CHALMERS
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Possibilities of More Flexible Electricity Use in Office Buildings

Master's thesis within the Sustainable Energy Systems programme

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Gothenburg, Sweden 2015

MASTER'S THESIS

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Master's thesis in collaboration with:

SWECO

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ABSTRACT

The increasing awareness of sustainability issues due to climate change increases the investments in renewable energy. The intermittency and unpredictability of those energy sources will have an impact on the electric power system. The increasing rate of urbanization also makes cities all over the world grow rapidly. To handle this in a sustainable way the energy and resource use must become more efficient. The challenges with renewable energy in the energy system and the demand for more efficient energy use in cities would both be facilitated by a more flexible demand side. This could be enabled by integration of more information and communication technology in the electric grid and in buildings.

The purpose of this project is to investigate how office buildings in Sweden can contribute to more efficient electricity use in a city. The overall problem dealt with has been how controlled management of the electricity consumption, solar power production and charging of electric vehicles connected to an office building can be combined to benefit the electric grid while profiting the property owner.

There are no technical problems in making the demand side more flexible, and thereby the electric power system more efficient. The challenges lies more in the organizational part and finding business models that make it profitable for all parts involved. The overall problem in realizing these measures at the moment, lies in the fact that there are not yet enough economic incentives since the variations in electricity price, and the electricity price in itself are too low. Some of the changes and possible solutions concerning the energy system depend on societal changes that cannot be fully predicted, thereby creating important uncertainties.

Keywords: Smart buildings, smart grids, Demand Side Response, DSR, Demand Response, DR, solar PVs, electric vehicles, EVs

PREFACE

This report has been written as a Master's thesis of 30 credits on the Master's programme Sustainable Energy Systems at Chalmers University of Technology in Gothenburg, Sweden.

The project has been carried out in collaboration with the department of Electrical installations at Sweco Systems AB in Gothenburg, Sweden. The report is based on an idea from Tomas Limmert at Sweco Systems AB. Most of the work has been done at Sweco's office in Gothenburg.

Many thanks to Tomas Limmert and Sweco Systems AB for letting me sit at their office, to Gustav Holmquist at Sweco Energuide AB for being my discussion partner in grid related issues and to the representatives from the different property owners and the grid company for taking the time for my interviews.

Fanny Hedberg

Gothenburg 2015-12-17

CONTENTS

ABBREVIATIONS

AC	Alternating Current
AMI	Advanced Metering Infrastructure
BRPs	Balancing Responsible Parties
CPP	Critical Peak Pricing
DC	Direct Current
DLC	Direct Load Control
DR	Demand Response
DSM	Demand Side Management
DSR	Demand Side Response
DSO	Distribution System Operator
ENTSO-E	European Network of Transmission System Operators
EU	European Union
EVs	Electric Vehicles
HVAC	Heating, Ventilation and Air-Conditioning
ICS	Interruptible/Curtailable Service
ICT	Information and Communication Technology
OBC	On Board Charger
PLCs	Programmable Logic Controllers
RES	Renewable Energy Sources
RTP	Real Time Pricing
SCADA	Supervisory Control and Data Acquisition
TOU	Time of Use Tariff
TSO	Transmission System Operator
V2G	Vehicle to Grid

1 INTRODUCTION

The increasing awareness of sustainability issues due to the risks of climate change increases the investments in renewable energy. The changes of the energy system with growing amounts of intermittent renewable energy sources (RES), such has wind and solar power, and a decreasing share of fossil fuels and thermal power will have a large impact on the operation of the electric grid. Due to the laws of physics, there has to be a balance in the grid between supply and demand, at all times. This fact in combination with the intermittency from the new sources of electricity constitutes a challenge.

The traditional electric grid was built for a centralized electricity production that was adjusted according to the demand. With increasing amounts of intermittent RES this will be more difficult. A higher share of intermittent RES in the energy system might imply a risk for e.g. congestion and frequency instability in the electric grid [1, 2]. For the Swedish case, intermittent RES currently implies mainly wind power connected at all levels of the electric grid [3]. A higher share of wind power makes it more difficult to keep the power balance due to the introduction of additional variation besides the variation in demand. The unpredictability of wind power implies that the Swedish Transmission System Operator (TSO) needs to make predictions on available capacity, which creates increased uncertainties in maintaining the power balance, compared to controllable production [4].The large amounts of hydro power in the Swedish energy system makes the situation easier to manage than in many other countries since hydro power can balance the electric grid to a relatively low cost [5, 6]. However, the Swedish hydro power cannot compensate for more than a certain amount of variation.

As the share of wind power increases, the low running costs of wind power decreases the electricity price in large periods of times, as electricity is dispatched according to merit order. In combination with decreasing operation times, this reduces the profitability for thermal power plants with higher running costs such as nuclear power [4, 7]. There has also been a legal decision on phasing out nuclear power from the Swedish energy system for several years [8]. The increased capacity tax on nuclear in Sweden further contributes to reduced profitability, which has increased the rate of phase out of old reactors. Less nuclear power, which acts as base load power production in the Swedish energy system, would complicate the operation of the electric grid in several ways. Nuclear power contributes with controllable capacity, i.e. the available capacity is known on beforehand, which facilitates keeping the power balance as the amount of available capacity in the grid is more stable. Nuclear power also contributes with voltage control and to the inertia of the electric grid [4].

The amount of wind power possible to connect to the grid without causing reliability and voltage quality problems varies depending on where in the grid it is connected. This limit may generally differ between a few percent up to 50% of the electricity consumption, depending on the type of disturbance that sets the limit [3]. The expected and planned fast increase in installed wind power capacity constitutes one reason for making it challenging for the grid [3]. Increasing amounts of wind power is also expected to lead to fewer hours with peak load, as the net load curve changes. For these hours it will take extremely high prices to get profitability in the operation of the power plant needed [9]. Thus, the will to invest in those types of power plants is likely to be reduced. Sufficient amount of capacity in the electric power system is vital for the reliability of the grid [3]. An overall problem with an increasing share of wind power, is the fact that although the energy production over the year might be sufficient to cover the demand, there might still be a capacity deficit at times since the production curve has no correlation with the load curve [4]. The Swedish power balance is becoming increasingly affected as the difference between available power and peak load power is decreasing [10]. See Figure 1 below.

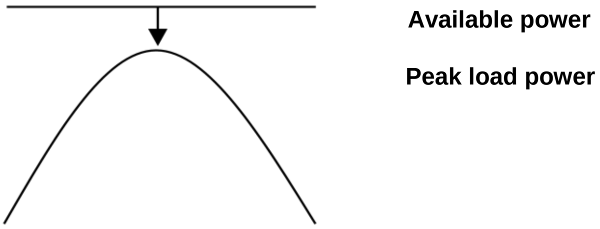

Figure 1. A decreasing difference between available power and peak load power has an impact on the power balance in the electric power system.

The previously mentioned challenges could be handled with flexible production or consumption [1, 2]. Changing the production is per definition difficult with intermittent RES. Reducing the electricity production from RES by curtailment is possible but implies that instead of using all the electricity produced, electricity needs to be produced by some other power production, which could be fossil fuelled plants, when there is a demand for it. By instead moving consumption to times when there is high production from RES, more of that production could be utilised [3]. This would be favourable from the sustainability perspective, aside from facilitating the operation of the grid. Moving consumption to times with high production from RES could also be beneficial from an economic perspective as RES have low running costs and the need for operation of more expensive power production could be reduced.

An important part of the development of the electric power system is therefore to make the electricity consumers more active and flexible in their demand. Making the demand side of the electricity system more flexible in its consumption is dealt with in the concept *Demand Side Response (DSR)*. DSR is also commonly called *Demand Response (DR).* DSR is enabled through increased use of information and communication technology (ICT) in the electric grid. The concept is included in the wider concept *Demand Side Management (DSM)* which comprises all implementations on the demand side of the energy system [1]. DSR is believed to be a key factor in the future electricity market [11].

1.1. Background

In the pursuit for a more sustainable society there is an aim to create cities with an efficient resource and energy use. Communication between all parts of the city such as buildings, infrastructure and technical equipment is an important factor [12]. Thus, ICT is the core of both DSR and the modern city. Currently, there is also a pursuit for more automated solutions in buildings to integrate different systems and processes to increase energy efficiency and service level for users [13]. The automated solutions are built upon technical systems in the building controlling all activities. These buildings enable implementation of DSR and thereby a potential of more efficient electricity use in buildings and in the city. DSR also implies a facilitated operation of the grid, besides the more efficient electricity production and grid capacity use [14]. Commercial buildings, such as office buildings and especially modern properties, generally have a vast amount of technical systems installed to monitor, control and operate the building [15]. The law regarding the Advanced Metering

Infrastructure (AMI) implies that most buildings in Sweden now have smart meters, i.e. meters that have e.g. remote reading capability and sampling of hourly measurements [16]. Smart meters constitute a potential important link between buildings and the electric grid.

The building sector in Sweden uses approximately 50% of the total electricity consumption [17]. Buildings therefore constitute an important part of the load. The largest potential loads to be moved in time in Sweden, as a DSR measure, are also equipment related to the heating demand. A shift in time for these loads has little impact on the convenience for the consumers. This applies to both the domestic and commercial sector. In the commercial sector e.g. the ventilation and intensity of lighting are other potential loads that could be controlled [1]. Thus, a change within the area of buildings could have a large impact on the operation of the electric grid.

Developments related to the energy system, such as the introduction of small-scale solar photovoltaics (PVs) and electric vehicles (EVs) change the electricity use in buildings. They could potentially facilitate a more flexible energy use in the building and thereby efficiency improvements for the electric grid [18]. The match between production from solar PVs and the demand in commercial buildings, such as office buildings could also imply that the potential of installing solar PVs in office buildings is good. Combining DSR, solar PVs and charging of EVs could potentially lead to a more flexible electricity use in office buildings.

In the building sector, energy efficiency usually refers to using as little energy as possible within the building, not considering the surrounding city. Thus, the perspective is rather narrow. The possibility of setting the building with a more flexible energy use in a larger perspective, and thereby how synergies and energy efficiency in a system perspective can be created, will be studied in this report.

1.2. Purpose

The purpose of this project is to investigate how office buildings in Sweden can contribute to more efficient electricity use in a city.

1.3. Objectives

The objectives of the report are to:

- Determine the role of the building in making the electricity use more efficient in the city, by involving DSR, small-scale electricity production from solar PVs and charging of EVs.
- Determine how these measures could be beneficial for property owners

1.4. Problem description

What is the interest for DSR on the grid side and on the demand side?
What would be a beneficial way to implement DSR in an office building for the property owner?
What impact would that implementation of DSR have on the electric power system?
How could the incentives to install solar PVs on office buildings be increased?
What would be a beneficial way to implement EV charging at office buildings?
How can DSR, solar power production and charging of EVs connected to office buildings be combined to benefit the grid and the property owner?

1.5. Limitations

The focus of the report has been office buildings in Gothenburg, Sweden. Residential properties have been excluded. The reason for focusing on office buildings was due to their substantial amount of technical systems installed, and the fact that a significant share of their electricity use occurs during daytime, which also coincides with the diurnal times of peak load in the grid. Only the current situation and conditions in Sweden and Gothenburg have been investigated. In other countries there might be other factors needed to take into consideration. Possible future changes of the energy system and the society have not been considered since they are difficult to fully predict. Only the electricity part of the energy use in the building has been considered.

2 THEORY

A theoretical background to the areas dealt with in the report is provided below.

2.1 The Nordic electricity market

The actual balancing of the electric power system is currently in the first stage done through planning. The Balancing Responsible Parties (BRPs), i.e. the suppliers, make prognoses on expected electricity consumption each hour. They are then responsible for delivering that amount of electricity to the grid. During the actual operation hour, the TSO takes over the responsibility for balancing the grid.

The Nordic electricity market is divided in different areas due to limited transfer capacity at certain places in the physical grid. Sweden is divided in four areas, area SE1 is furthest north and SE4 is the south part of the county. The electricity price in these areas varies both due to the relation between demand and supply on the market, but also due to congestion between the different areas [19]. The Nordic electricity market is an Energy-only market, which implies that the trading with electricity is done only in the form of energy, not capacity [20]. The trading on the Nordic electricity market is divided in three parts; Nord Pool Spot Elspot, Nord Pool Spot Elbas and the balancing power market. These markets handle the short term balancing of the electric power system in different time perspectives.

Elspot is a market for physical deliveries of electricity. It is auction based and electricity is traded on an hourly basis. Elspot is the place where the BRPs are supposed to act to keep the balance between produced and consumed electricity. The trading on Elspot closes at 12:00 p.m. the day before delivery [10]. In general terms, Elspot is called the day-ahead market [2].

After the closing of Elspot, Elbas opens, which also is a market for physical deliveries of electricity. The trading on Elbas is done per hour and takes place up until one hour before delivery. Elbas enables adjustments closer to time of delivery. The actors on Elbas are mainly electricity producers, distributers, industries and brokers [10]. Elbas is also called the intraday market [2].

The balancing market is separately handled in each Nordic country by the TSO. The purpose of the market place is to regulate short term unbalances and deviations in production during the hour of operation. The TSO can call off up-regulation or down-regulation based on bids from mainly electricity producers [10].

2.2 Demand Side Response

DSM consists of several strategies that in different ways change the electricity consumption pattern. *Peak shaving* deals with shutting down consumption sites in the grid during peak load hours. *Valley filling* means that new electricity demand is created during off-peak hours. *Load shifting* implies that loads are moved to periods with high electricity production, e.g. windy periods. *Strategic conservation* is a reduction of the total demand. *Strategic load growth* is the creation of a new demand, e.g. EVs. *Flexible load shape* refers to procurement of reserves for reliability reasons [21]. See Figure 2 below.

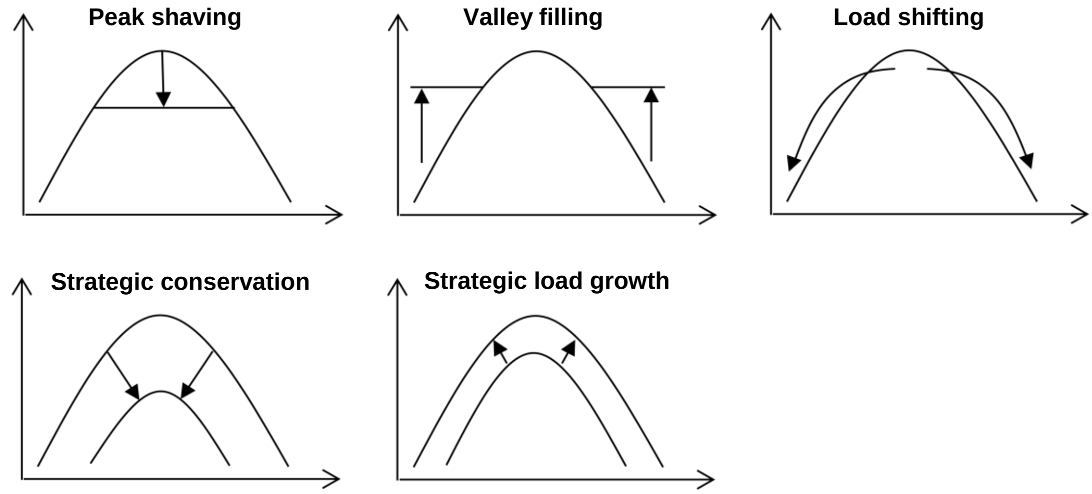

Figure 2. Different ways of changing the load curve through implementation of Demand Side Management.

There are four groups of actors that are of high importance for increasing the flexibility on the demand side; the electricity customers, BRPs, traders and grid companies [10].

One part of DSM is DSR which describes electricity demand that can be modified actively when receiving a signal [11]. Loads are moved in time or restricted through some sort of driving force for the electricity consumer, i.e. it does not necessarily imply that the total electricity consumption is reduced. DSR measures are mainly useful in the short to medium time range, i.e. milliseconds to minutes and hours to days [1].

DSR can be divided in two main parts, time-based and incentive-based programs. Both time-based and incentive-based programs are economically driven from the customer point of view [22]. Some of the most common suggested business models for DSR are described in more detail below.

2.2.1 Incentive-based programs

Incentive-based programs imply that the incentives are detached from the retail of electricity and are offered by grid operators or utilities [22].

Direct load control (DLC)

Direct load control implies that electricity customers are compensated economically for letting the Distribution System Operator (DSO) remotely control their electricity loads at times when the grid is under high stress [22]. DLC does not contribute to optimizing the system under normal operation.

Interruptible/Curtailable Service (ICS)

Interruptible/Curtailable Service is similar to DLC as it is built upon curtailing loads during times when the power system is reaching its maximum capacity. However, in ICS the loads are not remotely controlled. Customers are offered a discount on the retail tariff if participating in the program. If they do not reduce the loads as contracted, they are penalized. One disadvantage is that under normal operation, the ICS tariff does not contribute to any improvements of system performance.

Power tariffs

Power tariffs imply that customers receive a higher network tariff if they increase their peak demand. Usually it is based on the monthly peak demand but it could also be shorter periods. One disadvantage is that the peak demand of a customer might not coincide with the peaks in the electric power system, thus not improving the system operation [18].

2.2.2 Time-based programs

The time-based programs imply that customers change their electricity consumption based on the electricity price [22].

Real time pricing (RTP)

Real time pricing is a system where the electricity price varies between different times of the day and different days. Applied to the Nordic electricity market this would currently imply different price for each hour [10]. RTP implies letting customers pay the actual electricity price, i.e. letting them take part of the fluctuations in price due to the interaction between electricity demand and production and grid capacity [22]. This is supposed to lead to a reduction in electricity consumption when there is a deficit in the system and a high price and an increase when there is a surplus and a low price.

Critical Peak Pricing (CPP)

Critical Peak Pricing implies that at times when the situation is critical in the system, the electricity price is set high. The rest of the time it is reduced. These critical periods are not decided on beforehand, but rather adjusted according to the requirements of the grid. One disadvantage is that there are a limited number of hours per year to apply CPP [10, 18].

Time of Use Tariff (TOU)

Time of use Tariff imply that customers are offered time-differentiated electricity prices in a few price levels per day, on-peak and off-peak tariffs. These are supposed to make the customers shift loads from peak load hours to low demand hours. This method works well in a system with predictable production, in a system with a large amount of RES it is too static [18].

2.2.3 Potential benefits of Demand Side Response for the electric grid

Implementing DSR in buildings could benefit the electric grid in several ways. DSR could be a part of the frequency control in the electric grid. Aggregating a large number of controllable loads such as refrigerators, heat pumps, air-conditioning and water boilers could potentially contribute with considerable frequency stability. This applies both to times of sudden increase in demand or loss of production, and times with large variations in wind power.

The traditional incentives for DSR have been to flatten the demand curve to decrease the use of expensive peak power plants and avoid investments in transmission grid capacity [1]. Reducing the electricity consumption at peak load hours using DSR would thus imply lower operational costs [6]. However, as the share of intermittent energy production in the system increases, the importance of letting the load vary according to the production also increases, thus creating new peaks in demand [1]. DSR could thereby potentially enable an electricity consumption pattern better adjusted to the electricity production when it gets more difficult to control the production [18]. The potential for implementation is depending on type of RES and current grid capacity. For systems with RES placed close to consumers the new peaks might not have an impact on the upstream grid. When it comes to large centralized RES on the other hand, the transmission capacity of the grid might be a limiting factor for such a change. DSR offers a possibility of reducing the congestion in areas with limited transmission capacity. The congestion can e.g. be caused by high electricity production from RES in the area. It would imply that the electricity consumption could moved to that time period in that area, instead of investing in new transmission lines to transport the electricity to other areas where there is a demand for it.

By letting the load vary according to production, the integration of intermittent RES could potentially be larger without having to invest in grid reinforcements on the distribution level. For example a study investigating this has shown that using DSR, approximately 45% instead of 30% of the yearly energy use could be produced by local solar power installations [1]. However, both due to the varying capacity of the grid and the different requirements for different types of RES, grid reinforcements could be required if implementing DSR. Wind power production is usually installed further away from the consumers and sometimes at places with poor grid extension. It is also generally larger installations than solar power. Considering load following the fluctuations of wind power, there might instead be a risk of causing increased requirements for capacity in the distribution grid, as potentially significant power flows might be the result if DSR is implemented in large-scale in the same area.

The current low electricity prices in Sweden and worldwide, partly due to increasing amounts of RES with low running costs, also give reduced incentives for operation and investments in thermal power plants with higher running costs. As discussed, more wind power in the energy system is also assumed to lead to reduced operation times for peak load power plants. This implies that the electricity price at those hours needs to be higher in order to cover the costs for operation [4]. Reducing peaks in the load curve could thus imply reduced costs.

Incentives for grid companies to be interested in DSR include reduced need for investments and lower costs to the upstream grid due to the reduced capacity demand [10]. DSR introduces the possibility to develop and sell new services to customers or suppliers in the area. DSR could imply lower fixed costs than peak production plants. This could potentially increase profit as electricity is traded according to merit order based on the running costs of power plants. Thus, plants on the margin, as peak load production plants, get no coverage for their fixed costs [23]. However, the load patterns over the daily, weekly and seasonal time span have significant differences between different voltage levels in the electric grid. This generally makes the situation more complex and the potential benefits that could result from DSR more uncertain [24].

2.3 Office buildings in Sweden

The electricity use in office buildings and commercial buildings in general, is divided in two parts, facility electricity and tenant's electricity. Facility electricity is the electricity used for the operation of the building such as fans, pumps, lighting in non-rented areas, electric heating, heat pumps and chillers. The facility electricity is part of the operation costs of the building, thus the property owner is responsible for it. Tenant's electricity is the electricity consumed by the tenant. The rest of the electricity consumption is influenced by the activities of the tenant. The tenant's electricity is usually either handled separately by the tenant, or by the property owner and then charged for. The two parts constitute approximately half the total electricity consumption each [25].

Technical systems in office buildings today

The possibility of controlling the loads in a building based on the grid conditions is built upon the fact that there is some sort of technical system communicating with and controlling the loads in the building. The number and complexity of building automation systems installed in office buildings is steadily increasing to increase cost-effectiveness, energy savings, comfort, convenience and flexibility. Building automation refers to the technical systems used in a building to enable functions to run automatically. Including a control centre implies that these systems can be monitored and operated more efficiently and that a connection is created between the systems [15]. The technical systems installed in an office building today are used to control the supply of heating, ventilation, lighting and power. The systems also collect data about the conditions and events in the building through different types of sensors. Actuators transmit signals from the control system to different parts of the building. The Heating, Ventilation and Air-Conditioning (HVAC) systems and the electrical systems are generally separated and managed in different ways. HVAC systems are often centrally controlled while electrical systems generally are locally controlled [15].

The type of system used to control subsystems in a building is called Supervisory control and data acquisition (SCADA). SCADA is a computer based system that monitors and controls a process of some sort, consisting of different components [26]. A network of Programmable Logic Controllers (PLCs) manages a number of distributed sensors and actuators. The incoming data from these are collected and provided to the SCADA system [27]. Components are connected through some sort of ICT solution to enable communication between them [28]. The subsystems are centrally supervised and managed by a control computer [15].

2.4 Solar photovoltaics in Sweden

The solar cell technology is small-scale and can be applied in several different ways. The efficiency of solar PVs is about 10-15%. The technology has grown through applications within space industry and consumer electronics. The large investments in RES in e.g. Germany have had an important impact on the growth and the price development of solar PVs in recent years.

There are two main solar PV technologies; crystalline silicon solar cells and thin-film solar cells [29]. The electricity production is per kW solar PVs installed, placed in south direction with 42 degrees gradient, approximately 820kWh/year in Gothenburg [30, 31]. The highest production occurs from March to October, especially the period May to August [31].

In Sweden there is a possibility of receiving governmental subsidies for installation of solar PVs. Companies can currently receive at the maximum 30% of the cost for installation [32]. Apart from installation subsidies, the producer of small-scale renewable electricity production can also receive a tax reduction of 0.6 SEK/kWh for surplus electricity produced and fed in to the grid. This is supposed to reduce the difference between the prices for sold and bought electricity from the grid. The maximum total reduction is 18 000 SEK/year. The amount of electricity sold cannot exceed to amount consumed during a year [33]. The electricity production from small-scale solar PVs is currently exempted from energy taxation in Sweden, unless the producer could be considered a professional actor on the electricity market [34].

2.4.1 Potential benefits of solar photovoltaics for the electric grid

Solar PVs are usually placed close to where the electricity consumption takes place. In the perspective of the electric grid, this theoretically implies a reduced need for transmission of electricity and thus that less grid capacity is needed. The grid losses could also be reduced due to the lower transport demand. This type of electricity production could thereby increase the energy efficiency in the grid. With more of the electricity produced close to where it is actually consumed and the transport need thereby reduced, there is a potential of a reduced risk of congestion in some parts of the grid [35]. These benefits might be most evident in the transmission grid as a large share of RES, especially solar PVs, is connected to the distribution grid. Power production connected to the distribution grid has the potential of decreasing the costs to the upstream grid due to reduced demand for transporting electricity in that grid [36]. However, due to the intermittency of solar power, the potential of improving the operation of the grid and reducing investments in grid capacity is uncertain.

The impact on the distribution grid, when it comes to solar PVs on buildings, is also depending on the size of the installation in comparison to the electricity consumption in the building. If the installation is dimensioned according to the lowest consumption during the period with the highest production, i.e. during summer in Sweden, the amount of electricity delivered to the grid will be low. Thus, the impact on the grid will be low. This is currently the standard way of dimensioning solar PV installations in Sweden. This may however change with more favourable conditions for selling electricity to the grid [31]. If the installation is dimensioned to deliver electricity to the grid, the requirements on the grid will increase. The unpredictability of solar power will thereby create uncertainties in the dimensioning of the grid. In Sweden where the highest consumption takes place during winter, the distribution grid is currently dimensioned for the maximal load during that period. This implies that the grid, theoretically, would be able to handle at least a certain amount of electricity fed in from the solar PVs. However, as the traditional electric grid was built for one-way transmission of electricity, power flows at the non-intended direction in large-scale might imply difficulties in the grid. One part of the modernization and developments within the area of electric grids, is to ensure that two-way power flows will be feasible.

Electricity generation connected to the distribution grid have the potential to imply voltage support and improvements of power quality [35]. Seen from the grid perspective, local solar power production can contribute with reduction of peaks in demand. At times with high general demand, the electricity consumption from the grid could be decreased by the fact that the load can use the locally produced electricity instead of electricity from the grid. It could thereby also be a way to counteract price fluctuations [37].

2.5 Charging of electric vehicles in Sweden

The batteries in EVs need to be charged with direct current (DC). To enable charging with alternating current (AC) from the electric grid, EVs have rectifiers called On Board Chargers (OBC), installed.

Charging types and standards

Charging of EVs can be divided into three main groups, slow charge, semi fast charge and fast charge. Slow charging takes 6-10 hours for a full loaded battery; semi fast charging comprises charging done in approximately 1-3 hours. Fast chargers have no defined charging time but are designed to charge a battery to 80% of its capacity in 20-30 minutes.

For optimal functioning of the batteries, slow charging should be the main charging type used. The purpose of fast charging is mainly to extend driving range when there is not time for slow charging. Slow charging is done using the same single-phase voltage level as in buildings, in Sweden 230V and 10A or 16A, i.e. a charging power of 2.3-3.7kW. Semi fast charging can be implemented either using single-phase or three-phase AC, or using DC. The possible power level ranges from 7.3kW (230V/32A) to 22kW (400V/32A). Fast chargers have a charging power up to 50kW, usually using DC [38]. Inductive charging is a more modern way to charge EVs that implies new possibilities but is further away from implementation [39].

There are a number of standards for charging of EVs, within the European Union (EU). There has recently been a consensus to opt for the so-called Type 2 standard for AC and Combo 2 for AC and DC. The Type 2 standard is used for slow and semi fast charging using AC. Combo 2 combines the Type 2 standard with a connection for fast charging with DC.

Charging modes

There are different charging modes used with varying levels of safety. The differences lie in power level and communication between the vehicle and the charging station. Some of them have two-way communication between the vehicle and the charger, which implies better control, the possibility to monitor the charging and higher safety level. Some of them also enable communication with the electric grid [38].

According to the EU Directive on deployment of alternative fuels infrastructure, the charging of EVs should if technically and economically feasible use an intelligent metering system. This is supposed to promote charging directed at times when there is high capacity in the grid [40].

2.5.1 Potential benefits of electric vehicle charging for the electric grid

Charging of EVs implies several possibilities that could benefit the operation of the grid. There are two main strategies for controlled charging. When using one-way direction power flows to the vehicles, the strategy is a part of DSR. Two directional power flow between the grid and the vehicle is denoted *Vehicle to grid (V2G)*. V2G implies, apart from the charging, that EVs can be discharged when there is a deficit of electricity in the grid. Owing to the size of the batteries in vehicles, the charge and discharge capacity is small and it is suitable for short term balancing of the grid, i.e. during maximum a day. The possible adjustments of the load curve are increased using V2G compared to DSR since both deficits and surplus of electricity in the grid can be handled. However, the V2G strategy is more complex due to additional charging cycles and more exhaustive monitoring of the batteries. The amount of data needed to be recorded, stored and exchanged is also increased with V2G [41].

EVs offer a chance of complementing the intermittency of RES introduced at larger and larger scale in the energy system. For instance, wind power production has no correlation with the demand for electricity. During the night when demand is low, only base load power is in operation, i.e. wind power production at that time interval would imply competition. The electricity produced by wind power would thus either have to be curtailed or the base load power would have to run on part-load. An alternative solution would be to charge EVs. By controlling the charging to nights, the load factor of the grid would be improved, thus the usage of the grid would be more efficient. EVs may act as flexible loads or energy storage.

In general, a large amount of EVs in the system means that it would be possible to direct the charging at times when there is high electricity production from RES, and no demand for it from consumers. Controlled charging of EVs constitutes a form of variation management, i.e. a part of DSR as discussed. Controlled charging of EVs offers the chance of improving the efficiency of the electric grid [42].

3 METHOD

This project has mainly been carried out as a qualitative interview study. The report is to a large extent based on four interviews conducted with representatives from owners of a significant share of the commercial properties in Gothenburg. The representatives hold different positions in their respective companies, Environmental Manager, Project Manager, Energy Manager and Property Manager. The interviews have been undertaken either personally or over the phone. An interview with a representative from a grid company was also conducted over the phone in order to get their view on DSR. For interview questions, see Appendix 1.

The reason for using interviews as part of the base for the project was to get the perspective of the actors involved in the investigated issue. Advantages of this method include the potential to investigate how different measures are handled and received when realized in reality. Disadvantages include the small sample possible to use, which thereby only give some of the perspectives on the issue. Thus, the small amount of interviewed property owners cannot be regarded as a fully correct representation of the whole sector. The results may also be biased due to the lack of randomization and the fact that the actors involved might be too similar. The questions to the property owners could have been formulated differently to get more direct information about their view on DSR. The reason for not asking more direct questions regarding that area was due to the presumption that it would be a rather unknown area for the interviewed company representatives. The interview questions could also have been more detailed to facilitate the interpretation of the actual situation today regarding the different areas covered. Before starting up the project and investigating the available studies and material it was difficult to predict exactly what information that would be needed during the work.

As a complement to the interviews, a literature survey has been completed mainly to investigate the perspective of the grid side of the electric power system. The search has to a large extent been focused on finding out the view of the Swedish TSO regarding the current and future situation in the electric power system, and also their strategy for the development of the grid and the investigations done. Reports from the research company Elforsk have been studied in order to find information about the specific Swedish conditions and investigations done on how to handle the changes in the energy system.

4 RESULTS & ANALYSIS

In this section the results of the conducted interviews and the literature survey are presented. An analysis of the results is also included.

4.1 Demand Side Response in office buildings

A successful and efficient implementation of DSR in general is built upon that both electricity customers get enough incentives to move loads and that these incentives reflect the situation in the electric grid [18].

4.1.1 Interest for Demand Side Response on the grid side

In general, from the perspective of the system and the grid, a solution with an as predictable load as possible would be desirable to facilitate the operation. Some of the ways to implement DSR would imply the risk of not giving that predictability and might thus not be preferable if not adjusted. For a long-term solution the measures would have to be favourable for both the grid side and the consumer side [9]. Considering that the grid side are responsible for the reliability and security of supply, they have a large impact on the electric power system. The choice of how to implement DSR could thus be assumed to be highly influenced by their preferences. In general, more DSR in an electric power system implies more uncertainties for the operation of the electric grid. Applying DSR in a market is not as reliable as investing in more grid capacity for e.g. enabling larger amounts of RES or preventing congestion in the grid. DSR implies relying on actors which usually do not have the same motives or incentives for participating. There are no guarantees that those actors will stay in a DSR program long-term, increased grid capacity on the other hand will not disappear. Considering this fact, it can be questioned whether DSR actually can replace investments in grid capacity completely.

Different situations on different levels of the electric grid

A challenge when it comes to DSR and what economic incentives to use is that the situation in the grid might be very different at different levels of the grid. They might not be utilised close to their maximum capacity at the same time [10]. At certain times there might be high stress on the transmission grid and not in the distribution grid. If controlling loads in buildings based on the electricity price on Elspot, which is supposed to reflect the capacity of the transmission grid, there is a risk of causing overload in the distribution grid at certain times. The RTP business model might thereby not be preferable in the DSO's point of view. Thus, the efforts to improve system conditions locally and nationally may be in conflict with each other at times. For optimal system function it is therefore important to design DSR programs that handle both local and national conditions. However, increasing the electricity consumption at times with high production from wind power might be beneficial for the distribution grid if the wind power plants are connected at that level of the grid [18]. Otherwise there might be a risk of having to curtail the excess production or that it causes overload or congestion problems in the grid depending on the grid capacity. An important factor for the possibility of DSR to facilitate integration of intermittent RES is that the possible load to move in that area is of the same order of magnitude or larger than the production [24]. The problem with lack of correlation between requirements in the distribution grid and the transmission grid could be facilitated by combining RTP with other forms of DSR, or setting the electricity price more locally [22].

From the perspective of the DSO, DLC could be assumed to be preferable instead of RTP since it gives more predictability and the possibility to control the loads fully according to the needs of the distribution grid. Load management by the DSO have been shown to give a flat load curve as the most desirable when opting for the best solution in their point of view [22]. The AMI system could be used to control loads in a building and be the connection to the grid, letting the DSO manage different loads in a coordinated way [43]. However, the preferable implementation method is also affected by what purpose the DSR is supposed to fulfill. To function as a reserve for unexpected changes in the power balance, DLC could be assumed to be suitable as it offers a predictable and fast response [10]. The primarily need for DSR for DSOs could be expected to be for local congestion management, while it is probable that the most important use of DSR for TSOs will be for system balancing [11].

DLC would imply a reduced degree of freedom for a property owner. Assuming that the electricity market works as a market economy, it is likely that if there are enough incentives for grid companies to reinforce DLC they would be able to formulate a business model that would make it beneficial enough for a property owner to want to participate. From the property owner's point of view, one possible advantage of DLC, if a fixed compensation is used, compared to RTP could be that it implies an increased predictability of how much that could be earned on the DSR contract. This could be assumed to be desirable for companies.

Initiatives on the grid side

To ensure the reliability and the capacity balance of the electric grid, the Swedish TSO considers several methods. Increased flexibility on the demand side along with investments in transmission capacity for import, energy storage and also the addition of controllable electricity generation are seen as important measures to realise [4]. DSR is also included in the new grid codes from the European Network of Transmission System Operators (ENTSO-E), i.e. regulations which applies to the European energy sector [7].

In Sweden there is currently a law regulating that the Swedish TSO is responsible for acquiring a power reserve. The objective is to decrease the size of this power reserve gradually and replace it with increased market driven DSR. The time for this phase out has been postponed several times due to the fact that the capability of the market for DSR has been considered insufficient. The responsibility for balancing the grid is scheduled to be overtaken by the actors on the electricity market after the year 2020 [9].

The Swedish TSO is at present working on increasing the share of consumption bids on the balancing power market, i.e. actors that get paid for reducing their electricity consumption when there is not sufficient amount of production to cover the demand. The main driving forces for this review are the increasing amount of wind power in the system, the introduction of areas with price differentiation in Sweden which made it clearer that there is a lack of regulating bids in SE4 and the phase out of the power reserve in the year 2020. One of the changes discussed is to reduce the minimum bidding volume for load reductions to enable smaller actors to take part in the market. This limit was first decreased from 10MW to 5MW in SE4 due to the lack of regulating bids in that area [20]. The same change was then implemented in the other areas [44]. This could imply that by e.g. aggregating several buildings, they could constitute one of the actors on that market. Thus, this would give incentives for property owners to take part in DSR. However, more DSR on the balancing market implies unproven solutions. It demands more administration compared to relying on a few larger consumers contracted as capacity reserves, which could be described as easier and safer [9]. Aside from more consumption bids on the balancing power market, the Swedish TSO is also aiming at introducing DSR in all parts of the Nordic electricity market [20].

The Danish TSO have developed a proposal on how to handle large amounts of wind power in a power system. The proposal is supposed to be a solution for situations when there is a lack of bids on the balancing market. It implies that the prices on the regulating market are announced in real time, which is supposed to enable small consumers to participate in the balancing of the Nordic market [20].

Incentives grid side

Current laws, regulations and price regulations imply that there are no economic incentives for grid companies to make their customers move loads. In general, a problem is that the regulations in the electric power system and in the electricity market today do not support DSR. One example is that it is not legal for grid companies to trade with electricity as it is desirable to differentiate between a competitive business area and one that is regulated monopoly. This implies that it is not possible for grid companies to trade with capacity reductions done through e.g. DLC [10]. This makes it more difficult to efficiently use DSR solutions. However, the Swedish TSO has a large impact on the electricity market since there are problems with congestion in some parts of the transmission grid. This has led to the differentiation of Sweden in four price areas, based on the relation between demand and possible supply in that area, as discussed. To be able to use the flexibility on the demand side to optimize the operation of the grid, the incentives for grid companies to participate must be increased [9].

4.1.2 Interest for Demand Side Response on the demand side

Today electricity consumers have the possibility to be charged per hour for their electricity use [45]. This would imply that consumers could react on the price and change their consumption. However, the price differences for different hours are generally too small to give enough incentives for consumers to change consumption pattern [4]. At the moment, the small variations in electricity price and the low electricity price in itself are not sufficient to motivate investments in DSR either. Whether this will change or not is depending mainly on two factors, extension of the transmission grid to other countries in Europe and investments in RES in the Nordic countries [6, 9]. Increased transmission capacity implies that due to the higher price volatility in e.g. Germany, more electricity could be exported at times with high prices and more imported when the price is low. Thus, it would also increase the fluctuations in the Swedish prices [6]. Higher price volatility might increase the possibility of implementing DSR [9].

The low price sensitivity seen in a majority of electricity customers today sets high demands on the flexibility of the production side [46]. Higher price sensitivity would reduce the amount of production reserves needed in the electric power system and is likely to give more stable and predictable price formation [47].

Generally, a more flexible and price sensitive demand side might also imply that it gets more difficult for electricity suppliers to plan for how much electricity they need to be able to deliver. As discussed further below, there is an increased risk that this requires purchasing and selling expensive balancing power. Larger imbalances in the system increase the risks and requirements for power reserves for system operators [9]. The possibility of predicting the actions of the demand side in different situations is difficult on individual level but significantly facilitated when looking at the aggregated consumer behaviour. This could also be assumed to imply that DSR based on the electricity price, such as RTP, could be an efficient and reliable method [10]. An EU project about RTP conducted on Bornholm has shown it possible to forecast the response, though with some uncertainty [48].

Aggregation of smaller loads is one solution discussed to facilitate the implementation of DSR for smaller consumers, as buildings in varying sizes [10]. Aggregators, i.e. companies which handle the accumulation of electricity consumers, could be one of the new actors in a developing electricity market where the demand side is more active and flexible in its consumption [18].

As the market is constructed today there are no given actors that could handle the types of DSR contracts that would be possible to implement. However, the most logical actor to give the signals on when there is a need for demand changes are the one selling the electricity, i.e. the trader or the one delivering the electricity, i.e. the grid company. The TSO and DSOs could in different ways have an impact on the functioning of DSR, e.g. subsidies for DSR solutions [10].

4.1.3 Choice of business model for Demand Side Response

Theoretically, controlling flexible loads in an office building based on the electricity price would imply reduced costs for the property owner, assuming it is a functioning system on the electricity market as well. RTP is a business model that could offer this possibility. With RTP, the potential profitability is rather clear in the property owner's point of view. This business model offers a large potential to give incentives for customers to reduce consumption when desirable in the grid perspective. RTP also has a high degree of simplicity which is assumed to be important for customers [10]. RTP contracts have been offered to large industrial customers in Europe and the USA since the 1990s. The business model has thus been proven before. The introduction of the AMI technology enables a large-scale implementation of RTP [49].

As electricity customers can be charged per hour and smart meters are standardized today, it would theoretically be possible for them to individually implement RTP without any actual involvement from the grid side, provided that there are incentives for them to do so. However, currently a large part of the installed smart meters do not have all functions required to handle RTP [22]. The other types of DSR business models demand more involvement from the grid side. RTP might thereby be the easiest way of implementing DSR in the first stage of introduction, which might also imply being done in a smaller scale.

Practical implementation

The actual implementation of RTP would be simple theoretically as the information about the electricity price could be communicated from the smart meter to the SCADA system in the building and finally to different loads [27]. The loads most suitable to be moved in an office building would be the ones that are related to the heating demand in the building, including ventilation, as discussed.

It is likely that both the grid side and the consumer side would benefit from a fully automated solution to move the loads and to avoid manual involvement. This applies especially to office buildings due to the large scale on the electricity consumption and the low rate of personal involvement. A fully automated solution increases the predictability of the load controlled. It also increases the convenience and simplicity for the consumer, i.e. the property owner in this case. The EU project conducted on RTP on Bornholm showed a better response for customers who had technical equipment installed to control the electricity consumption according to the price, compared to customers who were supposed to change their consumption manually [48].

The form of heating used in the building have a large impact on the potential loads to be moved. Heat pumps constitute a flexible load, especially if combined with accumulator tanks. Heat could be produced and stored at times with low electricity prices and used at times with higher prices. The possibility of using thermal storage has been shown to give significant economic benefits for both the customer and the grid company [50]. According to the interviews, some property owners already have or are considering changing to heat pumps instead of district heating due to their lower operational costs. This would thus increase the possibilities for implementation of DSR in these buildings.

Profitability for property owners

There is a large potential in delaying the start-up of the ventilation in buildings through changes in the control system. It implies low costs and it is simple technologically and organisationally. The reduction per building would not be that large but by aggregating several buildings the reduction could be significant [23]. As the loads with the highest potential of contributing in DSR measures also constitute a large part of the electricity consumption that is included in the operational costs of the building, there is a clear potential for property owners to reduce costs.

According to the interviews, the costs for the facility electricity are approximately 12-15% of the total operating costs for the building. However, the actual level of cost reduction needed to make property owners interested in taking part in DSR is hard to estimate. The rental market for commercial buildings in Gothenburg is rather favourable in the property owner’s point of view since the demand is higher than the objects available in that market. This could imply that the cost reduction would have to be significant to be interesting as a possible cost reduction is likely to require investments. Due to the market situation, the property owners could potentially, simply increase the rent instead of investing in lowering the operational costs, to increase profits. However, other incentives such as environmental profile and regulatory demands could presumably have an impact. Environmental profile also appears to be of high priority for property owners.

Technical implementation

The technical solutions for implementing DSR in office buildings already exist. DSR could be programmed as one of the operation modes used by the control system in the building. Currently, not all buildings have the most advanced systems. Installing them in all buildings would facilitate implementation of DSR as those systems imply better control [51]. Neither is it given that the smart meter installed could handle RTP or that the communication between the smart meter and the control system in the building exist. One important issue regarding the communication between the building and the grid appears to be in the actual building. The communication between the HVAC systems and the electrical systems in the building does not generally exist. In the perspective of DSR, it would be a clear advantage if these were controlled by one system. It is not mainly a technical problem but rather an organizational since the area of HVAC and electrical installations have no history of collaborating. In most cases there are not yet enough economic incentives to invest in systems that connect the two parts either. However, it is not the technical part that impedes the development in the area of DSR. It is rather the lack of economic incentives and the fact that the situation in the Swedish electric grid is not yet critical from an operational point of view.

4.1.4 Impact on the electric power system of chosen business model

Adjusting the electricity consumption using RTP would theoretically imply that the consumption is adjusted according to the system conditions. RTP has the potential of improving system performance during normal operation and not only peak load periods. RTP would enable a more facilitated integration of intermittent RES since their production volatility causes increased price fluctuations [18]. It has been demonstrated that RTP within the Nordic electricity market could potentially contribute to a large decrease in grid capacity investments and thus significant economic savings [52]. A risk associated with turning off loads during periods of time is the rebound effect it might cause when turned on again. It implies that, depending on type of load controlled, a peak of varying size might result from the load returning to normal operation. This could generate new peaks in the demand curve. However, this could be avoided if considered [53]. Considering the rebound characteristics of different equipment is important before an implementation of DSR [54]. As the rebound is proportional to the load shed, the first step should be to design the DSR program to minimize the load reduction while still meeting the demands of the electric grid. This could be implemented by only involving a subset of the buildings involved in the DSR program, which would imply a need for an aggregator or similar. The loads could also be brought back to normal operation more slowly, i.e. not immediately after the end of the DSR period. By this control strategy different loads would randomly return to full operation within a certain time span afterwards [54]. The last strategy might be the most feasible alternative for RTP.

Economic considerations

RTP could be claimed to be necessary for an efficient electricity market. From an economic standpoint the consumer price should differ from time to time, since the consumption and thereby the marginal cost of production varies [52]. For the grid side, RTP could also imply benefits as the consumption increases during off-peak load periods which thus increases the price at those times. This could infer that the profitability to invest in base load power is increased [10]. This would be positive in the system perspective as lower profitability for base load and intermediate load power plants is one of the challenges arising from a growing share of intermittent RES.

RTP will be positive for the system as long as the loads are merely reduced. However, if loads are moved in time in large scale it might imply challenges for the electric grid. Since the actors involved in RTP programs will move their loads to the same time when the electricity price is low, it will imply that they will create new peaks in demand at these times [22, 55]. These actions might thereby counteract the original purpose of DSR. It is therefore important that this is handled somehow, e.g. through some sort of regulation or modulation of the changes in demand by an aggregator [24]. If a large share of the load is engaged in RTP programs this will also affect the price formation since the load pattern will change.

Time of price announcement

The time of price announcement for RTP has a large impact on what effect it has on the market and for the electric grid. A large-scale implementation of RTP will require that this fact is considered and handled. Studies on RTP conducted in Europe, the USA and Singapore generally indicate that RTP would affect the peak demand significantly. Some of them assumed a short time lag between price announcement and implementation, in order to reach equilibrium between demand and supply without increasing the requirements for balancing power. Existing RTP programs usually announce prices one day ahead [22].

If the price is announced a short time beforehand there is less possibility for consumers to react on it [10]. It also implies difficulties for consumers as they will have to forecast the electricity price for the next day [22]. However, the potential of reflecting the supply and demand situation is decreased if the announcement has a too long time lag [10]. Using the day-ahead market price would lead to that lower accuracy in reflecting system conditions. If the scheduled demand is not considered in the day-ahead market there might also be a risk of increased need for balancing power [18]. The operation of the grid becomes more difficult if customers decide on how to control their loads after the prices are set. The BRPs thereby have to make forecasts on how customers will act. This gets complicated especially at the most important times, i.e. when the grid is under high stress. As there are no current regulations regarding this issue, an implementation of RTP would imply potential difficulties for the BRPs. From the grid side perspective it would thus be desirable that DSR is regarded during the price formation on Elspot. For the BRPs and the functioning of the electric power system it would be desirable with more regulations on the day-ahead market and that the BRPs are given control over how the flexibility on the demand side is used through legislation or contracts [9]. At a low level of participation in RTP programs, the problem of forecasting the changes in demand with day-ahead announcement might not be that significant. However, already at this level, it could have a negative impact on the distribution grid [18].

4.2 Small-scale solar power production on office buildings

According to the interviews, the opinions regarding installation of solar PVs appear to vary among property owners. Overall they seem positive. Some do not consider it profitable while others are planning to install them mainly to reduce electricity costs. Many of the property owners that currently do have solar panels on their properties, or are planning to install some, do it for profiling or marketing purposes rather than financial profit. The willingness to install solar panels for marketing purposes appears rather strong. The property owners planning for installation of solar PVs to reduce costs are considering storage solutions rather than feeding excess electricity into the grid since it is considered more profitable. Obstacles for installation of solar panels includes physical constraints such as lack of space to place the panels on, and that the direction of the roof preferably has to be at south to maximize electricity production and thereby profitability. Some property owners consider the installation too expensive, thereby preventing them from installing. Other property owners do not share that view but they consider the regulations regarding subsidies for solar power installation too complicated and they are awaiting clearer guidelines before installing them. Incentives for installation of e.g. solar PVs today seem to a large part be due to image reasons. It is an advantage for companies to have an environmentally friendly approach in business. This is good in the introduction phase but to get a significant installation of solar panels, there is most probably a need for it to become more profitable economically.

4.2.1 Incentives for installation of solar photovoltaics

The varying opinions from property owners of whether solar panels have enough profitability could indicate that solar PVs are on the verge of becoming profitable. Considering the rather good investment will in solar power seen in property owners, it could be assumed that there is only a need for small changes regarding the economic situation in installing, using and selling electricity produced from solar panels on a building to increase the implementation rate. Thus, the economic situation today is relatively favorable. The decreasing cost for solar PVs in recent years is one reason for making it feasible. However, the accepted payback period for installing solar PVs seems to be longer than normally desired. It could be regarded as positive that installations are done despite of that fact, and might show that there are more incentives than economical behind an installation.

The match in production and demand could make it profitable for property owners to let solar PVs produce a part of their electricity demand. This fact also implies that there could be an incentive for the DSO to encourage local solar power production to unload the grid. The highest electricity production from solar power also coincides with the period when there is a high cooling demand in office buildings. Thus, solar PVs could reduce the costs for cooling for the property owner. As mentioned, one potential use of solar PVs could be for hedging against variations in electricity price [37].

The profitability of solar PVs is also depending on the price for electricity since the profit of installing solar panels lies in the difference between the market price for electricity and the investment cost divided by the possible electricity production. A higher electricity price would suggest that the profitability would increase. Considering that an office building usually uses most of its electricity consumption during the day when the total consumption from the grid is the highest and thereby when the peaks in price occurs, larger variations in price would also give the potential of higher profitability from a solar PV installation. Another possibility could be to sell, either excess or all, produced electricity from the solar PVs during the periods of high electricity price. However, this would depend on what conditions the electricity could be sold to the market. In Germany where the installed capacity of solar PVs have had a fast increase since the introduction of the Energiewende, the fixed feed in tariffs used have made solar power production and RES in general profitable, as the tariffs have been well over market price for electricity. However, it has implied large costs for consumers as these subsidies have been financed by a higher electricity price [56]. The current price for selling electricity to the grid, compared to the price to buy, implies that it is usually more favourable to produce electricity and use it at that same location. Thus, grid parity could be reached rather early [24]. This suggests that the solar PV installation should either be dimensioned according to the maximum power consumption in the building at the period with highest production, or that it might be a potential for storing the excess electricity production. This also suggests that the potential challenge that might arise with electricity generation connected to the distribution grid might not need to be handled yet for a while for the DSOs, at least regarding solar PVs [57].

Challenges

One possible factor that might have an impact on the economic situation, and thereby the willingness to install solar PVs for property owners is the possible change in taxation laws regarding electricity production that is suggested to come into force July 1st 2016. This change implies e.g. that a limit on installed capacity is introduced for electricity production that is exempted from energy tax. The limit is proposed to be set to 255kW installed capacity per legal person. Applied to the investigated situation this would imply that property owners cannot have more than 255kW of solar power installed on all their buildings. This limit does not imply a problem for a single building. For large property owners and thereby potential large amount of installed capacity to cover the demand of their buildings on the other hand, this limit is likely to be reached. The change is supposed to harmonize Swedish regulations with EU regulations. This change could presumably be an obstacle for solar power installation in many cases. However, the Swedish government is keen on trying to find some sort of subsidy that will compensate for these cases due to the objective of increasing the amount of RES in the energy system [34]. As mentioned, information from the interviews suggests that a large barrier for installing solar PVs lies in the uncertainties regarding the regulations. It could be considered unnecessary that political decisions are constraining the development within this area. Especially since the political will is to increase the amount of RES in the energy system.

The electricity production from solar PVs is low when the highest electricity demand during the year occurs. This fact might reduce the potential incentives for the TSO, DSOs and BRPs to support installation of solar power as a means for reducing the demand and the losses from the grid. On the other hand, despite the demand being generally lower when the main part of the electricity production from solar PVs occurs, they do correlate which could imply that solar power could even out the daily demand from the grid, i.e. remove the daily peaks.

Seen from the current situation, increased installation of solar PVs on office buildings would be facilitated with clearer regulations regarding subsidies. Further price reductions for both the actual solar panels and the installation of them would presumably also be favourable. It could be assumed likely that the price for solar panels would decrease further, as the worldwide installed capacity of solar PVs is rapidly growing due to a number of reasons. The learning-by-doing effect and the increased demand usually result in price reductions. Increased variations in electricity price and a higher electricity price per se could also be assumed to increase the incentives for installation.

Technical implementation

The technical implementation of solar PVs already exists and is relatively mature, although there could still be problems related to the installation. The technical aspects of installation of solar PVs should therefore not constitute the main problem, at least as long as installed capacity does not exceed maximal load in the building.

4.3 Charging of electric vehicles at office buildings

Charging of EVs at an office building constitutes a possibility of increased flexibility in the electricity consumption in the building by using them in DSR measures and V2G services. According to the interviews, it is not common to have charging possibilities connected to the buildings. Slow chargers exist in a few places, often due to requests from tenants alternatively to enable charging of their own company cars. Fast chargers are less common due to their higher cost and more complicated installation. Some of the property owners are investigating or planning to install fast chargers in connection to some of their properties. However, they have experienced that the process of getting building permits to do so is complicated and time consuming. The threshold for installation of slow chargers appears to be low but the actual incentive for installation is not that high either due to the fact that there is not yet any substantial demand for it from tenants.

4.3.1 Implementation of electric vehicle charging

When installing chargers at already existing buildings it is important to ensure that the installations can handle the high currents during long periods of time that charging causes. Approximately 93% of all properties in Sweden are older than 20 years and thus the electrical installations are not of the same standard as today and not adapted to current conditions. However, the preconditions in Sweden for developing a charging infrastructure are good as there is already a rather extensive infrastructure for engine heaters that could constitute the foundation for slow charging [38].

Considering the relatively low cost for installation of slow chargers, the general threshold for installation could thereby also be assumed to be low. As fast and semi fast charging imply a much higher cost for the charger compared to slow charging, the economic incentives would have to be higher. The general user pattern of vehicles makes them suitable for DSR measures and V2G services as the majority of cars are parked for a long period of time. It also implies that there is a small risk of affecting the comfort of the user [18]. This applies well with the situation at commercial buildings, especially office buildings, which would thus imply suitable conditions for implementation.

From the grid perspective it would probably also be more beneficial with controlled slow charging since fast charging sets higher demands on the grid due to the high power consumption [58]. Slow charging also causes slower changes in the electricity consumption compared to fast charging, which is beneficial for the grid. Slow charging enables vehicles to be involved in DSR and V2G services. Aside from enabling adjustments of the electricity demand, controlled charging of EVs would also allow for a higher quantity of vehicles to be introduced without the risk of overloading the grid at times [59]. A possible challenge in using EVs for V2G services is the battery degradation that might be the result of a large number of cycles of charging and discharging. This could have an impact on the willingness of car owners to participate in these types of measures. Business models for using the EV charging for V2G services become more complicated than using them for DSR measures [41].

However, possible business cases for property owners, both for the benefits that a more flexible consumption could imply and for economic profitability, are built upon the fact that EVs constitute a significant share of the total car fleet. The low number of EVs in Sweden at the moment is thereby an obstacle [59]. A possible future increase in the amount of EVs could imply an increase in electricity consumption at office buildings if charged when parked. The introduction of new flexible loads that could be managed according to e.g. RTP could potentially increase the incentives for property owners to take part in DSR.

Technical implementation

The easiest and most inexpensive way of implementing charging of EVs in a property would be to install slow chargers as they use the same single-phase voltage as in the building. It is also expected to be the most commonly used method for charging of EVs. As mentioned, at office buildings, cars are parked for several hours which make it highly suitable for slower charging. To enable making use of the charging for DSR and V2G services, a charging which enable communication with the electric grid must be used [38]. To allow for best possible compatibility for future requirements, it would be desirable to comply with the Type 2 standard.

4.4 Combined solution

The combination of DSR, solar PV production and charging of EVs implies possible synergy effects both for the property owner and for the city, i.e. the grid. They all contribute to a more flexible electricity consumption, which as mentioned before, is assumed to be desirable in an electric power system with increasing amounts of intermittent RES and for total system efficiency.

In this case, from the perspective of the grid, both solar power production and controlled charging connected to a building is a part of a more flexible demand side as they give the opportunity of changing the electricity consumption pattern for that building.

Implementation in office buildings

The building can both be used to reduce the demand from the grid but also to increase the demand at times when desirable. EVs and heat pumps in combination with accumulator tanks would give the possibility of increasing the electricity use connected to the building.

Considering buildings with solar power production and participation in DSR, it would be likely to assume that local energy storage in the building would be favourable. Excess production from the solar PVs could be stored and used later. This could enable larger installations to cover a higher share of the electricity consumption, and a better possibility to avoid using electricity from the grid when the total demand is high. Synergies could also be created if involving charging of EVs. Excess electricity production could then be used for charging purposes. The same principle would be applicable for other loads in the building. This would increase the value of the solar PV installation.

Energy storage would be useful for heating purposes as well. A building heated by heat pumps could produce more heat when the electricity is sold at a low price and store it in an accumulator tank. Thus, the possibilities for implementing DSR in a building would be facilitated through the higher flexibility created. These synergies could reduce the costs for the property owner and facilitate the operation of the grid.

Aside from the synergies that could be created by combining DSR and charging of EVs, it could also imply some challenges. The owners of the EVs are expecting to get their vehicles charged when parked. If the building is participating in DSR and the price stays high during a large share of the day, charging of EVs that day would be hindered. Alternatively, the optimization of the load curve for the building would be impaired. Combining these measures also makes the operation of the building more complicated which might increase the risk of problems arising. It might also increase the requirements for education of the personnel involved in the building operation.

Technical implementation

The technical solutions for combining DSR, solar PV production and charging of EVs in a building already exist. The difficulties lie in other factors such as the actual combination of those areas, creation of new business models and that the electricity price and the variation are yet too low to give incentives for these solutions.

5 DISCUSSION

A smart building including the installed systems enables a more efficient energy use in the building. A reduction in consumption on the end user side of the energy system will imply that the reduction in the demand for primary energy will be even larger due to the losses in the energy system. A lower end user demand will also imply that the requirements on the energy carrier infrastructure, such as the electric grid, will be reduced. An overall reduced load curve, also naturally reduces the peaks in consumption, which would lead to reduced demand for peak load production and transmission capacity in the grid. This also implies that the first step for property owners must be to increase the energy efficiency in their buildings. Generally this also seems to have high priority for property owners. Adding the fact that a smarter control of the electricity consumption in buildings also contributes to more efficient electricity consumption in the whole city, imply that automated solutions in buildings could have several positive effects in the energy system.

The development within ICT, and the use of it in different areas, is likely to be a key factor to reach an optimization of resources and energy. This would not only create a facilitated everyday life for people but also a reduced human footprint in nature.

5.1 Changes in the energy system

The changes of the energy system and the society are hard to predict. The distribution of different energy sources in the system and if e.g. EVs will have a large breakthrough are uncertain. What is certain is that political incentives are driving the market towards more sustainable solutions in all areas. However, the exact response from the market is not given. Today the situation is clearly not critical enough and thus there is not yet any demand for solutions such as DSR. The unclear energy policy from the Swedish politics creates large uncertainties about what direction different actors should be heading for the future. It makes it difficult to make long-term investments which might be needed to make things happen.

One part included in the changes of the energy system is the expectation of more fluctuating electricity prices due to more RES in the system. As mentioned, larger fluctuations in the price imply better incentives to move loads to times with lower electricity price, i.e. when demand is low and/or production is high. When comparing the variations in electricity price between Sweden and a county like Germany with large amounts of wind and solar power, it is obvious that the variations are much larger there [6]. The incentives for the above mentioned measures to make the operation of the grid more efficient would thereby be higher.

An increasing share of small-scale electricity production and EVs increases the complexity of the electric power system and might imply challenges aside from possibilities. The higher complexity can be facilitated through the use of more communication in the grid, i.e. having a smarter grid. On the other hand, more ICT in the system in itself implies a higher complexity and dependence on correct functioning of all parts. This also increases the vulnerability of the system. The development within the electric power system and the society increases the possibilities of connecting different parts of the energy system. EVs are one of the areas that can contribute. New approaches when it comes to urban planning could also potentially increase the possibilities of connecting different areas. More interconnections create increased potential of synergy effects and a more efficient system with less resource use. Thus, it brings the society one step closer to sustainability. However, increasing the interactivity between different actors in the energy system implies, apart from possible synergies, also increased complexity that might increase the risk of faults.

5.2 Building related issues

In an office building there are usually different actors responsible for the installation of equipment in the building and the actual use of it. Property owners installing more efficient equipment are thus not guaranteed to get benefits of it themselves, but merely their tenants. It is thereby an obvious risk that there is a problem with incentives. On the other hand, measures that reduce the costs for facility electricity will lower the costs for the property owner, thus possibly giving incentives for installation.

A major challenge in this type of implementation is the need for collaboration between different sectors that have no history of collaborating before. The organisational part might imply difficulties. The responsibility issues and how to make it profitable in one-way or another for all parts involved are factors that have to be taken into consideration.

Regarding the technical systems in a building there is still a problem that it might not exist a superior system for all the systems. There are barely any incentives to have one although it is possible technically. Often there is a control system for HVAC and for lighting but they do not communicate. This is likely partly driven by traditions and the fact that individual companies want to sell their own products. New regulations might be a solution in order to facilitate implementation of DSR. However, the most important loads for DSR measures are, as mentioned, related to the heating demand of the building, i.e. controlled by the HVAC systems. This could imply that at least in the introduction phase, it could be enough to connect this superior system with the information about the grid condition from a smart meter. Not all office buildings have the latest most advanced technological systems installed due to the costs or construction year. DSR might imply a new reason for installation of those systems, except the possible reduction in energy use. Thus, there might be more incentives for this type of installation and thereby increase the chances of it actually being implemented.

According to the interviews some property owners offer so-called *Green rental agreements* to their tenants, meaning that tenants agree on tougher control of the electricity use in the building to reduce total energy use. The fact that there is a demand for that sort of agreement might imply that there could also be a possible demand for DSR, locally produced electricity and charging of EVs in a controlled way to contribute to a more efficient system. Adding other incentives than just economic profit might imply that the profitability demands to be fulfilled to take part in DSR might decrease. Energy efficiency and environmental profiling are two important areas that could increase the incentives for DSR.

The possible impact DSR could have on the indoor climate if ventilation and heating loads are controlled is a challenge to be handled. Considering the different incentives for DSR and indoor climate respectively there might be a risk of conflicts of interests between the property owner and the tenant.

As smart phones and other smart everyday technological equipment becomes more and more common among people in general, the knowledge, interest, experience and demand for smart solutions in general is likely to increase. It could be assumed to lower the threshold for implementation of smart solutions in all areas, including buildings. It is more and more taken for granted that things should function in a smarter way in society.

The interest to invest in the mentioned different kinds of solutions is rather uncertain. There might also be a difference between smaller and larger actors in that area of properties. The companies interviewed in this report are all large actors. It could be assumed that smaller companies, or certain company structures, would have higher demands on profitability for investing in new technological solutions.

5.3 Ethical issues

The ethical aspect is applicable when it comes to the potential impact on the comfort and convenience of the people working in the building. If e.g. heating and ventilation is controlled according to DSR this might be impaired. As discussed, they will not have any impact on such decisions either. The decisions on reducing those loads will mainly be based on economic profitability and thus the user perspective might not be enough considered.

As the smartness of applications and equipment increases the amount of personal data stored, possibly available for anyone to see, also increases. In the case of managing loads in a building, data is collected about routines and habits regarding the electricity use in the building, i.e. the business going on in the building. This would potentially imply that if this data is analysed by the wrong actors, it could be used for the wrong purposes and thus imply a security risk. The development of the related security might not happen as quickly or be enough considered. Thus, this type of automation might both increase the security risk and impair the personal integrity of people involved.

In general, when it comes to automation of different processes and technical equipment, the monitoring of the people involved increases. It could be argued that unless you have something to hide, this is not a problem. However, principally it could be considered wrong. In the case of automation of buildings and the electricity use, the majority of the people affected by this have no choice, whether they want to be part of this or not, as they are merely tenants and employees. Thus, the need to handle the integrity issue adequately will presumably increase also when it comes to the electricity consumption in buildings.

Many people accept the general increase of supervision in society today due to the advantages it brings when it comes to convenience, or simply the lack of knowledge about it. It could not be assumed likely that many people would trade the increasing amounts of ICT in society for higher personal integrity. This increases the importance of actually considering this issue when designing systems and equipment.

6 CONCLUSIONS & RECOMMMENDATIONS

The conclusions of the project and recommendations for property owners and for further studies will be presented below.

6.1 Conclusions

RTP would be a beneficial way to implement DSR in office buildings in Sweden as it offers simplicity in implementation, a clear business model and an evident potential profitability for the property owner. However, current variations in electricity price and the electricity price itself are too low to create enough incentives for implementation. Other areas such as energy efficiency in buildings and environmental profiling are important to increase the incentives for DSR in general. RTP have the potential to enable consumption to be adjusted according to the system conditions. It offers possible improvements of system performance during normal operation, not only during peak load. RTP could facilitate integration of intermittent RES as their production volatility causes increased price fluctuations. However, RTP also implies a risk of creating new peaks in demand and affecting the price formation. The time of price announcement for RTP is an important factor to consider as it will have a large impact on the system. To better reflect the system conditions RTP could be combined with other forms of DSR. RTP and DSR in general seem to have support on the grid side of the system theoretically. However, there are currently not enough incentives for the grid side to support implementation and additionally there are several laws and regulations that impede such a development.

The interest to install solar PVs on office buildings in Gothenburg appears rather high. Solar power could be close to reaching grid parity, considering the general high rate of installation. The interviews also suggest that there could be a trend seen among property owners as they are considering installation due to economic profitability, not only environmental concern. Solar PV installation could however be facilitated through clearer regulations regarding subsidies. Further reductions of the costs for solar panels and installation could increase the installation rate. A higher electricity price and larger variations in price could also in this case be assumed to give more incentives for installation.

Slow chargers could be assumed to be the most feasible way to implement EV charging at office buildings. The general long periods of time for parking and the possibility to use slow charging with a charging mode that communicates with the electric grid and thereby enables DSR and V2G services, constitute the main reasons. However, the share of EVs in Sweden and Gothenburg is yet too small to give incentives for property owners to install large-scale charging stations in connection to their buildings. Still, there is already an interest for small-scale installations.

There are a number of ways to create synergies and increase the flexibility in electricity consumption in office buildings by combining DSR, solar power production and charging of EVs. The production from the solar PVs could enable a reduced need for electricity from the grid at times with low total production and/or high demand. Charging of EVs could do the opposite if desirable. EVs as well as e.g. accumulator tanks could also be used as energy storage to be able to store energy at times when the solar PVs have high production or the electricity price is low.

6.2 Recommendations for property owners

As a property owner independently could implement load management based on the electricity price and that it is technically uncomplicated, it could be recommended to, as a first stage, investigate incorporating RTP in the environmental management within the company. That would correspond to the function that e.g. solar PVs have had for some time, showing environmental awareness and that the property owner is at the forefront of that field. The real cost benefits could come as conditions change in the electric power system and in society.

It is likely to assume that the amount of EVs will increase in the years to come and that the need for charging stations will be significant. It could therefore be advisable to investigate solutions for large scale installation of EV chargers including ICT, in connection to the building.

6.3 Recommendations for further studies

Currently there are studies conducted on required cost reductions to make private customers interested in DSR. Investigations on what cost reductions that would make commercial customers interested in taking part of DSR would therefore be useful.

To facilitate an implementation of DSR, it could also be recommended to investigate what variations in electricity price that would be needed in order to increase the interest for DSR among commercial customers.

The increased uncertainties that relying on smaller customers engaged in DSR bring, imply that there could be a need for more investigations on the required number of customers involved to secure the operation of the grid.

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APPENDIX 1

Interview questions – property owners

1. How large share of the total costs for operation and maintenance does facility electricity constitute?
2. How do the electricity contracts in your properties look like (towards your tenants)?
3. What is the largest obstacle for installation of smart control in a building?
   a. What payback period does it take for you to install in new equipment within building automation?
4. What is your view on installation of solar panels? Do you see any obstacles besides the investment?
5. What is your view on charging of electric vehicles connected to the property? Do you see any obstacles besides the investment?
6. What does the relationship with your tenants look like? Do you get any particular requirements from your tenants? Do you have any particular requirements on your tenants?

Interview questions – grid company

1. What is your view on the development of the energy system with an increasing share of RES and decreasing share of thermal power?
2. How do you (plan to) handle increasing amounts of RES in the electric grid?
3. What is your view on DSR?