accordance with the interpretation of the Active customer scenario using load-shift method 3 described in section 3.1.3.2.

Table 3.4. *End-consumer costs for 2010 with the SRS price model with different percentages of load-shift. Costs in SEK for the year 2010. (Based on* (39) *and* (37)*)*

Type apartment	Yearly costs, no LS	Yearly costs, 5 % LS	Yearly costs, 15 % LS	Unit
Family	6122	6055	5957	SEK/year
Couple, 64+	3716	3670	3600	SEK/year
Couple, -64	4153	4110	4047	SEK/year
Single, 64+	2841	2808	2762	SEK/year
Single, -64	2855	2827	2787	SEK/year

Table 3.5. *End-consumer costs for 2011 with the SRS price model with different percentages of load-shift. Costs in SEK for the year 2011. (Based on* (39) *and* (37)*)*

Type apartment	Yearly costs, no LS	Yearly costs, 5 % LS	Yearly costs, 15 % LS	Unit
Family	5559	5520	5442	SEK/year
Couple, 64+	3364	3338	3284	SEK/year
Couple, -64	3780	3756	3705	SEK/year
Single, 64+	2583	2564	2526	SEK/year
Single, -64	2602	2586	2554	SEK/year

Table 3.6. *End-consumer costs for 2012 with the SRS price model with different percentages of load-shift. Costs in SEK for the year 2012. (Based on* (39) *and* (37)*)*

Type apartment	Yearly costs, no LS	Yearly costs, 5 % LS	Yearly costs, 15 % LS	Unit
Family	4952	4897	4816	SEK/year
Couple, 64+	3008	2973	2918	SEK/year
Couple, -64	3358	3323	3271	SEK/year
Single, 64+	2309	2283	2243	SEK/year
Single, -64	2308	2285	2251	SEK/year

The cost reductions that can be achieved by a customer acting in accordance with the Active customer scenario ranges from 16-67 SEK for a 5 % load-shift to 48-165 SEK for a 15 % load-shift, corresponding to yearly savings of 0,6-3,1 %, depending on type apartment and year of consumption. This corresponds to yearly cost savings of between 124 and 429 million SEK each year for the private apartment end-consumer segment if assuming roughly 2,6 million apartment households (41).

3.1.3.4 Comparison with earlier studies

By comparing the costs for the ”Family” type apartment in the year 2010 with the costs calculated in the precious studies, mentioned in section 3.1.3.2 and summarized in appendix A, differences in both the design of the SRS price model, as well as in the interpretation of the “Active customer” scenario are evident. In table 3.7, the costs and savings for the three studies are summarized. The “Family” apartment of this study is chosen for comparison as its yearly consumption is closest to that of the reference apartment of the other two studies, denoted “The F25 apartment”.

Table 3.7. *Comparison of the end-consumer costs and savings of the three different studies with and without a 15 % load-shift. Costs in SEK for the year 2010.* (15) (38)

	Vinnova Energy Transfer Tariff (38)	**SRS price model, previous** (15)	**SRS price model, current**
Load-shift	**484 kWh (14 %)**	**15%**	**15%**
Load-shift method	**1**	**2**	**3**
Yearly costs	1816	6668	6012
Yearly costs, 15 % LS	1577	6402	5839
Savings	**13,16%**	**3,99%**	**2,90%**

Apparently, both the costs and cost savings differ to such a degree that they become hard to compare. The 13,16 % savings that the network tariff study resulted in only take into account costs for the distribution of electric energy and the VAT for the same (38). The cost for the energy itself and, perhaps more importantly, the non-varying costs of taxes are not included. These facts indicate that even though the network tariff can be designed as to create a strong long-term economic incentive to the customer, the effects will be diluted by the other cost components.

The total savings of the previous SRS price model of 3,9 % for a 15 % load-shift comes closer to the results in this study (15). The reason why the earlier price model resulted in slightly larger percentage savings might have three explanations. Firstly, the earlier study used an empirical load curve instead of an approximated one. The empirical load curve had a distinct “summer-break” where the residents probably where away and did not use the apartment. Secondly, the studies used slightly different cost components, see appendix A for a comparison of the price model design of the three studies. Thirdly, and probably most importantly, the current price model has significantly fewer peak hours, which leads to less load being shifted from expensive hours to inexpensive hours.

3.2 Gap analysis of challenges of end-consumer DR and the SRS price model

Pilot studies always differ to some degree from real-life conditions. However, the aim should be to mimic these real-life conditions as closely as possible and by doing so render the pilot studies' results useful. The SRS Smart Grid pilot project will be using state of the art technology and solutions, some of which are untested and unproven (36). Prior to extrapolating ex-ante estimations of changes in consumption patterns, a gap analysis has been undertaken in order to elicit some of the most crucial challenges of a Swedish national scale implementation of the SRS price model and end-consumer DR among apartment building households. The study is limited to apartment building households since the SRS project will consist of apartment buildings rather than houses.

3.2.1 Gap analysis

Gap analysis as a tool stems from the field of benchmarking and process improvement (42). There are numerous ways of how to perform such an analysis, as are the fields of its application. Gap analysis can be used to compare existing processes to processes performed by competitors or those obtained by benchmarking, as well as to define the gap between a current state and a desired state (43). In these applications, the processes are compared side-by-side and step-by-step and the inconsistencies; the "gaps", between them are elicited (44). The inconsistencies are thereafter analyzed to determine if there are any benefits associated with incorporating the benchmark process or portions of the benchmark process to the current process (42).

In this study, the method will be used to evaluate what challenges that need to be met in order to enable and encourage DR of private apartment end-consumers use of electricity and rendering the Active customer scenario true, that is; to go from a current state to another, more desirable state (45). The process to elicit these improvement gaps can be summarized as follows (46);

1. Identify the current state.
2. Identify the desired state.
3. Identify and document the improvement gaps between the states.
4. Grade or evaluate the improvement gaps in regard of importance and difficulty.

3.2.2 Pre-study gap analysis

The current state is readily available since no DR is currently available on a Swedish national scale. The desired state is taken from the Active customer scenario, namely; enable DR and a 5-15 % load-shift of private apartment end-consumers (8). The gap analysis approach can be summarized through the schematic outline in figure 3.7.

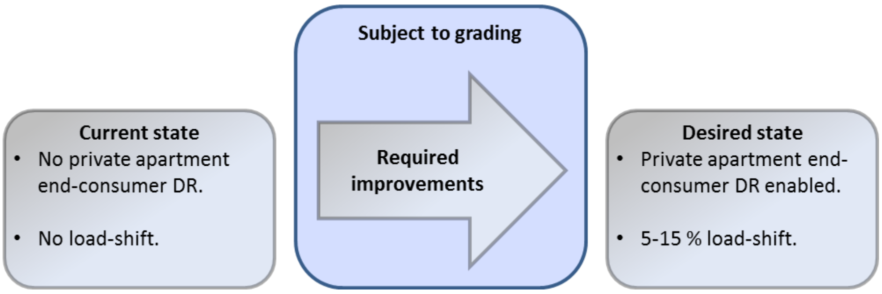

Figure 3.7. *Elicitation and grading of necessary improvements to enable national scale end-consumer DR and a 5-15 % load-shift. (Based on* (46)*)*

The gap analysis of the SRS project has been based on three available documents specifying the SRS Smart Grid pilot project (8) (36) (47). Characteristics of the SRS price model, specified in section 2.3.2 and the SRS pilot projects' reference apartment, described in the three above mentioned documents have been compared with available statistics and studies of the Swedish conditions of apartment households. The pre-studies often focus on technological solutions and market solutions. Therefore, this analysis have focused on the customers experience of these proposed solutions that do not only separate the SRS Smart Grid pilot project from the current national conditions, but also where these conditions are deemed to be hard to overcome. The grading of the improvement gaps in regard of importance and difficulty has not been undertaken as it is of a strictly subjective nature.

The literature review of the three available documents specifying the SRS Smart Grid pilot project compared with the national scale conditions have resulted in four important gaps or challenges of a national scale implementation of the SRS price model and DR in Swedish apartment households. These four challenges are deemed to be; *the lack of moveable loads in a foreseeable future*, *the heterogeneous cost of distribution*, *the suggested price models low peak to off-peak price ratio* and *the comparatively small cost of electricity of the apartment end-consumers*.

Lack of moveable loads

The description of the SRS Smart Grid pilot apartment specifies a number of appliances denoted smart machines which are often white goods, see section 2.3 (36). End-consumer DR is often assumed to be facilitated by these appliances, even though the Active customer scenario does not specify this fact (8). Since approximately 80-90 % of all Swedish apartment building residents have access to a common laundry rooms and dishwashers are not as common in apartment households as in houses, the possible and suggested loads that can be moved are limited (48). However, the appliances may be more common in the apartments themselves in the future. These possible changes in household white goods will probably take time to implement, especially if the economic incentives or other incentives are small.

Heterogeneous cost of distribution

Even though electric energy is traded on an open market (Nord Pool Elspot), the cost of distribution operates under a natural monopoly, as described in section 2.2.2. The costs of distribution are dependent on the configuration of the local distribution grid and differ greatly depending on location, see figure 3.8. Omitting the extreme high and low costs, the middle 80 % of the costs still ranges in an approximate 50 % interval. By introducing combined price models for electricity that includes both the cost of energy as well as the cost of distribution, new challenges will arise in how to market and explain these new price models to end-consumers. Customized price models that take geography into account are not an unreasonable solution but this places greater demands on the electric utility companies' communication and their transparency. An inability to market coherent electricity subscriptions across the nation will most likely lead to misunderstandings and low DR participation (49).

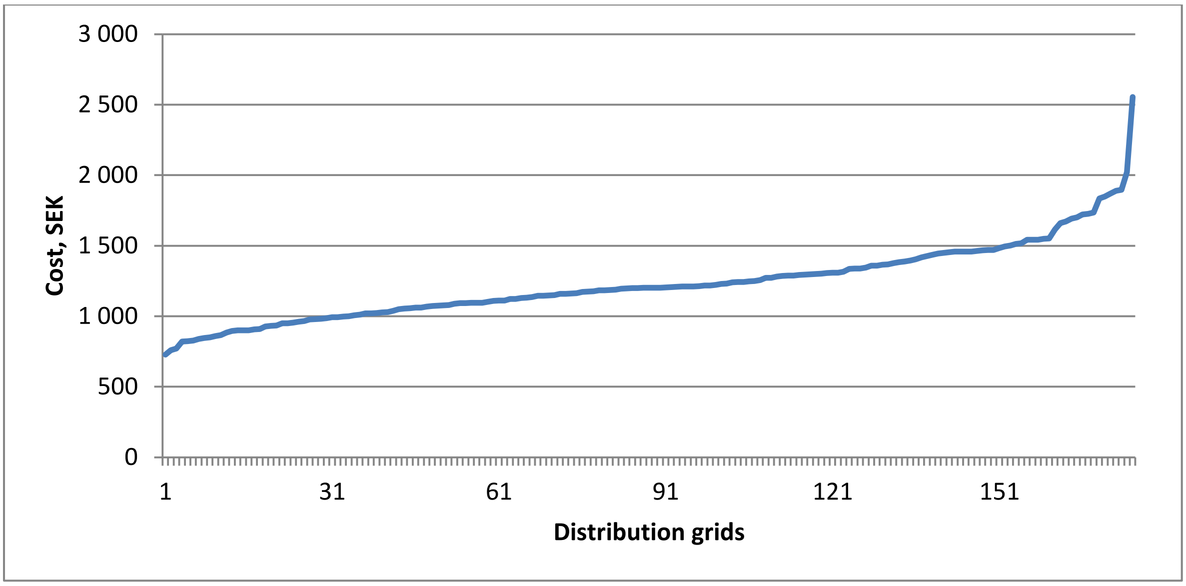

Figure 3.8. *Distribution of yearly costs of distribution for an apartment with a fuse size of 16 A and an annual consumption of 2000 kWh. (Based on* (20)*)*

Low peak to off-peak price ratio of the suggested price model

An earlier meta-study within the SRS project suggested that in order for a price model to be effective, the cost of electricity should be divided into distinctive price blocks with the peak to off-peak price ratio preferably larger than three (15). The suggested SRS price model is divided into distinct price blocks but has a low peak to off-peak price ratio. Based on historical electricity prices between 2010 and 2012, the average ratio is never above three, as described in section 3.1.2.

Comparatively small cost of electricity for end-consumers

84 % of all Swedish apartments are heated solely by district heating (50). The yearly electricity consumption of an apartment is therefore low compared to that of houses that are often heated with electricity in some aspect (50). The cost savings that can be made by participating in DR projects can therefore be unreasonably low. This is especially the case if participation has an impact on the experienced comfort of the customers, which may be the case if not smart machines, such as the before-mentioned white goods, are available.

A summary of the elicited challenges of a Swedish national scale implementation of the SRS price model and end-consumer DR is presented in table 3.7.

Table 3.7. *Summary of the elicited challenges of a Swedish national scale implementation of the SRS price model and end-consumer DR.*

SRS project state	**Current national state**	**Gap description**
Smart machines will facilitate load-shift. Many of these machines are white goods.	80-90 % of all apartment households have access to common laundry rooms. Dishwashers are not as common as in houses.	Lack of moveable loads on a national scale. Distribution of moveable loads may take time.
The SRS price model combines cost of energy with cost of distribution.	Different actors supply electric energy and electricity distribution.	Heterogeneous cost of distribution makes it hard to market on a national scale.
Short term economic incentives of the SRS price model will facilitate load-shift.	SRS price models' average peak to off-peak price ratio is never above three.	Low peak to off-peak price ratio of the suggested price model.
Long term economic incentives will facilitate load-shift.	Cost of electricity is low for apartment customers in comparison with house customers.	Small potential cost savings may be too weak of an incentive.

3.4 Summary of Challenges of a national scale implementation of demand response and the SRS price model

In this chapter, the challenges of a national scale implementation of end-consumer DR and the SRS price model have been analyzed. The analyzes are divided into two separate parts; one concerning the economic incentives of the SRS price model and one concerning the Swedish national scale conditions in relation to those of the SRS pilot project.

The SRS price model has been updated a number of times, both regarding the magnitude of the cost components and the pre-defined peak and off-peak hours. Based on spot price data of the years 2010-2012, the current price model cost components have high internal consistency, meaning that the economic incentive the distribution cost component network tariff component creates and the economic incentive the energy cost component creates coincides in the majority of cases. The number of times where a conflicting incentive was found was 6, 3 and 3 for 2010, 2011 and 2012 respectively. The risk for a conflicting incentive and therefore an unclear total incentive of the SRS price model is therefore deemed to be small.

The end-consumers have a clear short term economic incentive to move loads from peak hours to off-peak hours due to the high impact of the network tariff. This high impact probably stems from the fact that the SRS price model does not have any fixed costs, as is customary with regular network tariffs. However, the current SRS price models peak to off-peak price ratio is still deemed to be small with an average ratio below three for the years 2010-2012 in both the summer and the winter season. In a state of the art meta-study undertaken within the SRS project it was suggested that a peak to off-peak price ratio of at least three should be used in order to encourage peak demand reduction if no enabling technology, such as smart machines, is used (15).

The long term economic incentive that the SRS price model results in are dependent on the costumer load curve, the definition of the Active customer scenario as well as the SRS price model itself. The interpretation of the Active customer scenario is dependent on the definition of the price models pre-defined peak and off-peak hours. The scenarios' load-shift from peak to off-peak hours is made complicated by the fact that the price model has off-peak hours during the weekends in the winter season. This study has assumed that loads can be moved from weekdays to weekends but not between weeks or between seasons. The cost savings an end-consumer can make by acting in accordance with the Active customer scenario are 0,6-1,2 % or 16-67 SEK of the total yearly electricity costs for a 5 % load-shift and 1,8-3,1 % or 48-165 SEK for a 15 % load-shift, depending on type apartment and year. This corresponds to yearly cost savings of between 124 and 429 million SEK each year for the private apartment end-consumer segment if assuming roughly 2,6 million apartment households and 15 % load-shift (41).

The 3,1 % cost savings are slightly lower than the 3,9 % cost saving of a 15 % load-shift that an earlier study within the SRS project estimated (15). The difference is assumed to be due to the difference in the price models peak and off-peak hours and in extension the interpretation of the Active customer scenario, rather than any differences in cost components. The savings are considerably lower than the 13,16 % savings calculated from a different study which evaluated the distribution cost network tariff only (38). This indicates that even though the network tariff can be designed as to create a strong long-term economic incentive to the customer, the effects will be diluted by the other cost components.

The second part of this chapter concerned the conditions of the SRS pilot project compared with the Swedish national scale conditions. By comparing the attributes and solutions that are planned to be used in the SRS pilot project, presented in the SRS project pre-studies, with the Swedish national scale conditions, a number of challenges for a national scale implementation of end-consumer DR and the SRS price model has been elicited.

Firstly, DR in the SRS pilot project relies heavily on smart appliances such as white goods for facilitating easy load-shift. In Sweden, 80-90 % of all apartment households have access to common laundry rooms with washing machines and clothes dryers. Dishwashers are not as common in apartments' households as in houses. Even if the trend might be to install more white goods in the apartments themselves, such a change may take time and thus delaying a large scale introduction of smart machines in households. The challenge is therefore not only to update existing appliances but also to introduce new appliances to some degree.

Secondly, the SRS price models' complexity might be hard to market and therefore reach potential customers. The cost of electric energy is today dependent on where in Sweden a customer lives, with four different price areas. By combining the cost of electric energy with the cost of distribution, an unreasonable number of electricity subscription combinations might be created.

Thirdly, the suggested SRS price model has a low peak to off-peak price ratio. Based on historical electricity prices between 2010 and 2012, the average peak to off-peak price ratio is never above three.

Finally, the total yearly costs for electricity might be too low for apartment customers to promote DR as a way of saving money. Since apartment households are rarely heated by electric heating and the washing and drying of clothes can often be undertaken in common laundry rooms, the total costs of electricity is not nearly as high as for households living in houses. Future developments may increase the potential costs for a customer and therefore increase the incentive to load-shift, but calculations based on historical prices, the total costs (as well as savings) might be considered modest.

4. National scale impact of private apartment end-consumer DR and the Active customer scenario

In order to draw any conclusions of private apartment end-consumer DR and the Active customer scenario on a national Swedish scale, a basic understanding of the total consumption that they may affect is needed. This chapter will present this information based on the features of the SRS price model.

Firstly, in section 4.1, a national scale aggregation of the electricity consumption of Swedish private apartments is calculated. This step is crucial in order to draw conclusions regarding national scale load-shift. Secondly, in section 4.2, the results of a national scale load-shift according to the Active customer scenario presented in section 3.1.3.2 is estimated. Changed hourly power demand in the form of an updated load curve is presented. The chapter ends with a summary in section 4.3.

4.1 National aggregation of the electricity consumption of apartment households

Since the SRS pilot study consists of apartments and not houses, the total consumption of Swedish apartments needs to be approximated. As mentioned in chapter 2, the electricity consumption per capita in Sweden is high in an international comparison. The total, yearly electricity demand usually ranges between 125-132 TWh per year for all sectors (51) (3) (17). A large proportion of this energy is consumed by the energy intensive industry, especially paper and pulp industry (17).

Another large proportion is consumed by different public services such as street-lighting, hospitals and other public facilities while the last large use is that of households. However, most available estimates merge the total national consumption of services and households and only distinguish it from industry usages, making the electricity consumption of households hard to estimate. (50)

The Swedish Energy Agency (Energimyndigheten) estimate the distribution of the total yearly electricity use in Sweden of 2011 as illustrated in figure 4.1.

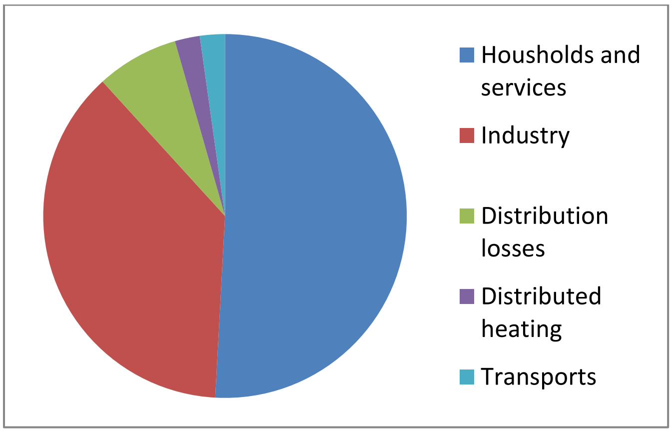

***Figure 4.1**. Distribution of the total yearly electricity use in Sweden of 2011, divided on sectors. (Based on* (3)*)*

The housing and service sector represents the largest proportion of Sweden's electricity use. Difficulties emerge when trying to separate the consumption of the housing sector from that of the service sector. The consumption of households is usually in turn divided on the consumption of houses and apartments, respectively. To estimate the electricity consumption of apartment buildings, the Swedish Energy Agency uses a survey study that focuses on energy consumed for heating purposes. However, the survey is only sent to property owners, which means that the consumption of private households within these properties is not taken into account. Furthermore, only energy (electricity as well as other sources of energy) consumed on property level used for heating, services and certain lighting are investigated. Electricity consumption of apartment buildings that cannot be affected by the apartment households themselves can be common lighting, ventilation, elevators and common laundry rooms. (40)

A similar survey is sent out to house owners, which in some aspect is more detailed since it considers consumption on individual customer level, even though the estimates are not divided on appliance level of consumption. This lack of usage segmentation can, in itself, be a source of uncertainty since it is hard to estimate how much of the consumption is used for heating purposes and how much is used for specific household consumption. Despite these weaknesses, the latter house survey can at least estimate the specific electricity use of houses by comparing the consumption of houses that are heated with electricity with that of houses using other heating solutions. (52)

Unfortunately, no corresponding survey exist that estimates the specific electricity consumption of private apartment private end-consumers, but the specific consumption of apartment households is sometimes estimated based on the households' area (53) or by comparing the consumption of apartments with the specific consumption of houses (50).

Given these difficulties, this thesis will use an approximation of apartment consumption based on combined publicly available statistics regarding consumption as well as the number of households in Sweden. The statistics contains of two important sets of data. Firstly, a household data base provided by the Swedish Central Bureau of Statistics (Statistiska Centralbyrån) is used, which contains a description of all Swedish households divided into categories of number of inhabitants and housing situation, see figure 4.2 (41). A total of roughly 2.6 million apartment households are estimated to exist in Sweden (41).

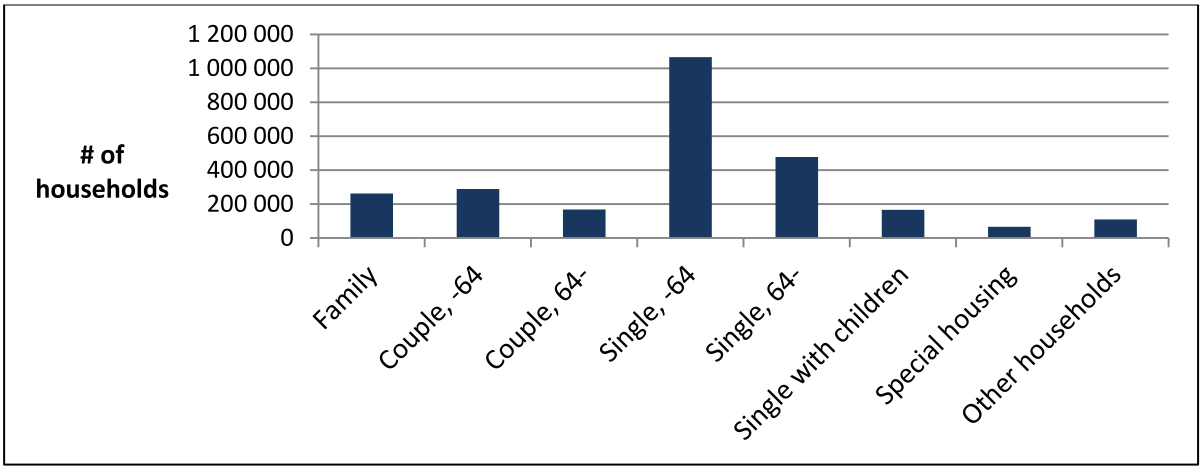

Figure 4.2. *Swedish private apartment households divided on inhabitant age and number of inhabitants (based on* (41)*).*

Secondly, a study of the specific hourly electricity consumption of different apartment types, performed by the Swedish Energy Agency is used (2). The specific electricity consumption is all consumption except consumption used for heating purposes. The study and apartment types are the same as those used in section 3.1.3.1 and the apartment consumption is divided on both usage and hour of consumption. The consumption data is divided on weekdays and weekends with seasonal variations for the electricity consumption of cold appliances, televisions, audiovisual sites, cooking usages and lighting (2). Heating in Swedish private apartments is usually supplied by district heating and heating is therefore not included in the calculations (40).

Since the household types in the study by the Swedish Energy Agency roughly corresponds to those presented in the data of the Swedish Central Bureau of Statistics, the two sources may be combined. By multiplying the number of a certain household type with its corresponding type apartments' estimated hourly consumption and thereafter adding up all the different household types, an aggregated, national load curve is constructed. The benefit with this approach is that the electricity consumption can be divided on to the real usages, such as lighting, cooking etcetera and divided on the hour of consumption, rather than just result in a single total and annualized value. Such a value, along with the numerical inputs in the form of number of each apartment and its corresponding yearly consumption is presented in table 4.1.

Table 4.1. *Electricity consumption of Swedish private apartment households. (Based on* (41) *and* (2)*)*

Type apartment	Number of households	Yearly consumption, kWh	Total yearly consumption, TWh
Single, -64	1 064 999	1 613	1,72
Single, 64-	478 036	1 555	0,74
Couple, -64	288 378	2 314	0,67
Couple, 64-	168 912	1 998	0,34
Single with children*	166 380	2 314	0,39
Family	262 032	3 363	0,88
Special housing**	67 106	1 555	0,10
Other households**	109 969	1 555	0,17
All households	**2 605 812**		**5,01**

**The consumption of the category "Single with children" is counted as "Couple, -64".*

***"Special housing" consists predominantly of end-consumers living in retirement homes* (41)*. The consumption of the categories "Special housing" and "Other households" are counted as "Single, 64-", for the sake of simplicity.*

Electricity consumption of the households "Single with children" is approximated as "Couple, -64" and the households "Special housing" and "Other households" are approximated as "Single, 64-" for the sake of simplicity. The total, annualized consumption of all Swedish private apartment households is by these calculations 5,01 TWh which is in line with earlier estimates of approximately 5 TWh, calculated through an approach based on the square meters of all Swedish apartments (53). The apartment households total yearly consumption constitute 6,5 % of the total yearly consumption for the household and services sector in Sweden (17). The single households "Single, -64" and "Single, 64-" consumes roughly 50 % of the electric energy used in Swedish apartments as well as constitute the majority of all apartment households.

The resulting aggregated, hourly electricity consumption during a typical weekday for all private apartments in Sweden divided on usage is presented by the load curve in figure 4.3.

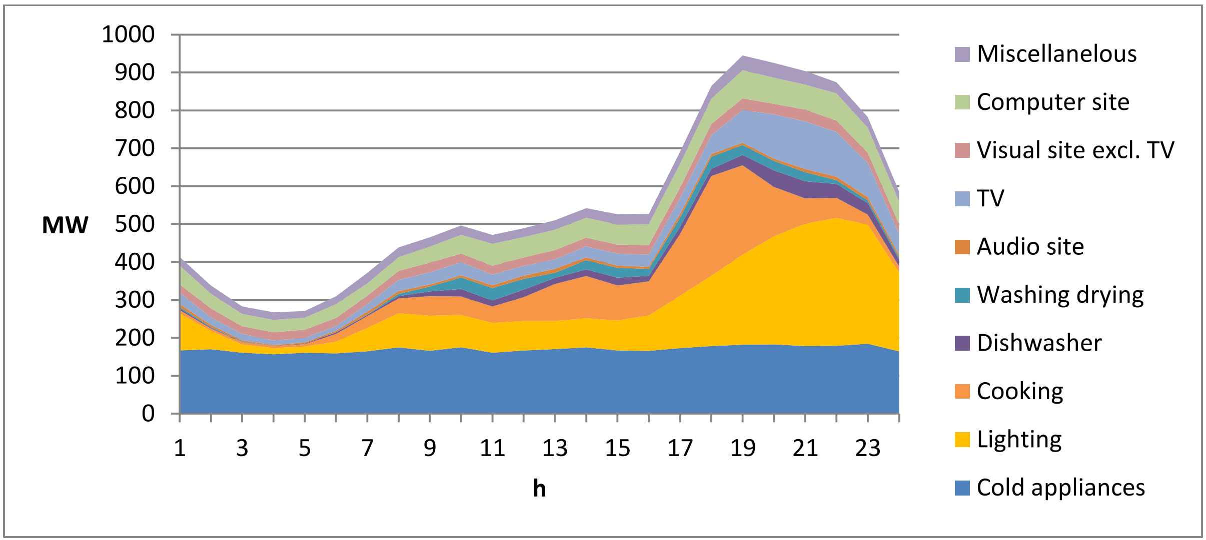

Figure 4.3. *Aggregated, hourly electricity consumption of all apartments in Sweden during weekdays, divided on use. Electricity used for heating is excluded. (Based on* (41) *and* (2)*)*

Figure 4.3 represents an average weekday, without any weighting of seasonal usages. The load curve has a high constant proportion of consumption that is used for cold appliances such as refrigerators and freezers while the peak load is dominated by energy used for lighting and cooking. Electric energy used for televisions and computers are also quite high and dependent on the hour of consumption which coincides with the peak of electricity usage of cooking. The consumption of these usages is in turn lagging slightly in comparison with the electricity usage for lighting purposes.

The peaks are higher in the winter time due to seasonality effects on lighting, cooking, televisions and audiovisual appliances, see figure 4.4 for an example of how the energy used for cooking varies over one year.

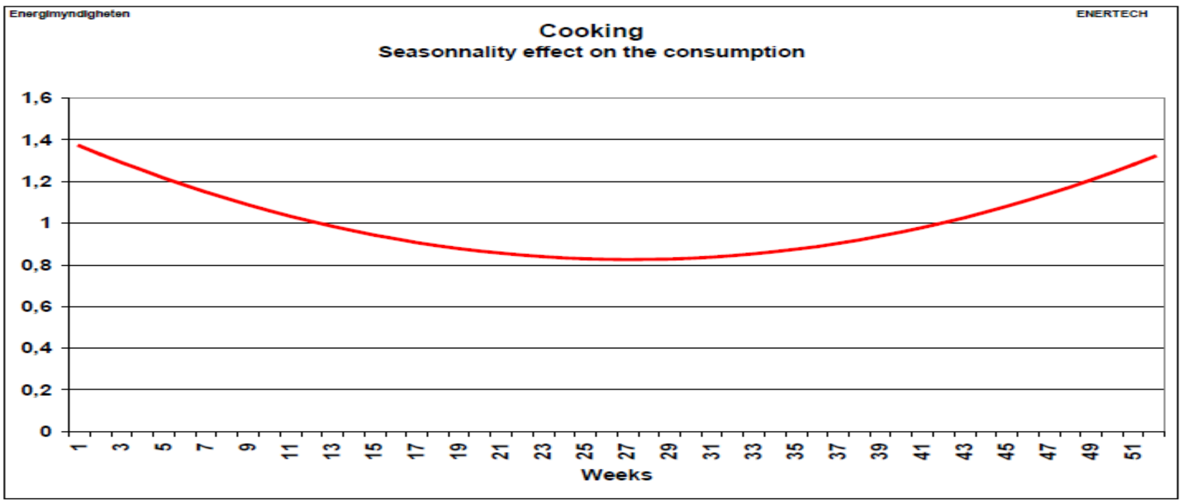

Figure 2.265.1: Cooking – Seasonality effect

Figure 4.4. *Weighting function of electricity used for cooking.* (2)

In figure 4.5, the same load curve is divided on type apartment instead of usage. By dividing the aggregated load curve on type apartment rather than on usage, it is clear that the single households "Single, -64" and "Single, 64-" constitute not only the majority of the Swedish apartment households and the total annual electricity consumption of apartment households, but that they also constitute the majority of the peak demand for the hour between 18.00 and 19.00 (data point 19.00). Almost 46 % of the total demand during this hour can be attributed to single households.

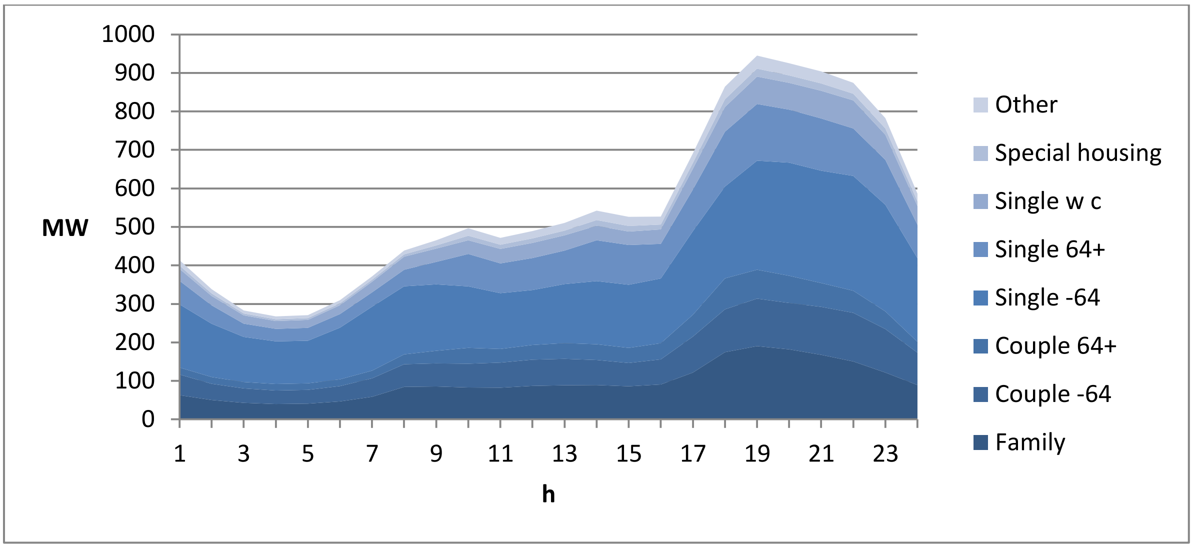

Figure 4.5. *Aggregated, hourly electricity consumption of all apartments in Sweden during weekdays, divided on households. Electricity used for heating is excluded. (Based on* (41) *and* (2)*).*

4.2 National scale load-shift

With the aggregated, hourly electricity consumption of apartments in Sweden calculated, the aggregated load-shift can be approximated. Since the load-shift is dependent on end-consumer DR and the plausibility of the Active customer scenario, there are of course no guarantees that the desirable load-shift will take place, even if the challenges presented in section 3.2 are overcome. For the sake of consistency, however, the Active customer scenarios maximum load-shift of 15 % from peak hours to off-peak hours will be used to approximate a theoretical, aggregated load-shift for all private apartments in Sweden. The interpretation of the Active customer scenario load-shift method 3, is explained in section 3.1.3.2, is used.

4.2.1 Revised national load curve

By assuming that a load-shift is implemented by moving 15 % of all private apartment households total consumption from peak hours to off-peak hours, a revised national load curves is estimated and presented along the original, see figure 4.6. The consumption that is redistributed is distributed evenly, that is; the same amount of consumption is distributed to each off-peak hour as described in load-shift method 3 in section 3.1.3.2.

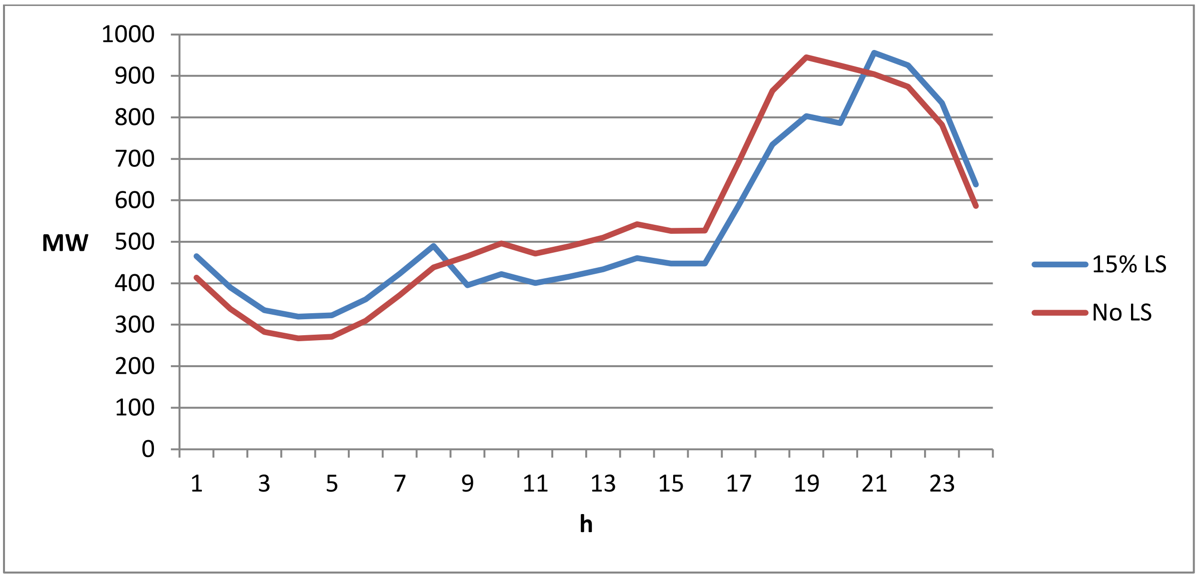

Figure 4.6. *Approximation of the aggregated, hourly electricity consumption of all apartments in Sweden during a typical weekday in the winter season. Electricity consumption after a 15 % load-shift is included. (Based on* (41) *and* (2)*)*

The load-shift results in a delayed consumption peak that will occur at the hour between 20.00 and 21.00 (data point 21.00), two hours after the original consumption peak. The peak has also increased slightly, from 945 MW at 19.00 to 955 MW at 21.00. This new pattern of electricity demand may have two specific impacts on the Swedish electric power system. The hourly price of electricity may change as electricity is priced by marginal pricing, as described in section 2.2.1 and local distribution grids and national transmission grids may experience new bottlenecks as the transmission may increase during certain hours and decrease during other hours.

The suggested load-shift could increase the maximum demand from private apartment households within a 24 hour period. This does not has to pose a problem since the electricity transmission in the distribution grids consist of energy for other sectors such as houses, industries, services etcetera. The delayed peak demand from the apartment customers could actually be beneficiary if compared with the national load curve, see figure 4.7. However, the increased demand between 07.00 and 08.00 (data point 08.00) of 440 MW to 490 MW on weekdays could add to national peak demand at that hour.

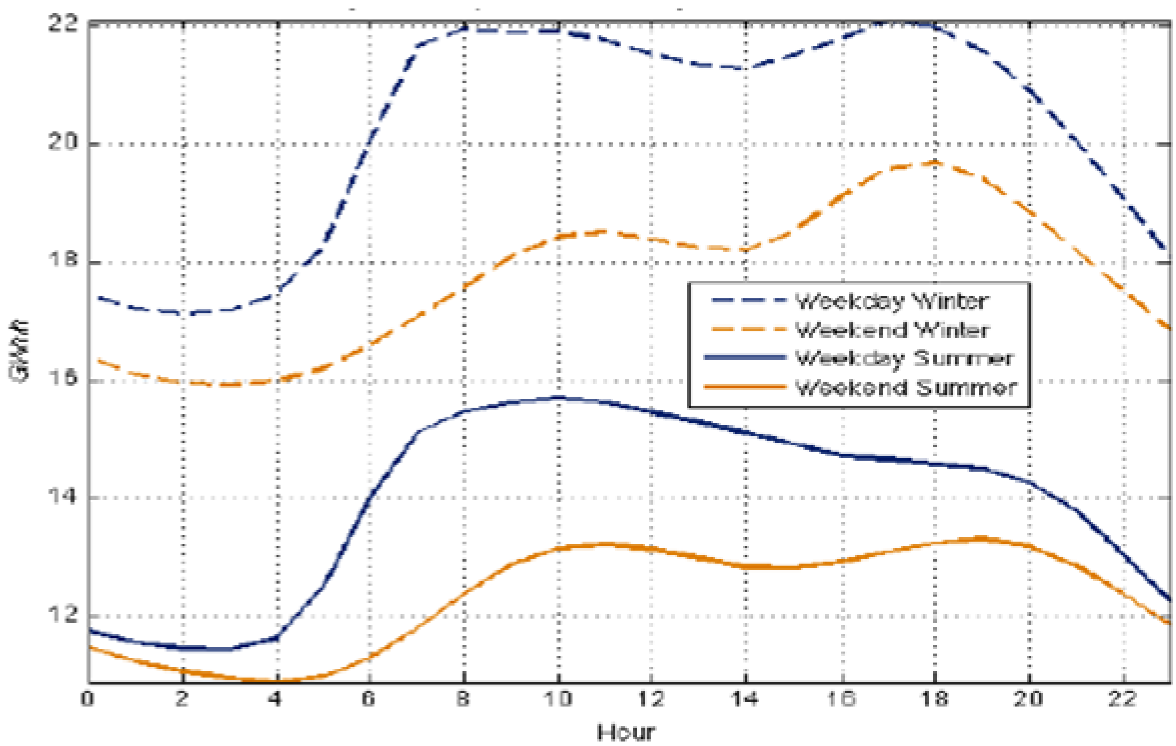

Figure 4.7. *Consumption profile for the Swedish national grid on an average weekday/weekend during summer/winter in 2010.* (38)

4.3 SUMMARY NATIONAL SCALE IMPACT OF END-CONSUMER DR AND THE ACTIVE CUSTOMER SCENARIO

In this chapter, the national scale impact of end-consumer DR and the Active customer scenario within apartment customers have been analyzed. The analysis is divided on two tasks; firstly, a national scale load curve for all Swedish apartment households has been estimated. Secondly, a 15 % load-shift of that load curve has been approximated in line with the Active customer scenario.

There is a lack of estimations of the total hourly electricity consumption of Swedish apartment households. Estimates provided by authorities often merge the consumption of apartment households with that of houses, public services or the consumption of the apartment buildings themselves; consumption that apartment customers do not have the capability to affect.

The aggregated, specific electricity consumption of all Swedish apartment households have in this study been estimated by the hourly load curves of five type apartments presented in a study by the Swedish Energy Agency (2) in combination with the number of each type apartments in Sweden provided by the Swedish Central Bureau of Statistics (41). The resulting load curve provides an estimate of the yearly specific consumption of Swedish apartments of 5,01 TWh, which is consistent with earlier estimates of approximately 5 TWh (53). 50 % of this consumption is assigned to households containing singles. The total yearly consumption constitute 6,5 % of the total yearly consumption for the household and services sector in Sweden.

The aggregated load curve has a high constant proportion of consumption that is used for cold appliances and the peak load is dominated by energy used for lighting and cooking. Electricity used for televisions and computer sites are also quite high and dependent on hour of consumption with a peak that coincides with that of cooking, which in turn is lagging slightly in comparison with the electricity demand for lighting. The aggregated load curve has an estimated peak between 18.00 and 19.00 of 945 MW during a typical weekday. The peaks are higher in the winter time due to seasonality effects on lighting, cooking, televisions and audiovisual appliances.

By shifting 15 % of the total national consumption of the Swedish apartments from peak to off-peak hours, the peak would be offset by two hours to the hour between 20.00 and 21.00 and increased with 10 MW. The suggested load-shift would thereby increase the maximum demand from apartment households. This does not, in itself, has to pose a problem since the electricity transmission to apartment households only constitute a part of the total electricity transmitted. The delayed peak demand from the apartment customers could actually be beneficiary if compared with the national load curve. However, the increased demand between 07.00 and 08.00 of 50 MWh on weekdays could increase the national peak demand during that hour.

5. Sensitivity analysis of extrapolated results

There are numerous ways of how to perform a sensitivity analysis. In this chapter, two different approaches will be used. Firstly, in section 5.1, the end-consumer costs and savings calculated in section 3.1.3.3 will be revised using different electricity prices and a time-differentiated energy tax. Thereafter, in section 5.2, the aggregated load curve from section 4.1 will be updated with a probable consumption reduction stemming from more effective lighting solutions in Sweden. The two analyses are meant to put the end-consumer cost savings as well as the aggregated load-shift in perspective. The chapter is summarized in section 5.3.

5.1 End-consumer costs

To calculate future end-consumer costs and cost savings, the SRS price models future cost components need to be estimated. Network tariffs, green certificates, energy tax, retail costs and the varying price of electric energy can all be assumed to change in the future. The energy tax has increased during the last years, even when taking inflation into account (54) while the cost of the network tariff is dependent on how large investments that needs to be made in the distribution and transmission grids (4). The costs of green certificates are dependent on both renewable production as well as the yearly legislated quotas while retail costs are subject to an open market (4). However, in order to estimate future end-consumer costs, a sensitivity analysis of three parameters will be performed.

5.1.1 Sensitivity analysis parameters

The end-consumer costs and percentage cost savings for the year 2011 presented in section 3.1.3.3 will be updated with three different parameters; spot price level, spot price volatility and the design of the energy tax, illustrated in figure 5.1. The definition of each parameter will be presented along with the end-consumer costs and savings for the respective parameter in the sections 5.1.1.1 to 5.1.1.3. An additional combined scenario that uses all three parameters ends the section.

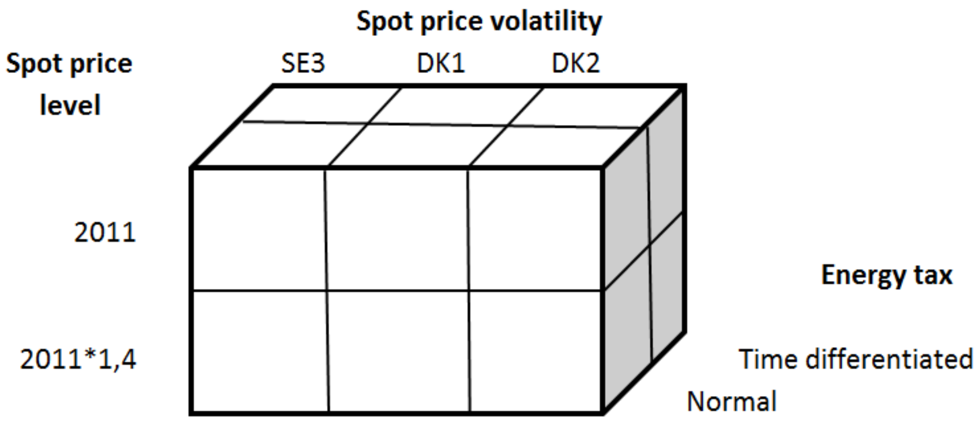

Figure 5.1. *Parameters for the sensitivity analysis of end-consumer costs and savings.*

5.1.1.1 Spot price level

Since electric energy is priced by marginal pricing in Sweden, future electricity prices depends on both future consumption and future production. Even though many sectors and usages may be made more efficient, the total national consumption of electricity is often assumed to increase (55) (4). This is due to the fact that in order to make some processes and usages more efficient in an overall energy perspective, these processes and usages are often assumed to use more electric energy. For instance, this is the case for the transport sector, where a lower total energy use of the sector may be accomplished by increasing the use of electric energy at the expense of the use of fossil fuels (55). Future electricity prices can also be influenced by a higher market coupling to the markets on the European continent, where higher prices may exist. This influence is dependent on the transmission capacity between the countries and is usually a question for the TSO's, even if private actors may come to play a more important part in the expansion of international transmission (4).

A study based on the use of the energy system model MARKAL made by the consulting firm Profu in 2010 suggests a vision scenario that states that the Nordic and thereby Swedish power system is climate neutral by the year 2030. Until this date, stricter climate legislation will increase the price of electricity but beyond 2030, when the production is assumed to be CO2 neutral, the spot prices will level out. The Profu report makes numerous assumptions regarding future electricity production, electricity consumption, efficiency programs and transmission solutions. The resulting production mix and consumption patterns are estimated by the MARKAL model to generate electricity prices that are roughly 40 % higher than those of 2011. Therefore, this price level will be used when calculating future end-consumer costs and savings. (55)

By using electric energy spot prices that, in every hour, is 40 % higher than the spot prices in 2011, the end-consumer costs for different amounts of load-shift are calculated and presented in table 5.1.

Table 5.1. *End-consumer costs for the SRS price model with different amounts of load-shift for the different five apartments. Costs in Swedish SEK for the year 2011 with a 40 % spot price level increase.*

Type apartment	Yearly costs, no LS	Yearly costs, 5 % LS	Yearly costs, 15 % LS	Unit
Family	6301	6260	6177	SEK/year
Couple, 64+	3807	3780	3723	SEK/year
Couple, -64	4288	4262	4209	SEK/year
Single, 64+	2925	2905	2865	SEK/year
Single, -64	2954	2937	2902	SEK/year

The costs are of course higher than in the original scenario, but the percentage savings of the different type apartments acting in accordance with the Active customer scenario presented in section 3.1.3.2 are lower than in the original scenario, see figure 5.2.

Figure 5.2. *Percentage cost savings of the different type apartments acting in accordance with the Active customer 15 % load-shift scenario. Original spot price level compared with a spot price level increased with 40 %.*

5.1.1.2 Spot price volatility

In addition to the spot prices level, the spot price can also become more or less volatile. The volatility is dependent on the cost structure of the production capacity; less expensive base production in combination with more expensive peak capacity production generates spot prices that fluctuates. The spot prices can fluctuate between seasons as well as within days, as is the case in Sweden with higher prices during daytime than during the night and higher prices during the winter than during the summer.

Since the fluctuations are dependent on the cost structure of the production capacity and that the Swedish future production mix might change, the end-consumer cost calculations have been performed for the spot price volatility of the two Danish price areas; DK1 and DK2. Denmark has, as opposed to Sweden, a power system based on combined heat and power plants and wind power which generates more fluctuating spot prices which can be the case in Sweden if greater market coupling with the continent or a greater proportion of wind power is implemented. (19)

The sensitivity analysis are based on the spot price volatility of the Danish price areas but the spot price level of Sweden, resulting in the same yearly average energy spot price but a different distribution of high spot prices and low spot prices. The end-consumer costs and cost savings for the type apartments are represented in table 5.2 and 5.3.

Table 5.2. *End-consumer costs for the SRS price model with different amounts of load-shift for the five type apartments. Costs in Swedish SEK for the year 2011 with spot price volatility of DK1.*

Type apartment	Yearly costs, no LS	Yearly costs, 5 % LS	Yearly costs, 15 % LS	Unit
Family	5589	5546	5459	SEK/year
Couple, 64+	3388	3359	3299	SEK/year
Couple, -64	3797	3770	3714	SEK/year
Single, 64+	2597	2577	2534	SEK/year
Single, -64	2608	2590	2554	SEK/year

Table 5.3. *End-consumer costs for the SRS price model with different amounts of load-shift for the five type apartments. Costs in Swedish SEK for the year 2011 with spot price volatility of DK2.*

Type apartment	Yearly costs, no LS	Yearly costs, 5 % LS	Yearly costs, 15 % LS	Unit
Family	5602	5557	5466	SEK/year
Couple, 64+	3398	3368	3306	SEK/year
Couple, -64	3804	3775	3717	SEK/year
Single, 64+	2604	2582	2538	SEK/year
Single, -64	2610	2592	2555	SEK/year

Apparently, the spot price volatility of Denmark would give a greater economic incentive to load-shift and greater percentage cost savings for the five type apartments, see figure 5.3.

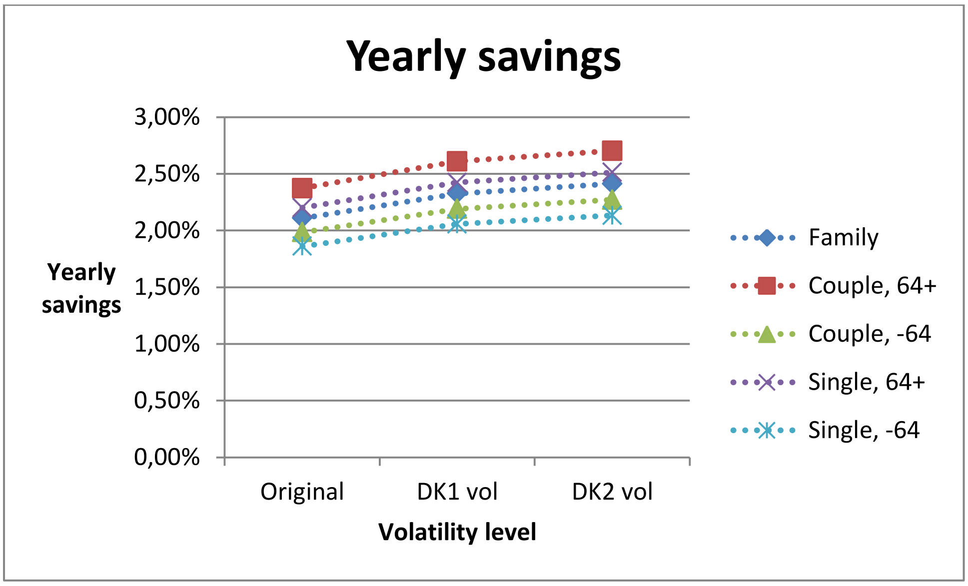

Figure 5.3. *Percentage cost savings of the different type apartments acting in accordance with the Active customer 15 % load-shift scenario. Original spot price volatility compared with the spot price volatility of DK1 and DK2.*

5.1.1.3 Time differentiated energy tax

The Swedish energy tax is fixed as of 2012, meaning that a kWh is taxed the same regardless of the hour of consumption. In 2012, the energy tax was 29 öre/ kWh. This aspect of the energy tax could be modified to create an additional incentive for more end-consumer load-shift.

One way to do this is to make the energy tax time differentiated so that consumption during the peak and off-peak hours, pre-defined in the SRS price model, are taxed differently. By utilizing an energy tax that is 18 öre/kWh during off-peak hours and 38 öre/kWh during peak hours, the yearly costs and cost savings in table 5.4 are achieved.

Table 5.4. *End-consumer costs for the SRS price model with different amounts of load-shift for the five type apartments. Costs in Swedish SEK for the year 2011 with a time differentiated energy tax.*

Type apartment	Yearly costs, no LS	Yearly costs, 5 % LS	Yearly costs, 15 % LS	Unit
Family	5523	5470	5361	SEK/year
Couple, 64+	3365	3329	3255	SEK/year
Couple, -64	3738	3704	3635	SEK/year
Single, 64+	2571	2545	2493	SEK/year
Single, -64	2560	2538	2493	SEK/year

The yearly costs for the customers who chose to not alter their consumption do not differ greatly from the yearly costs of the original scenario. However, by choosing to load-shift 15 % of their consumption in accordance with the Active customer scenario, greater cost savings can be achieved, see figure 5.4. Of the three parameters investigated, the time differentiated energy tax has the largest impact on end-consumer percentage cost savings.

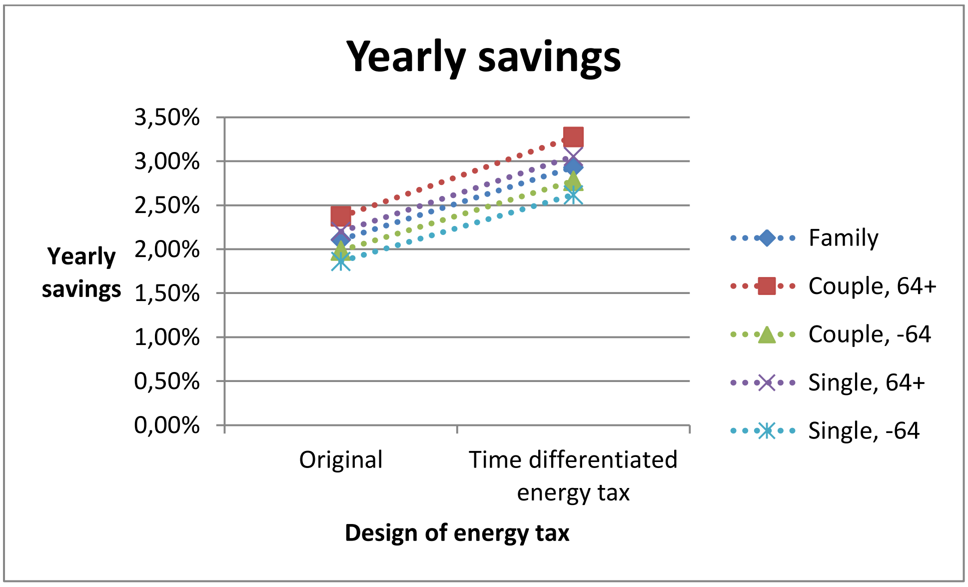

Figure 5.4. *Percentage savings of the different type apartments acting in accordance with the Active customer 15 % load-shift scenario. Original design of the energy tax compared with a time differentiated energy tax.*

5.1.1.4 Combined scenario

In addition to the sensitivity analysis of the three parameters presented in section 5.1.1.1 to 5.1.1.3, an additional, combined scenario, has been created. The scenario applies the design of the three parameters that gave the largest percentage cost savings increase for the end-consumers.

The combined scenario uses the original spot price level of 2011, the spot price volatility of DK2 and a time differentiated energy tax. The resulting end-consumer costs and cost savings are presented in table 5.5.

Table 5.5. *End-consumer costs for the SRS price model with different amounts of load-shift for the five type apartments. Costs in Swedish SEK for the year 2011 with spot price volatility of DK2 and a time differentiated energy tax.*

Type apartment	Yearly costs, no LS	Yearly costs, 5 % LS	Yearly costs, 15 % LS	Unit
Family	5566	5506	5386	SEK/year
Couple, 64+	3399	3359	3277	SEK/year
Couple, -64	3762	3724	3647	SEK/year
Single, 64+	2592	2564	2505	SEK/year
Single, -64	2568	2544	2494	SEK/year

The percentage cost savings of the combined scenario are larger than any of the earlier calculations, as would be expected, see figure 5.5.

Figure 5.5. *Percentage savings of the different type apartments acting in accordance with the Active customer 15 % load-shift scenario. Original cost savings of 2011 compared to the combined scenario with the original spot price level, the spot price volatility of DK2 and a time differentiated energy tax.*

5.2 LOAD CURVE

The load-shift that may be implemented by the interpretation of the Active customer scenario presented in section 3.1.3.2 for private apartment end-consumers could potentially increase the peak demand by apartment end-consumers by roughly 10 MW during a typical weekday. To put this increase into perspective, another future consumption development will be presented here. Since September 2012 all light bulbs were prohibited for sale in Europe (56). Since the peak demand of apartment end-consumers were dominated by electricity used for lighting and cooking, this prohibitions possible influence on the total apartment end-consumer demand will be estimated.

5.2.1 REDUCED ELECTRICITY CONSUMPTION FOR LIGHTING PURPOSES

New light sources such as LED and halogen lights can realistically save up to 75 % of the electric energy needed for lighting purposes (56). Since electricity used for lighting purposes is both a large part of apartment customers yearly consumption and a large part of the peak demand, such a large reduction have an fundamental impact on the segments total usage. By implementing a 75 % power reduction for all light sources, the total apartment load curve will change to that in figure 5.6. The new load curve has a lower peak to off peak ratio and a 200 MW lower peak demand. That corresponds to an approximately 20 % peak demand reduction during the peak hour between 18.00 and 19.00.

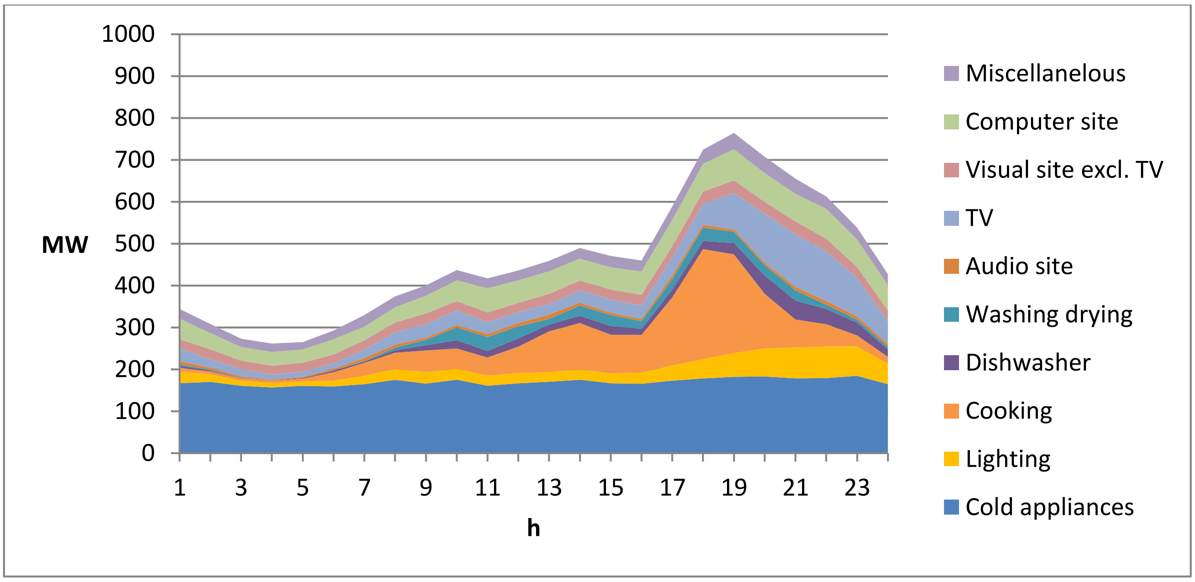

Figure 5.6. *Aggregated, hourly electricity consumption of all apartments in Sweden during weekdays, divided on use. Electricity used for heating is excluded. Electricity used for lighting purposes has been reduced with 75 % during all hours. (Based on* (41)*and* (2)*)*

5.3 Summary of the sensitivity analysis

The sensitivity analysis has focused on two aspects of the previous chapters; end-consumer costs and cost savings and the aggregated national scale load curve of private apartment end-consumers.

The end-consumer costs and cost savings that may face a customer using the SRS price model and acting in accordance with the Active customer scenario are in the sensitivity analysis based on the variation of three parameters; spot price level, spot price volatility and the design of the energy tax. The interpretation of the Active customer scenario load-shift method 3 from section 3.1.3.2, from which all cost savings are calculated, remained the same.

The variation of parameter one uses theoretical future electricity spot prices that are 40 % higher than those of 2011 (55). The percentage cost savings that can be achieved by an private apartment end-consumer are slightly lower than in the original cost savings calculations.

The variation of parameter two uses the spot price volatility of the two Danish price areas DK1 and DK2. The percentage cost savings that can be achieved by an private apartment end-consumer are slightly larger than in the original cost savings calculations (39).

The variation of parameter three uses an energy tax that is time differentiated with the same peak and off-peak time periods as the SRS price model. The percentage cost savings that can be achieved by an private apartment end-consumer are roughly 40 % higher than in the original cost savings calculations.

To put the estimated load-shift presented in section 4.2 into perspective, the aggregated load curve for all private apartment end-consumers where analyzed. Since the load-shift resulting from the proposed Active customer scenario would increase the peak demand of private apartment end-consumers, a future development regarding lower electricity consumption for lighting purposes were approximated. If the total electricity consumption for lighting usages where to be reduced by 75 %, the private apartment households peak demand of electricity would be reduced by 200 MW. This peak demand reduction is independent of any load-shift and realistic as a result of the 2012 European ban on light bulbs (56).

6. CONCLUSIONS AND DISCUSSION

This chapter will summarize the findings of the study. The answers to the three research questions are presented in section 6.1 followed by a discussion concerning the results and implications derived from them in section 6.2.

6.1 CONCLUSIONS

What are the challenges of a Swedish national scale implementation of end-consumer DR and the SRS price model for private apartment end-consumers?

The challenges of a national scale implementation of end-consumer Demand Response and the SRS price model are presented in two parts. Firstly, an analysis of the current, suggested SRS price model is given. Secondly, a gap analysis of the SRS project and the Swedish national conditions are presented.

Based on spot price data of the years 2010-2012, the current price models Cost components have high internal consistency, meaning that the economic incentive the network tariff component creates and the economic incentive the spot Cost component create coincide in a majority of cases. The risk for a conflicting incentive and therefore an unclear total incentive of the SRS price model is therefore deemed to be small. The end-consumers also have a clear short term economic incentive to move loads from peak hours to off-peak hours due to the high impact of the network tariff. However, the current SRS price models peak to off-peak price ratio is still deemed to be small with an average ratio below three for the years 2010-2012 in both the summer and the winter season. The long term economic incentive that the SRS price model can create is dependent on the costumer load curve, the definition of the Active customer scenario and the SRS price model itself. The interpretation of the Active customer scenario is dependent on the definition of the price models pre-defined peak and off-peak hours. The cost-savings an end-consumer can make by acting in accordance with the Active customer scenario is 0,6-1,2 % or 16-67 SEK of the total yearly electricity costs for a 5 % load-shift and 1,8-3,1 % or 48-165 SEK for a 15 % load-shift, depending on type apartment and year. This is slightly lower than the 3,9 % cost saving of a 15 % load-shift that an earlier study estimated. The difference is assumed to be due to the difference in the price models peak and off-peak hours and in extension the interpretation of the Active customer scenario, rather than any differences in Cost components.

By comparing the attributes and solutions that are planned to be used in the SRS pilot project with the Swedish national scale conditions, a number of challenges for a national scale implementation of end-consumer DR and the SRS price model has been elicited.

Firstly, DR in the SRS pilot project relies heavily on smart appliances such as white goods for facilitating easy load-shift. These white goods are more uncommon in Swedish apartment households than in houses. The challenge is therefore not only to update existing appliances but also to introduce new appliances to some degree. Secondly, the SRS price models' complexity might be hard to market and therefore reach potential customers since it combines the costs for distribution and the costs for energy. Thirdly, the suggested SRS price model has a low peak to off-peak price ratio. Based on historical electricity prices between 2010 and 2012, the average peak to off-peak price ratio is never above three. Finally, the total yearly costs for electricity might be too low for apartment customers to promote DR as a way of saving money.

What would be the results of a Swedish national scale implementation of end-consumer DR and the SRS price model for private apartment end-consumers?

There is a lack of estimations of the total hourly electricity consumption of Swedish apartment households. This study has estimated the aggregated, specific electricity consumption of all Swedish apartment households from the hourly load curves of five type apartments presented in a study by the Swedish Energy Agency in combination with the number of each type apartments in Sweden provided by the Swedish Central Bureau of Statistics. A large proportion of the total households, the total yearly electricity consumption and the peak power demand stems from single households.

Given the interpretation of the Active customer scenario presented in section 3.1.3.2, a Swedish national scale implementation of end-consumer DR and the SRS price model would lead to lower consumption during most of the hours where the national demand is high.

However, the consumption of apartment customers during the hour 07.00-08.00 would increase which could add to the total national demand during this hour. The national demand during this hour is high, why a demand increase could be troublesome from a transmission and distribution as well as a production point of view.

How can an accompanying sensitivity analysis be performed, given the before-mentioned extrapolation of private apartment end-consumer DR and the SRS price model and taking into consideration possible future developments in the power system?

Two different approaches were used in this study to evaluate possible future scenarios. Firstly, the end-consumer costs and savings calculated in section 3.1.3.3 were revised using a slightly different distribution of household electric appliances as well as future, estimated electricity prices that were 40 % higher than those in 2011. Secondly the aggregated load curve from section 4.1 was updated with a probable consumption reduction stemming from more effective lighting solutions in Sweden.

The cost savings that could be made by an end-consumer acting in accordance with the Active customer scenario were naturally higher with higher consumption and with higher electricity prices. However, the percentage savings were lower which may reduce the incentive of the SRS price model in the future.

To put the estimated load-shift presented in section 4.2 into perspective, the aggregated load curve for all apartment customers where analyzed. A possible future development regarding lower electricity consumption for lighting usages were estimated. If the total electricity consumption for lighting usages where to be reduced by 75 %, the private apartment households peak demand of electricity would be reduced by 200 MW. This peak demand reduction is independent of any load-shift.

6.2 Discussion

The SRS project is meant to test and evaluate new technology as well as new market models. Many of the suggested solutions are not available on a Swedish national scale and may not be so in the future. The pilot project is meant both as a testing scene for solutions that may be implemented in Sweden as well as to provide the involved companies with a testing ground for developing technology and solutions that may be marketed to an international market or to customer segments beyond that of the SRS project. (57)

However, in order to achieve any large scale impact, the results of a pilot study must be applied to larger surroundings. Consequently, the applications and solutions should be tested to fit Swedish conditions in order for the pilot study's results to be valid in the Swedish power system. Given that starting point, the future results from the SRS pilot project should be evaluated by the national conditions of its surroundings, e.g. Sweden.

The reference apartment that have been used when evaluating price models and end-consumer DR in the SRS pre-studies are quite big in a national comparison with a yearly consumption above the national average. In order to further evaluate the SRS price model impact on a national scale, it may be wise to do so for a wider variety of apartments to better mirror the national customer base.

In order to get comparable results regarding costs and savings calculations for end-consumers, a stricter definition of the Active customer scenario and the associated load-shift may be needed. Since the price models peak and off-peak hours does not only affect the actual costs of the customers but also the interpretation of the Active customer scenario, conflicting results may occur.

The SRS pilot apartment is equipped with appliances and solutions that are meant to facilitate easy load-shift, such as smart machines in the form of white goods. These appliances are not yet publicly available since the technology is still being tested, but given the current national access to common laundry rooms, an implementation of such appliances might not just be a question of updating or replacing existing machines but also to introduce these appliances in the apartments themselves.

The end-consumer cost savings cannot be argued to be large on an individual customer level, nor can the resulting aggregated load-shift of Swedish private apartment end-consumers, especially if comparing with other actions, such as large efficiency programs similar to the current ban on light bulbs. However, the aggregated cost savings for the entire private apartment end-consumer segment corresponds to between 124 and 429 million SEK each year. The end-consumer cost savings is assessed to be hard to influence from a DSO's perspective, since the network tariffs' time-differentiated component is easily diluted by the other cost components. This may lead to difficulties regarding the marketing of end-consumer DR, especially since approximately half of all Swedish apartments consists of single households which have low electricity costs as it is.

However, the pilot apartments may better represent the conditions and consumption profile of house households, which in itself would generate important results. If the primary aim of the SRS pilot study is to obtain reliable experiences of how a national scale implementation of end-consumer DR might be implemented by apartment customers, additional focus need to be directed towards the discrepancy between the conditions of the pilot study and the national conditions. However, if the primary aim is to develop new techniques and models that might be applied to different national and international markets or different customers, such as house owners, businesses and services, the need to consider these is not as urgent.

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8. APPENDIX

APPENDIX A – COMPARISON OF PRICE MODELS

	SRS price model, current	SRS price model, previous (used in (15))	Vinnova Energy Transfer Tariff (used in (38))	Unit
Object				
Type apartment	Family	F25	F25	
Yearly consumption	3359	3443	3443	kWh
Load profile	weighted	empirical	empirical	
Distribution costs				
Fixed	0	0	0	SEK
Peak summer	49	41,4	49,12	Öre/kWh
Off-peak summer	24	20,2	24	Öre/kWh
Peak winter	90	75,6	89,52	Öre/kWh
Off-peak winter	30	25,1	29,84	Öre/kWh
Energy costs			-	
Energy	Spot	Spot	-	Öre/kWh
Energy tax	29	28	-	Öre/kWh
Green certificate	3,2	5,02	-	Öre/kWh
Retail	10	10	-	Öre/kWh
VAT	25	25	25	%
Time				
Peak summer	all days 08.00-20.00	all days 06.00-22.00	weekdays 08.00-20.00	
Off-peak summer	Other	Other	Other	
Peak winter	weekdays 08.00-20.00	all days 06.00-22.00	weekdays 08.00-20.00	
Off-peak winter	Other	all days 22.00-06.00	Other	
Seasons				
Summer	1 Apr-31 Oct	1 Apr-31 Oct	1 Apr-31 Oct	
Winter	1 Nov-31 Mar	1 Nov-31 Mar	1 Nov-31 Mar	