Possibilities for battery storage in a rapidly changing energy system

How will power tariffs affect profitability of residential battery storage?

Jorunn Cardell & Elin Öhman

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Dokumenttitel och undertitel

Möjligheter för batterilagring i ett snabbt föränderligt energisystem
– Hur kan effekttariffer påverka lönsamheten för batterilagring i hemmet?

Sammandrag

Det svenska elnätet är i behov av stora investeringar och flexibilitetsåtgärder för att upprätthålla ökad efterfrågan på energi och effekt, samt ökad andel variabel förnybar elproduktion. Ett sådant tillvägagångssätt är det ökade införandet av effekttariffer för småkunder bland svenska nätoperatörer som syftar till att uppmuntra slutkonsumenter att utjämna last. Med batterilagring i hemmet kan konsumenter minska sitt nyttjande av effekt, maximera användning av egenproducerad solel, samt bidra till flexibilitetsåtgärder på lokal nivå. Syftet med examensarbetet är att fastställa möjligheter, hinder och lönsamhet för batterilagring i hemmet under nuvarande förhållanden 2018, samt 2030, med avseende på flexibilitet och effekttariffer. De tillämpade metoderna triangulerar en inledande litteraturstudie, en kompletterande intervjustudie med några svenska nätoperatörer, en intresseorganisation i energibranschen och en representant för Miljö- och Energidepartementet, samt en teknoekonomisk fallstudie med fokus på batterilagring i kombination med solelproduktion och effekttariffer.

Resultat från litteratur- och intervjustudien visar att behovet av flexibilitet ökar med ökad efterfrågan av energi och effekt samt högre andel intermittent förnybar elproduktion. Mer dynamiska nätavgifter kan ge slutkonsumenter större incitament att bli mer aktiva gällande sin förbrukning, och bidra till lastförskjutning- och utjämning, samt att konsumenterna i högre grad betalar för den faktiska belastning de orsakar nätet. Föreslagna lagförändringar beträffande ökat batterilagringsstöd, fler möjliga stödmottagare och en tydligare definition i svensk lagstiftning av elektrisk energilagring kan påverka lönsamheten hos batterilagring i hemmet. Den teknoekonomiska fallstudien presenterar ekonomiska kostnader för det avsedda hushållet utan system, beräknat med nätavgifter för svenska nätoperatörer SEOM och Vattenfall Eldistribution, följt av möjliga ekonomiska besparingar som tillhandahålls av solcells- och batterisystemet. Diskonterade återbetalningsperioder bestäms för 2018 och 2030. För 2018 är diskonterade återbetalningsperioder för solcells- och batterisystemet höga, medan dessa minskat betydligt till 2030. Detta beror främst på uppskattade minskade framtida batteri- och solcellspriser, samt antagna ökade nätavgifter och ökad energiskatt på el.

Lagändringar gällande batterilagring behövs för att underlätta en större implementering av denna lagringsteknik i Sverige. En bredare introduktion av effekttariffer för småkunder bland svenska nätoperatörer kan få ekonomiska effekter för slutkonsumenter, beroende på kundens medvetenhet av sin effektförbrukning. Det kan ytterligare påverka efterfrågeflexibilitet bland konsumenter genom att ge ett ökat ekonomiskt incitament att flytta och utjämna last, vilket skulle kunna motivera en investering i batterilagring i hemmet. Fortsättningsvis har aggregatorer framtida potential att bidra till flexibilitet i elsystemet. Framtiden för batterilagring i hemmet anses därmed positiv tack vare fördelar såsom ökad flexibilitet samt möjligheten för slutkonsumenter att minska sina effektkostnader.

Nyckelord

Batterilagring i hemmet, effekttariff, flexibilitet, elnät, aggregator, effekt- och kapacitetsbrist

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Possibilities for battery storage in a rapidly changing energy system
– How will power tariffs affect profitability of residential battery storage?

Abstract

The Swedish grids are in need of large investments and flexibility measures in order to sustain increased power and energy demand and increased penetration of intermittent renewable electricity production. One such measure is the larger introduction of power tariffs among Swedish network operators for their small customer segment, intended to incentivize end consumers to level out load. With residential battery storage, consumers can reduce their demand charge, maximize use of self-produced PV electricity, as well as contribute to flexibility measures on a local scale. The purpose of the thesis is to determine possibilities, barriers and profitability of residential battery storage under current conditions 2018 and in 2030, with regards to flexibility measures and power tariffs. The applied methods triangulate an initial literature study with a complementary interview study with a few Swedish network operators, one interest organisation and a representative for the Ministry of Environment and Energy, along with a technoeconomic case study on battery storage in combination with PV production as well as power tariffs.

Results from the interview and literature study show that the need for flexibility increases with increased power demand and larger penetration of variable renewable electricity production. More dynamic grid tariff structures could provide consumers with a larger incentive to become active customers and contribute to load shifting and levelling, as well as further entail that consumers to a higher degree pay for the actual strain they apply on the grid. Regulatory changes regarding increased battery storage subsidy, more possible beneficiaries and a clearer definition in the Swedish Law of Electricity regarding battery storage could positively impact the profitability of residential battery storage. The technoeconomic case study presents economic costs for the considered household without system, calculated with regards to grid fees of Swedish grid operators SEOM and Vattenfall Distribution, followed by potential economic savings provided by the considered PV and battery system. Discounted payback periods are determined for 2018 and 2030. For the 2018 case, discounted payback periods for the considered PV and battery system are high, while for the estimated case of 2030, payback periods have significantly decreased. This is mainly due to assumed decreasing prices of battery storage and PV, and increased energy tax on electricity and grid fees in 2030.

Regulatory measures regarding battery storage are needed in order to facilitate a larger implementation of this storage technology in Sweden. It is concluded that a larger introduction of power tariffs among Swedish network operators could have an economic effect on residential consumers, depending on the level of customer activity. It could further impact demand flexibility among consumers by providing an increased economic incentive to shift and level out load, thus motivating an investment in residential battery storage. Moreover, aggregators have a future potential of contributing to flexibility measures in the electricity system. Conclusively, the future of residential battery storage is considered positive due to benefits relating to flexibility measures as well as the possibility of lowered demand charges for residential consumers.

Keywords

Residential battery storage, power tariff, flexibility, electrical grid, aggregator, power and capacity shortage

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Preface

This Master thesis is written during the spring of 2019 in Stockholm, Sweden.

The authors have largely written the report together. The authors of the report have received significant helpful feedback and guidance from supervisors Karin Ericsson and Marcus Wigren. Karin Ericsson, LTH, has provided important knowledge regarding report structure and securing that the thesis fills all necessary requirements. She has participated in several skype-meetings as well as personal meetings in Lund, and has read the report in segments and provided invaluable comments and feedback.

Marcus Wigren, CEO of battery supplier Nilar, has guided and provided the authors with sound advice and directed the authors to other knowledgeable employees within the company, as well as other contacts for further information retrieval. The authors have also been given workspaces at the Nilar office in Täby and have received compensation for their work.

The authors would further like to express their greatest gratitude to all interviewees taking part in the interview study, as well as everyone who has provided thoughts, comments and ideas for the thesis. Acknowledgment should further be given to all friends that have read the report during the work and offered constructive criticism as well as enthusiasm.

Additionally, the authors would like to thank all colleagues at the Nilar office and factory for providing extensive amounts of information and knowledge. Thank you for all the interesting discussions and inputs at the coffee machine.

Jorunn Cardell & Elin Öhman
Lund University, Faculty of Engineering
14th of June

Abbreviations

A – Ampere
Ah – Ampere hours
AI – Artificial Intelligence
BESS – Battery Energy Storage System
BMS – Battery Management System
Brf – Private Housing Cooperative
BTM – Behind-the-meter
CCS – Carbon Capture Storage
CHP – Combined Heat and Power
DoD – Depth of Discharge
DSO – Distribution System Operator
Ei – The Swedish Energy Markets Inspectorate[1]
EMS – Energy Management System
EU ETS – EU Emissions Trading System
EV – Electric Vehicle
FCR – Frequency Containment Reserve
GHG – Greenhouse Gases
Hz – Hertz
IEA – International Energy Agency
IoT – Internet of Things
ISO – Independent System Operator
kW – Kilowatt
kWh – Kilowatt Hour
LCOE – Levelized Cost of Electricity
LFP – Lithium Iron Phosphate
Li-ion – Lithium-ion
NEPP – North European Energy Perspectives Project
NiCd – Nickel Cadmium
NiMH – Nickel Metal Hydride
NMC – Nickel Manganese Cobalt Oxide
MEE – The Swedish Ministry of Environment and Energy
O&M – Operation and Maintenance
PV – Photovoltaics
REC – Renewable Electricity Certificate
RTO – Regional Transmission Operator
SAM – System Advisor Model
SEA – The Swedish Energy Agency[2]
SoC – State of Charge
Svk – Svenska kraftnät
TSO – Transmission System Operator

[1] Energimarknadsinspektionen
[2] Energimyndigheten

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1 Introduction

The Paris Agreement, the European Commission climate strategies and the goals decided in The Swedish Energy Agreement[3] from 2016, are all directly or indirectly supporting an almost fossil free future with high penetration of renewable electricity (Regeringskansliet 2016, United Nations Climate Change 2019, European Commission n.d.). The overall long-term goal of the Paris Agreement is to keep the global temperature increase below 2 degrees Celsius compared to pre-industrial levels and attempt to restrict the rise to only 1.5 degrees Celsius, in order to prevent catastrophic climate changes. The European Commission have several energy targets for 2020, 2030 and 2050, where the penetration of renewable energy in the EU should be 20 % by 2020, 32 % by 2030, and in 2050 the EU should be climate neutral. Sweden has set the goal of 100 % renewable electricity by 2040 and that there must not be any net emissions of greenhouse gases no later than 2045. If these goals are to be achieved, substantial changes regarding the energy system are necessary.

Simultaneously the Swedish electricity grid is facing difficult challenges within the coming years and is in need of extension and restoration (Sweco 2017). Sweco predicts that an estimated 1 554–1 638 billion SEK over the period 2017-2050 is needed to secure electricity supply and provide necessary flexibility in the system. An ever increasing penetration of variable renewable electricity in the Swedish power system is posing both challenges and possibilities. The future of the Swedish nuclear power plants is unknown and a considerably more variable electricity price is expected with more renewable production (Konsumenternas Energimarknadsbyrå 2019a). The Swedish power grid of today needs to be adapted in order to sustain the rising strain with increased e-mobility, smart digital systems and increased intermittent electricity production. It is clear that the future power system will be in large need of flexibility, thus balancing supply and demand of electricity combined with providing alleviation to the grid.

In order to combat this problem, different solutions are proposed, one of those being energy storage. Since a large portion of renewable energy production comes from intermittent and weather-bound energy sources, storage solutions are key to increase the flexibility in the production of electricity from renewable energy (Energimarknadsinspektionen 2016c, Power Circle 2016). Electrical energy storage in general, and residential battery storage in particular, can provide many different benefits in different parts of the electricity system (Energimarknadsinspektionen 2016c). However, the future prospect of residential battery storage and how it could be increasingly applied within the Swedish grid is still uncertain.

One measure towards increasing flexibility within the system is for the Swedish grid operators to incentivize their customers to shift and level out their use of power. This is one of the reasons why network operator Vattenfall Distribution will introduce power tariffs for their small customer segment in 2020, and why Ellevio is considering this tariff structure. A few smaller grid operators have already implemented power tariffs into their grid fee structure (Ny Teknik 2018). The question is how a larger implementation of power tariffs among Swedish grid operators could affect the economic incentive for battery storage?

1.1 *Purpose, Aim and Research Questions*

The overarching purpose of this Master thesis is to investigate possibilities, barriers and economic profitability of decentralised residential battery storage at present, and within the time frame of 2030.

[3] Energiöverenskommelsen

A partial objective of the thesis is to investigate how residential battery storage could alleviate regarding power and capacity shortage in the Swedish local grids. An additional partial objective is to examine how a larger implementation of power tariffs in Sweden will affect demand flexibility among Swedish electricity customers, and thus result in a possible increased implementation of residential battery storage.

The aim of the thesis is to answer questions regarding if and how residential battery storage systems can be increasingly utilized in the Swedish electrical system on a local scale, and what factors and aspects that are necessary in order for this to occur. Further it intends to discuss which economic parameters and policy instruments are important to promote economic profitability for batteries in order for this technology to be part of the solution towards a more flexible electricity system.

1.1.1 Research Questions

- How is the legal framework for residential battery storage in Sweden structured today, and which changes are necessary and possible within the coming years?
- How can residential battery storage increase flexibility on a local scale in the Swedish electricity system?
- How will an increased implementation of power tariffs affect the profitability of residential battery storage?
- Which are the major economic drivers and barriers for residential battery storage on the Swedish electricity market within a shorter and a longer time frame?

1.2 *Delimitations*

The thesis regards residential battery storage and the studied cases are set in Sweden. Environmental aspects regarding battery storage systems such as development, usage and recycling are not considered. It is further assumed that life time and technical specifications provided by the manufacturers are accurate as provided.

The authors refer to the studied type of battery as residential battery storage in the report. The batteries are assumed to be placed behind-the-meter (BTM) and connected to buildings. The batteries described in the case study are utilized in order to peak-shave, to cut power peaks, and thereby lower the demand charge for end customer.

1.3 *Disposition*

The thesis is structured with an introductory part presenting aim, research questions and purpose of the report, found in Chapter 1. Thereafter the applied methods of the different parts of the report are presented in Chapter 2, followed by Chapter 3, containing definitions and terminology. A theory section including Chapters 4-7 provides useful information on the contemporary and future market conditions surrounding and affecting residential battery storage, as well as on power tariffs and the Swedish electricity market. An interview study with chosen actors knowledgeable of the electricity market and battery storage is presented in Chapter 8. This is followed by a case study which presents relevant economic information on residential battery systems in combination with for example different power tariffs and battery costs, found in Chapter 9. The information retrieved from the literature study presented in the theory section, the interview study and the case study, is discussed and analysed in Chapter 10, followed by a method discussion in Chapter 11. Finally, in Chapter

12 conclusions regarding the research questions are presented alongside recommendations and propositions of potential future work within this field of study.

2 Methods

The authors have chosen to utilize a triangulating approach to the method of the report, and thus combining a literature, interview and case study. This is applied in order to provide a comprehensive view of economic profitability of battery storage in combination with power tariffs and how batteries can contribute to flexibility on a local scale in the Swedish power grid.

In order to gain extensive knowledge on the subject, an initial **literature study** was performed. Delimitations regarding age of sources were set with the intention of using as updated information as possible, mainly due to the fact that the battery storage market is currently rapidly changing. With respect to this, sources no older than 2014 were used. The database LUBsearch was used in order to access scientific articles on tariff structures and battery technology. Highlighted search words have been battery storage, power tariffs, grid regulation and demand flexibility. Government documents such as SOU 2018:76[4] and material provided by the Swedish Energy Agency (SEA) and the Swedish Energy Markets Inspectorate (Ei), were studied in order to determine for example the Swedish government's approach to battery storage and local flexibility measures in the electricity system. Substantial amounts of information on battery technology, storage possibilities and battery design were obtained through Nilar. The reference program EndNote was used to collect and store sources.

Through a semi-structured **interview study**, the authors collected extensive information on challenges regarding the Swedish power grid, current as well as planned power tariff designs and active measures towards demand flexibility. The interviews further provided information regarding what this means for residential battery storage within the coming years. The interviewees were representatives of a number of Swedish grid operators, such as Vattenfall Distribution Sweden, Ellevio, SEOM (Sollentuna Energi & Miljö) and Sala-Heby Energi Elnät, the Swedish Ministry of Energy and Environment (MEE) and Anna Wolf[5], Power Circle. The interviews were held at respective interviewee's location and were recorded. The interviews have been summarized. At uncertainties or need for explanations, the interviewees were asked to further elaborate on those questions. When further uncertainties appeared during the work of the interview study, the interviewees were asked to explain and elaborate via e-mail. The interviewees have read the study and have approved the presented information and quotes as correct.

Lastly, a **technoeconomic case study** was performed, focusing on possible savings and payback periods regarding power tariffs in combination with residential battery storage and photovoltaic (PV) production. The simulation program System Advisor Model (SAM) in combination with Excel were used in order to determine economic profitability, payback periods and the impact of power tariffs on the economics of residential battery storage. The case study further includes a sensitivity analysis.

[4] SOU = Statens Offentliga Utredningar

[5] Policy Officer Energy Systems and Smart Grids

3 Definitions & Terminology

Aggregator – An actor on the electricity market that has the ability to combine the use or production of electricity of several customers in a group, and use that aggregated volume in order to release already existing flexibility within the system

Battery Management System (BMS) – Controls charge & discharge of battery

Behind-the-meter (BTM) - Batteries referred to as behind-the-meter are placed behind the electrical meter at the end customer

Concession – Grid permit

C-rate – Specifies the speed of which that a battery is charged or discharged

Cycle – Process of charging and discharging battery

Demand charge – Part of grid fee cost relating to power outtake

Depth of Discharge (DoD) – Defines level of battery depletion

Electricity supplier – Company selling and supplying electricity

Electrolyte – Allows for conduction of electricity and is typically in liquid form in between the positive and negative electrodes within the battery

Energy fee – Part of grid fee relating to use of energy [SEK/kWh]

Grid fee – Fee paid to grid operator for utilization of grid

Grid operator – Actors who own and maintain the grids. Also referred to as network operator

Power tariff – Part of the grid fee relating to power outtake [SEK/kW]

Power fuse – Decides the amount of power that can be used at the same time. A too small power fuse breaks if too much electricity is used, but a larger power fuse is more expensive

Prosumer – Acts as both consumer and producer of electricity.

State of charge (SoC) – Battery charge level

4 Power grid & Electricity Market

This chapter contains brief information regarding the Swedish power grid and its different actors. It is included in order to provide the reader with a setting for where in the system batteries could be applicable. Further, the layout of the Swedish energy and electricity market is presented. Main focus is on the Swedish electricity mix, how electricity is traded, applied rules and regulations, different pricing models, different future scenarios for the Swedish energy market, as well as micro-production of electricity.

4.1 *Structure*

The Swedish power grid consists of three parts with different voltage levels:

- Transmission grid (220 – 400 kV)
- Regional grid (20 – 230 kV)
- Local grid (230 V – 20 kV) (Danielsson & Salqvist 2016)

The Swedish transmission grid is owned by the Swedish government and run and supervised by the Transmission System Operator (TSO) Svenska kraftnät (Svk), that has the responsibility to balance the grid at all times (Svenska kraftnät 2017). Svk administrates 15 000 km of power lines in Sweden with approximately 160 transformer stations. Electricity produced in power plants around the country are transported to the regional grids (Svenska kraftnät 2018c).

The regional grids connect the transmission grids with the local grids, and are also a junction for larger industries and production facilities. The regional grids are run and maintained by market actors, given permission from the government to do so according to concession (Energimyndigheten 2015).

The local grids in Sweden are also run under concession and it is the grid that reach the largest amount of end customers. They connect the regional grids with smaller production facilities and end consumers (Energimyndigheten 2015).

All power grids in Sweden are natural monopolies, meaning that the operators are regulated by Ei on the matter of profits. Network operator is also referred to as grid operator in the report (Energimarknadsinspektionen 2018c).

With the rapid changes facing the Swedish electricity grid, the traditional system with an electricity supplier, network operator and consumer is to be considered old-fashioned. The system is becoming more connected and new actors such as prosumers have been introduced (NEPP 2019). These commonly relate to household consumers with self-production of PV electricity.

4.2 *Electricity Mix*

Today Sweden mostly relies on hydro and nuclear power for electricity, with a penetration of 40 % and 39 % respectively, as seen in Figure 1. Renewable electricity production has seen a high increase during the 21st century in Sweden, where wind power stands for the fastest increase and accounts to 11 % of the electricity production today (Energimyndigheten 2019).

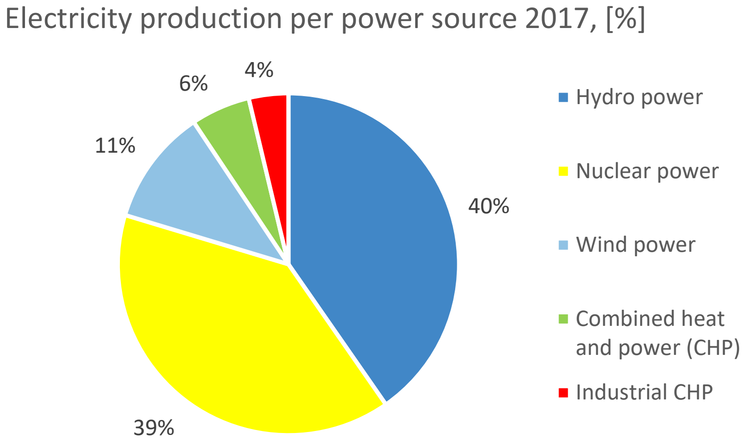

Figure 1 The electricity production per power source in Sweden, 2017. (Figure based on data from "Energy in Sweden Facts and Figures 2019", (Energimyndigheten 2019)).

The total electricity production in Sweden 2017 was 160.2 TWh. Figure 2 portrays the total Swedish electricity production per power source between years 1970 – 2017 (Energimyndigheten 2019).

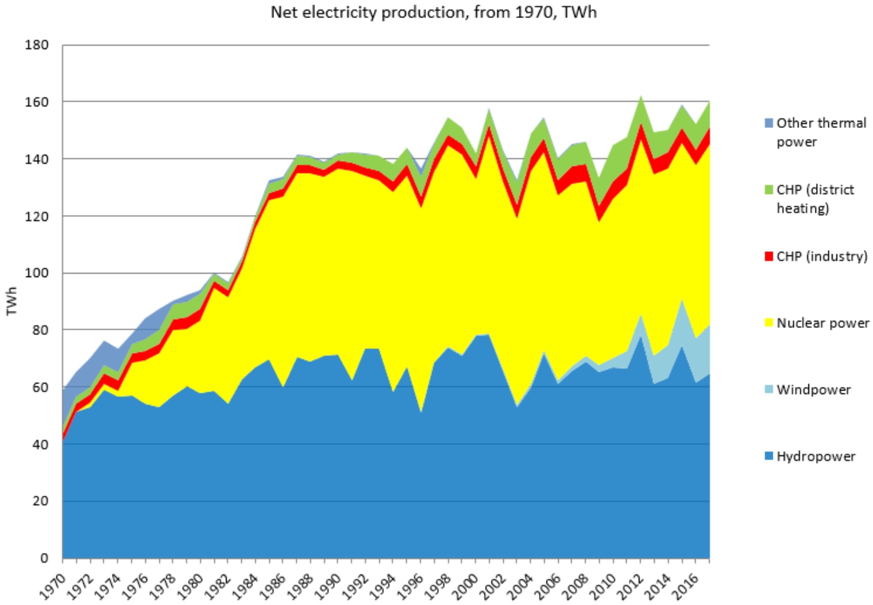

Figure 2 The electricity production per power source in Sweden between 1970-2017 (Energimyndigheten 2019).

In Figure 3 the total electricity use per sector for the same period is displayed. The usage including distribution losses reaches 141.7 TWh 2017. It is clear that housing and services accounts to the largest share of electricity used, even though Sweden has a substantial amount of energy intensive industry. To understand how the total electricity consumption in Sweden can decrease, it is thus important to understand what solutions for electricity reduction are available for the housing and service sector (Energimyndigheten 2019). With expected increased electrification of the industry and transport sector, the use of electricity within these sectors is likely to significantly increase.

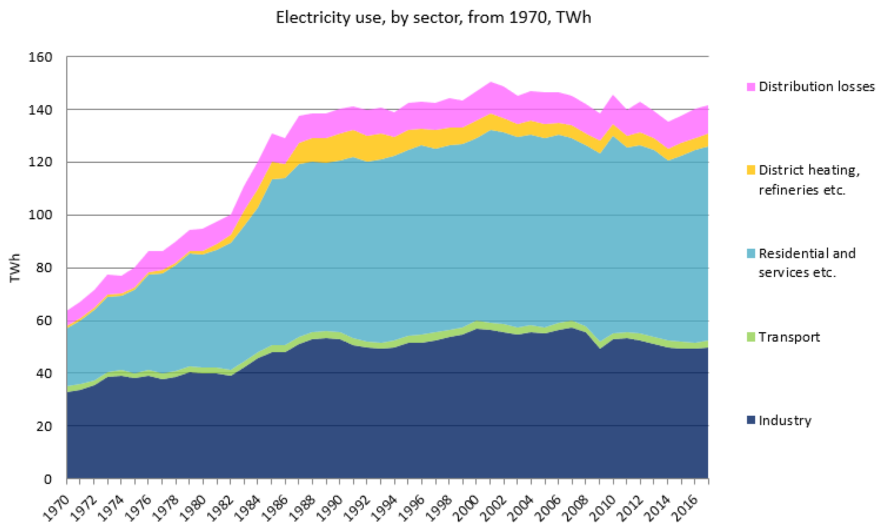

Figure 3 The electricity use per sector between 1970-2017 (Energimyndigheten 2019).

4.3 *Nord Pool and Nasdaq*

The electricity wholesale market in Sweden is part of a larger wholesale market that spans over the Nordic and Baltic countries, as seen in Figure 4 (Energimarknadsinspektionen 2018c). Additionally, the figure shows how the Nordic-Baltic electricity system is interconnected to the European electricity grid. Even though the electricity grids across Europe are somewhat integrated, all countries answer for their own operative management and that the national grid constantly is balanced. This is managed by the respective TSO, in Sweden Svk.

Figure 4 The Nordic-Baltic electricity market region (Energimarknadsinspektionen 2018c).

In Sweden there are four different pricing regions named SE 1 – 4, divided with regards to geography, see Figure 4. SE1 regards the northern part of the country and SE4 regards the southern part. The electricity prices in the different regions are mainly dependent on the transfer capacity of electricity to and from that region. More electricity is produced in northern than southern Sweden in contrast to consumption, which further affects prices (Svenska kraftnät 2017). In Figure 4 the green dotted lines portray transmission of electricity between SE 1 – 4 and surrounding countries.

In 1996 the Swedish electricity market was deregulated and turned into an energy-only-market, where electricity producers get paid by the hour for their sold electricity and not for their installed capacity. The electricity market system is divided in four divisions; the Hedging market, Day-ahead market, Intraday market and the Balance market, see Figure 5[6]. It is also possible to trade bilaterally directly between the actors on the electricity market (Energimarknadsinspektionen 2018b).

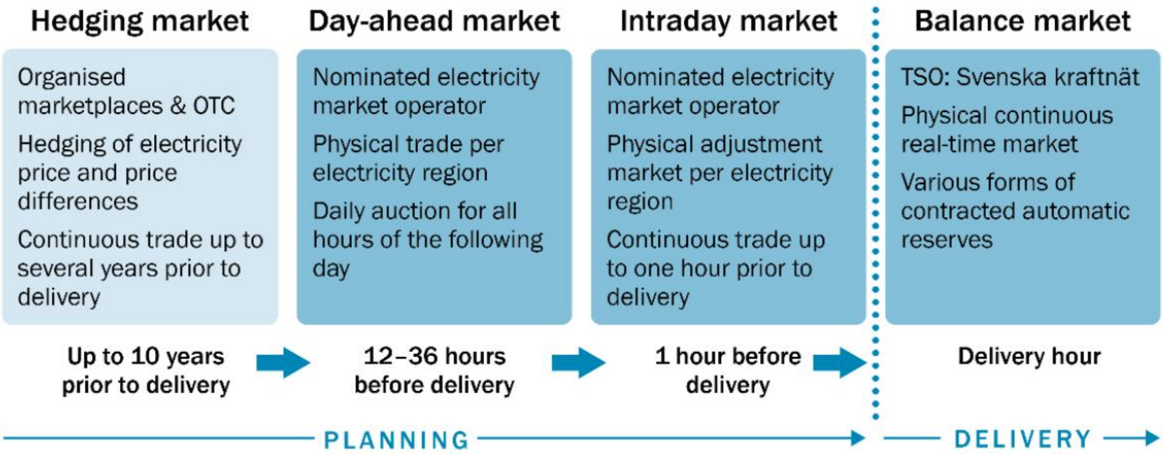

Figure 5 The Swedish electricity trading markets (Energimarknadsinspektionen 2018b).

The **Hedging market** is solely for financial trading, which takes place on Nasdaq Commodities and EEX[7]. On EEX it is possible to trade and secure financial electricity contracts for up to six years, and up to ten years on Nasdaq Commodities.

The **Day-ahead market**, also called the **Spot market**, is the main trading market for physical trading. Here trading of electricity supplies for the next day is done, 12-36 hours before delivery, and it is Nord Pool that manages the Spot market, which is called Elspot. On Nord Pool approximately 90 % of all electricity used in the Nordic-Baltic region is traded, whereas the rest is traded bilaterally. The electricity price on the Spot market is determined by the marginal cost of the most expensive production unit. All stakeholders that get acceptance are allowed to trade. This means that buying bidders, that have made bids higher than the established market price (where buying and selling bids meet), are allowed to buy electricity at the hour of trading. Likewise, all selling bids lower than the established market price, can produce and sell their electricity on their market at the hour of trading. To make the bids from different actors and production categories equal, all actors with acceptance will trade with the established market price and not with the price of their initial bid (Energimarknadsinspektionen 2018b).

The **Intraday market** is where the actors are given the opportunity to trade for balancing their power traded on the Spot market and is called Elbas. It opens at 14:00 the day before and closes an hour before the actual operating hour. In the Nordic countries the Intraday market is fairly small compared to what is traded on the Intraday market in other European

[6] OTC = Over the counter
[7] European Energy Exchange

countries and what is sold on the Nordic Spot market. It is mostly balancing providers that trade on the Intraday market (Energimarknadsinspektionen 2018b).

In Sweden the frequency in the grid should always be 50 Hz. When there is a deviation from this, some sort of regulatory measure is necessary. On the **Balance market**, automatic and manual reserves are traded by Svk together with the rest of the TSOs responsible for the regulatory reserves. The automatic reserves are procured by Svk and consist of one energy-related component and one capacity related component. The Nordic Regulating Power Market is the manual reserves market, where up- and down regulation are voluntarily bid on. Trading can be performed from two weeks before the start of the day of delivery and up to 45 minutes before the hour of delivery. The same type of marginal pricing is used on the Regulating Power Market as on the Spot market. Thus, all bids on upscaling of balance power will get the same price as the most expensive bid and prices on downscaling of balance power will get the same price as the cheapest bid. The smallest amount of power that can be bid on is 5 MW in SE4 and 10 MW in SE1-3 (Energimarknadsinspektionen 2018b).

A short summary of the different electricity trading systems for the Nordic-Baltic market are shown in Figure 6. Correlating this to Figure 5, it can be seen that the Hedging market consists of financial trade of electricity and that the Day-ahead market, Intraday market as well as the Balance market consist of physical trade.

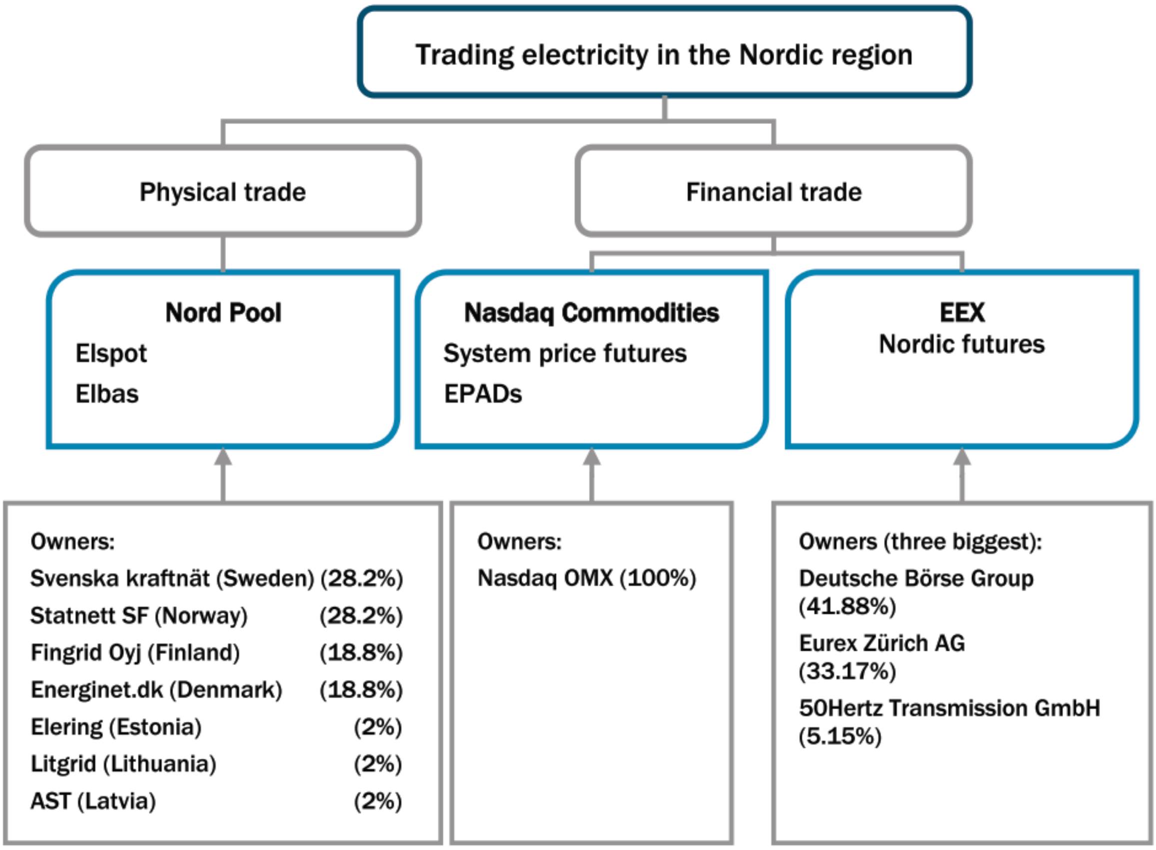

Figure 6 The Nordic-Baltic electricity market trading spots (Energimarknadsinspektionen 2018b).

4.4 *Rules and Regulations*

Rules and regulations for the electricity market affect possibilities and responsibilities for the actors involved. Rules that are relevant for the understanding and outcome of this thesis are presented in this chapter.

4.4.1 Regulation Period and Revenue Cap

The grid operators' fee for connection and transmission of electricity, is regulated by Ei via a cap on their revenue (Energimarknadsinspektionen 2017c). This is done since the grid operators are natural monopolies. Therefore, some sort of regulation is necessary for an overall fairness in Sweden's different grid regions and to secure that customers pay a reasonable fee for their use of grid services (Energimarknadsinspektionen 2016a).

Starting in 2012, the regulation of the grid operators' charges is done in advance and are valid for a period of four years. This means that the grid operators leave a proposal regarding their revenue cap in advance. Based on the results from the previous regulation period (i.e. if the grid operators earned more or less than the revenue cap), Ei decides on the new revenue cap for the coming regulation period. The revenue cap needs to be adequate in order for grid operators to not only cover the costs of, but also get return on their operation, maintenance and investments costs. However, it should not be larger than that the grid operators still manage to operate their business with reasonable prices (Energimarknadsinspektionen 2017c). The current regulation period of 2016-2019 is coming to an end and the new regulation period will be valid for 2020-2023.

4.4.2 Grid Operators Use of Batteries

As mentioned in Chapter 1, battery storage is seen as a possible source for increasing flexibility in the grid. Battery storage could also contribute with other system benefits on both distribution and transmission level in the grid (Energimarknadsinspektionen 2016b). Moreover, battery storage within the grid could postpone or prevent grid investments and restorations (Energimarknadsinspektionen 2016b, Roslund & Ärnström 2016). However, as of current conditions, grid operators are not allowed to use battery storage unless it is to secure electricity delivery at grid failures or to cover their losses (Energimarknadsinspektionen 2016b). This is due to that they are not allowed to sell, buy or produce electricity.

One alternative could be new business models where other actors, such as electricity users or suppliers, own and run the battery storages in the grid. Therefore the network operators can procure the service and hence get access to the benefits that battery storages can contribute with[8].

4.4.3 Necessary Bid Sizes for the Balance Market

In Europe the frequency in the grid should always be 50 Hz. When there is a deviation from this, some sort of regulatory measure is necessary. There are four types of Balance markets, the FCR-N[9], FCR-D[10], aFRR[11] and mFRR[12], where the first thee mainly relate to frequency and the last to the regulating power market. To enable participation on these markets,

[8] Anna Wolf, Power Circle. Interview 2019-03-12.
[9] Frequency Containment Reserve – Normal
[10] Frequency Containment Reserve – Disturbance
[11] Frequency Restoration Reserve – Automatic
[12] Frequency Restoration Reserve – Manual

different requirements are set regarding for example activation time and minimum bid size (Svenska kraftnät 2018a). Requirements for the different reserves can be seen in Figure 7. The considerable requirements on smallest bid size exclude smaller possible reserve markets such as households with battery storage, or smaller businesses and organisations with reserves.

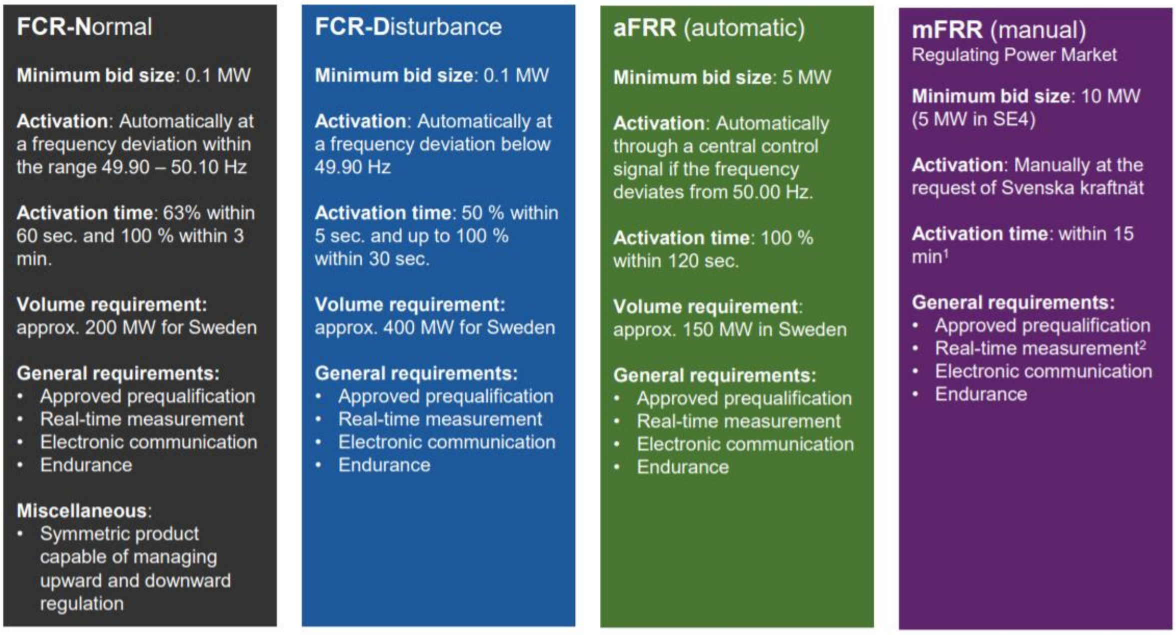

Figure 7 Overview of the different balance reserves and their requirements (Svenska kraftnät 2018b).

4.5 *Electricity Costs*

The total cost of electricity for household consumers consists of three parts: one share to the electricity supplier, one to the grid operator and one regarding tax and VAT. Renewable electricity certificates (RECs) are included in the electricity rate. For an approximate consumer of 20 000 kWh per year with variable electricity price, the cost allocation is shown in Figure 8 (Energimarknadsinspektionen 2018b).

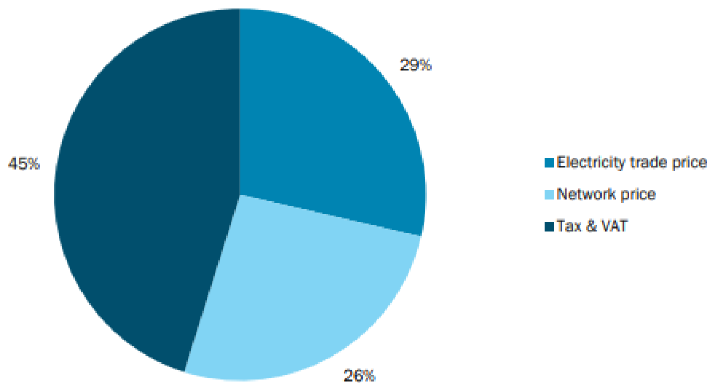

Figure 8 Electricity cost components for a 20 000 kWh/year electricity consumer 2017 (Energimarknadsinspektionen 2018b).

Most Swedish electricity customers choose between a variable or fixed electricity price, while very few choose hourly pricing (Energimarknadsinspektionen 2018b). For a residential customer with a consumption of 20 000 kWh/year in SE3, the total electricity cost with a variable electricity price contract was approximately 26 000 SEK, and approximately 25 000-26 000 SEK with a fixed price set over one year, in year 2017. According to Konsumenternas

Energimarknadsbyrå[13] (2019d) a normal Swedish household with a yearly consumption of approximately 20 000 kWh, had a total electricity cost of 29 000 SEK during the year of 2018.

Grid fees, commonly comprised of a variable component for electricity transmission and a fixed fee, have increased steadily over the last decade for residential consumers (Energimarknadsinspektionen 2018b). For a consumer with a power fuse of 20 A, they are currently slightly above 0.30 SEK/kWh, see Figure 9. The tax rate that electricity customers paid for electricity in 2018 was 0.4138 SEK/kWh, including VAT (0.331 SEK/kWh without VAT) (Konsumenternas Energimarknadsbyrå 2019b).

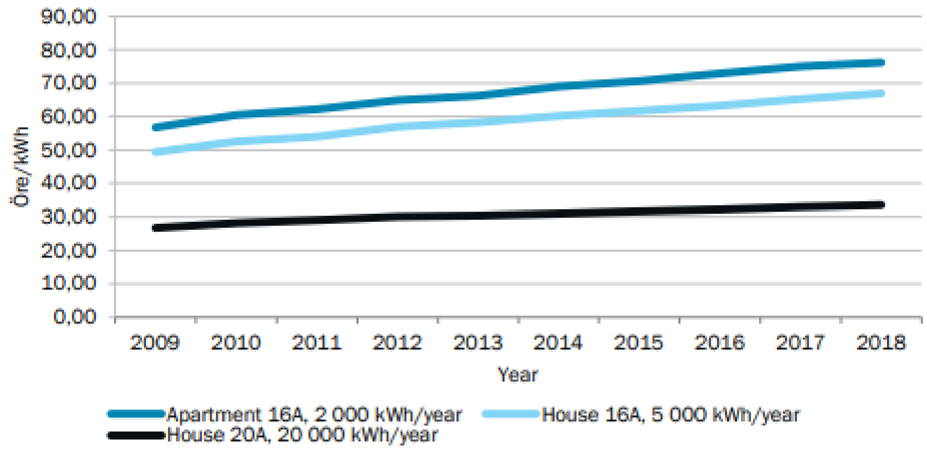

Figure 9 Development of total network charges for three types of residential electricity customers (Energimarknadsinspektionen 2018b).

4.5.1 Grid Fee

The grid fee looks different from one network operator to another and is the fee that customers pay for utilizing the electricity grid (Konsumenternas Energimarknadsbyrå 2019e). One part is normally fixed and the remaining part usually depends on the customer subscription and consumption. Often the grid fee consists of a fixed fee (SEK/yr), an energy component (öre[14]/kWh). In a few cases a power component (SEK/kW) is also included. The energy component and power component are also referred to as tariffs.

Three general grid tariffs are:

- Fuse subscription
- Time-differentiated tariff subscription
- Power tariffs (Danielsson & Salqvist 2016)

Fuse subscription is perhaps the most common grid subscription today and is designed in such a way that the customers subscribe to a certain level of current. A one-family house normally utilizes a fuse subscription of 16-25A. By switching to a lower fuse subscription, customers have the possibility to lower their grid fee (Ny Teknik 2018).

Time-differentiated tariffs as well as power tariffs are considered capacity efficient, since they are aimed at an efficiently use of capacity in the grid. The time-differentiated tariffs

[13] The Consumers Energy Market Bureau
[14] 100 öre = 1 SEK

usually cover a certain part of the day and are intended to incentivize customers to shift their electricity consumption towards times when the grids are less burdened. Power tariffs are set to incentivize customers to lower their power peaks, which has a stabilizing effect on the grid and allows the distributors to plan more efficiently, and perhaps also lower their subscription fee towards overhead grid (Danielsson & Salqvist 2016).

4.5.2 Power Tariffs

Power tariffs are defined as one part of the grid fee relating to the consumer's power outtake. Using many electrical applications at the same time creates power peaks. Customers pay for those power peaks over a certain period of time and it is often more expensive to use power when many others do simultaneously, such as during mornings or after work. Power tariffs are also referred to as demand charges.

A number of Swedish network companies have this type of tariff today, such as SEOM and Karlstad Energi. Larger distribution companies, such as Vattenfall Distribution and Ellevio have started investigating how an introduction of this type of tariff could be designed. Vattenfall Distribution plans to introduce power tariffs in 2020 which would affect a substantial amount of the Swedish grid customers (Ny Teknik 2018).

Power tariffs can be constructed in different ways and are based on the method of measuring a certain number of the highest power peaks for customers over a period of time, commonly one month. A mean value of these peaks is calculated which in turn decides the price for that period of time. This type of tariff means that customers who have the ability to be flexible are able to adjust their consumption, and thereby lower the demand charge. Customers without this ability will likely face higher charges[15]. Many distribution companies consider this pricing model to be fair in regards to that the consumers will pay an increased amount for using power when the grids are heavily exploited by many others at the same time. It is seen as a possibility for consumers to actively affect their power consumption and have a positive effect on the flexibility within the system (Energimarknadsinspektionen 2017a).

Network operator SEOM has a time-differentiated power tariff that also varies between high and low load, periods of the day and depending on season. Customers pay the power tariff on weekdays between 07-19 (SEOM 2019). As mentioned, Vattenfall Distribution will introduce power tariffs in 2020 and have set a preliminary tariff design. Their inclusion of a power tariff for their small customer segment would mean an increased possibility for their customers to affect their demand charge. It would additionally allow for an increasingly efficient use of the local grids by providing an incentive for load levelling (Nilsson, Sinclair & Watne 2019). The different tariff structures are presented in Figure 10. It should be noted that Vattenfall Distribution's tariffs are preliminary.

[15] Thorstein Watne, Vattenfall Distribution. Interview 2019-03-07.

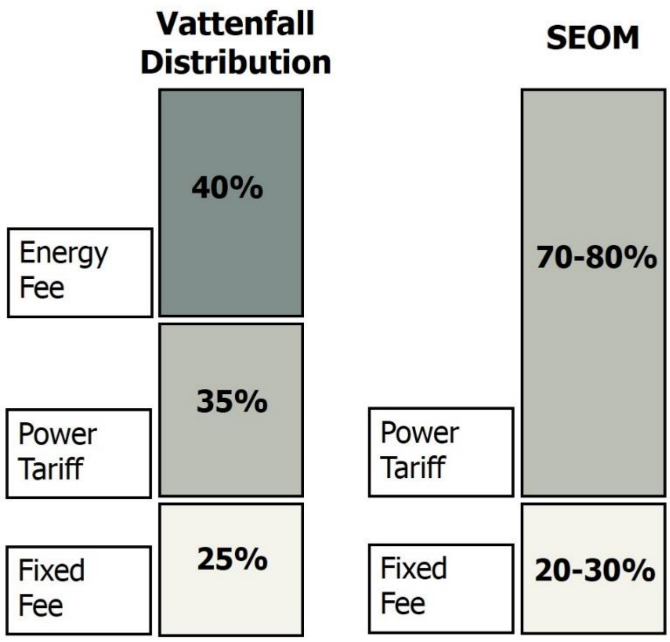

Figure 10 Grid fee components for the small customer segment for Vattenfall Distribution and SEOM. Figure based on preliminary data from Vattenfall Distribution (Nilsson et al. 2019) and SEOM (SEOM 2019b).

4.5.3 Supplier Centric Model

In 2015, Ei was given a government mandate to investigate changes needed in order for Sweden to introduce a so called supplier centric model, in combination with an information model. These two combined would be called a data hub[16]. According to Energiföretagen, this change could be the biggest change regarding the electricity system in Sweden since the deregulation of the electricity market (Lindholm 2017).

The idea behind the supplier centric model is that electricity customers only should be in contact with their electricity supplier. The customer therefore will only receive one invoice instead of the current two and should have no contact with the grid operator except in situations such as blackouts (Svenska kraftnät 2019a). This means that the electricity supplier will also handle the invoicing for the grid fee. According to Svk, the data hub will be a central IT-system handling all necessary data regarding the electricity market. It is aimed at providing a portal with information for customers, energy service actors, suppliers and distributors (Svenska kraftnät 2019b).

4.6 *Micro-Production*

Micro-producers of electricity are defined as producers that use more electricity than they produce. The power fuse could be of maximum 63 A and the production plant should have a maximum output of 43.5 kW per year (Varberg Energi 2019). Should the producers produce more electricity than they consume over the period of one year, they are instead called small-scale electricity producers and are thereby obliged to pay a connection fee. The micro-producers can further sell the excess electricity to an electricity supplier and obtain an economic compensation from the network owner, based on the grid service they provide to the grid (Vattenfall 2019b).

[16] Elmarknadshubb

4.6.1 Renewable Electricity Certificates

RECs were first introduced in Sweden in 2003 and fill the purpose of stimulating increased production of renewable electricity. For every produced MWh of renewable electricity, the producer receives one REC that can be sold, in order to generate an extra income. The purchasers of RECs are normally industries, as well as electricity suppliers who are obliged to do so due to quota obligation (Häger 2017). However, many micro-producers today do not choose to collect RECs due to administration costs from their respective electricity supplier (Stridh 2018).

4.6.2 Tax Reduction

A tax reduction on self-produced electricity is applicable for micro producers of renewable electricity in Sweden. This applies when the plant is connected to the same connection point as the home owner's building, and the power fuse is no higher than 100 A (Skatteverket 2019). The tax reduction amounts to 0.6 SEK/kWh. Micro-producers do not pay energy tax on electricity or VAT on the electricity that they use in their own building (Vattenfall 2019b). Additionally, micro-producers receive an additional small income for grid services[17], paid by the grid operator, for the relief they provide to the grid (Solkollen n.d.). It usually amounts to 0.03-0.07 SEK per delivered kWh to the grid.

4.7 *Future Energy Scenarios*

In order to take a look into the future regarding battery storage and this technology's possibility to contribute to flexibility, future scenarios presented by the SEA and the North European Energy Perspectives Project (NEPP) were studied. These future scenarios were chosen due to their relevance to the Swedish energy system, as well as their magnitude and objectiveness. The presented scenarios and analyses are speculative and intended to paint a broad picture of the future of what the Swedish energy system may look like, regarding energy demand and electricity production among others.

4.7.1 Future Scenarios from SEA

SEA presents four different future scenarios for the future Swedish energy system in the report *Four Futures* (2016a), where factors such as electricity consumption and production as well as the Swedish and European climate goals are taken into account. Estimated use and production of electricity are found in an appendix to *Four Futures* (Energimyndigheten 2014). The four scenarios are called Forte, Legato, Espressivo and Vivace. In the report, the following larger trends are accounted for in all four scenarios:

- Increased global warming
- Reduced poverty and increased level of education
- Issues regarding nature, environmental and health issues receive more interest
- New services available due to digitalization
- Continued quick technical developments
- Globalization connects countries in new ways
- Increased housing needs
- Increased competition regarding natural resources (Energimyndigheten 2016b)

For the first scenario, Forte, the major forces driving the energy system are low energy prices for the Swedish industry, economic growth and a strong delivery dependability within the

[17] Nätnytta

system. Forte is the scenario that focuses mostly on economic growth. The electricity production is estimated to be 209 TWh by 2050 in comparison to estimated electricity use of 176 TWh.

Scenario Legato regards a strong focus on decreasing the environmental impact caused by the energy system and working globally to solve the climate issues. Focus is also on a fair distribution of resources, with an electricity production of 180 TWh by 2050. Estimated electricity use is 148 TWh.

The third scenario, Espressivo, describes a future energy system where customers play an important role in contributing to flexibility within the system and wanting individual solutions. Decentralization and services are implemented, with increased small-scale self-production. The electricity production is 162 TWh and electricity use 145 TWh by 2050.

Scenario four is Vivace, intending to describe how Sweden can be an example of how economic growth and thorough climate action are compatible. Sweden becomes a world leader in developing green technology and sustainable innovations. Electricity production is 189 TWh and electricity use 176 TWh by 2050.

Figure 11 presents a comparison between the four different future scenarios. The considered areas are main priorities for the scenarios, governmental focus, type of energy system, penetration of renewables in the energy system, demand flexibility and solutions for levelling power peaks.

	Forte	Legato	Espressivo	Vivace
Main priority	Energy works as a fuel for growth and well-being	Energy is a globally limited resource to be justly shared	Energy is a means to express individuals' lifestyles	Energy is a trampoline for growth on terms dictated by the climate
State's focus	Needs of the industrial and commercial sectors	Fast climate adjustment	Individual solutions	Research and innovation
Energy system	Centralised	Renewable	Decentralised	High-tech
Share of renewables in the energy system	50 percent	Nearly 100 percent	75 percent	Nearly 100 percent
Demand-side flexibility	Limited	Medium to high	High in the own system	High and entirely automated
Solution to peak-load effects	Strategic effect reserves	Centralised governance of effect distribution	Individual/local responsibility for effect supply	The market solves effect situations

Figure 11 Comparison between the four different scenarios (Energimyndigheten 2016a)

4.7.2 Future Scenarios from NEPP

NEPP also has modelled and analysed future scenarios for the Swedish energy system, and their two main scenarios are presented in the report *Two NEPP scenarios* (NEPP 2018b). The two main scenarios are called Green Policy Plus and Climate Policy Mix, based on key trends such as the European energy and climate politics, technology development and development of the global energy system towards 2050. A substantial sensitivity analysis for the parameters that are crucial to the progress of the energy system have been performed. The scenarios are based on four global trends that describe the assumed evolution of the technical energy system and its surroundings. These four trends are:

- Political goals, policy instruments and other resolutions
- Technology development and accessibility to new technology
- Development of energy demand
- Price development and supply on the fuel markets (oil, coal, natural gas and biofuels)

The Green Policy Plus scenario has an increased focus on renewable energy, especially within district and electric heating. Two major incentives in this scenario are continuous substantial support to renewable energy in combination with quickly evolving technology. The European energy and climate policies are assumed to be dominated by support systems of renewable energy of different kinds. This will lead to low energy prices, partly due to technology development. The electricity production in Sweden 2045 is estimated to be slightly above 160 TWh (NEPP 2018b).

The Climate Policy Mix scenario instead focuses on reduction of greenhouse gases (GHG). It is based on a mix of European and Swedish political goals regarding GHG emissions, efficiency measures and share of renewable energy for 2020, 2030 and 2050, with a focus on GHG emissions after 2030. Possible options in addition to increasing the use of renewable energy sources are carbon capture storage (CCS) and nuclear energy. The electricity production in Sweden 2045 is estimated to be slightly above 180 TWh (NEPP 2019).

4.7.3 Electricity Price Developments

The electricity price that end customers pay in Sweden and the Nordic region is dependent on several factors, such as demand and supply in the considered region, the Nord Pool price of electricity, weather, REC prices, emission trading (EU ETS) and coal, oil and natural gas prices (Nordic Green Energy 2017, el.se 2019, Fortum 2019b, Fortum 2019a). The weather affects the price in several ways. Dry years often lead to low water reservoir levels and thus lower hydro power production, leading to higher electricity prices. Cold winters also affect prices, due to increased demand for heating, including electric heating.

The weather forecast in general affects electricity prices since it gives an indication regarding the estimated electricity production from wind, solar and hydro power. The Nord Pool electricity price is based on marginal pricing, which is described in more detail in Chapter 4.3 (Energimarknadsinspektionen 2018b). The highest price sets the price for all electricity that is bought at the moment, and thus if much electricity is needed and expensive energy sources such as coal are used, the electricity price will increase. A high electricity price could make more types of power production profitable due to increased income, and thus support systems, like subsidies, would not be needed for an expansion of such power production (Energimyndigheten 2016a). On the other hand, a low electricity price could lower incentives for households and industries to be energy efficient.

Konsumenternas Energimarknadsbyrå (2019a) predicts that a larger portion of variable intermittent electricity production will result in more variable electricity prices. It is further predicted that there will be higher peak prices as well as increased duration of price dips, due to that production cannot be planned unlike the electricity production from fossil fuels. It is further likely that there will be periods of prices close to zero.

SEA presents Figure 12 in *Four Futures* (2016a). The report estimates that all four future scenarios include an increased electricity price and the predicted price differences between the scenarios are small. This could be due to that the models used for the simulations in the report do not take the variations in intermittent production into account, as well as that Sweden is connected to its neighboring countries.

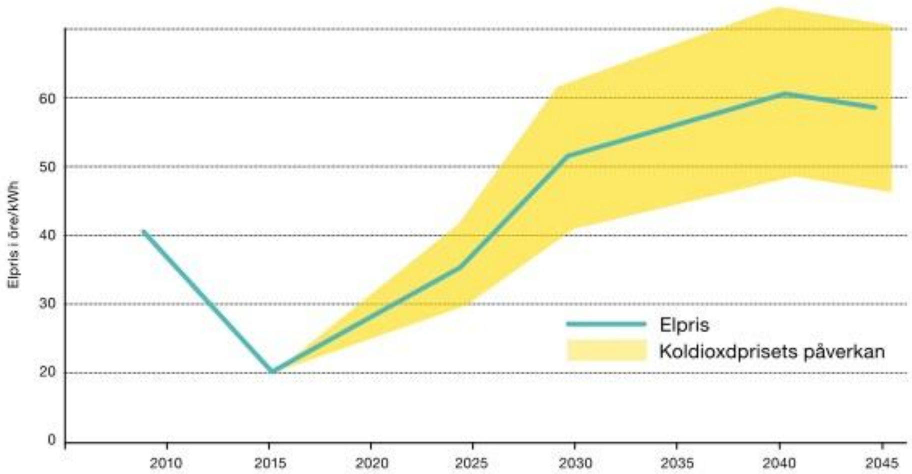

Figure 12 Modeled future electricity price development. Yellow area shows the effect of CO2-prices, blue line represents electricity price in öre/kWh. (Energimyndigheten 2016b).

Additionally, NEPP (2018b) presents estimated future electricity prices. Figure 13 shows three different price developments, based on weighted time mean (blue line), weighted after the wind profile (red line) and weighted power (green line). The left graph shows scenario Green Policy Plus and the graph to the right Climate Policy Mix. Electricity prices are in SEK/MWh.

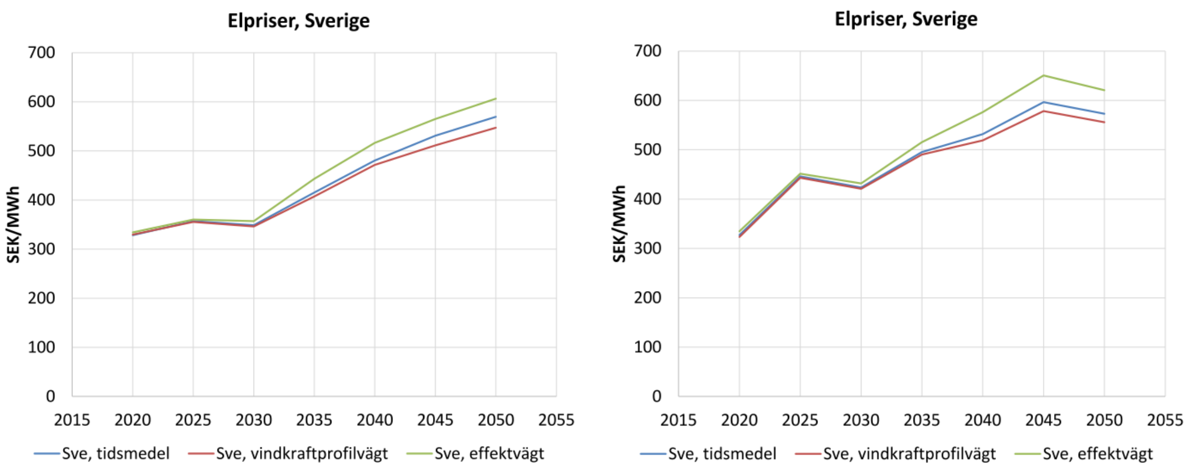

Figure 13 Three different weighing options for future electricity price development for NEPP:s two scenarios (NEPP 2018b).

5 Flexibility in the Power System

Flexibility is commonly described as need in order to balance demand and supply. In this context, it regards both flexibility within larger production plants as well as smaller decentralized measures that could be liberated by for example decentralized battery storage solutions (Energimarknadsinspektionen 2016b).

5.1 *Overview*

According to Ei (2016b), flexibility in the power system can be provided by demand flexibility, storage as well as by flexible production and has traditionally been handled by quickly ramping up and down power plants such as gas turbines. In Sweden hydro power typically fills that function. Flexibility can further be provided in the system by expansion of the grid network, i.e. by laying more cables and building overhead-lines. Figure 14 illustrates possible actions or means to provide increased flexibility in the system and during which time scales they are applicable. Energy storage and demand flexibility are measures that can be applied to provide flexibility within the hour.

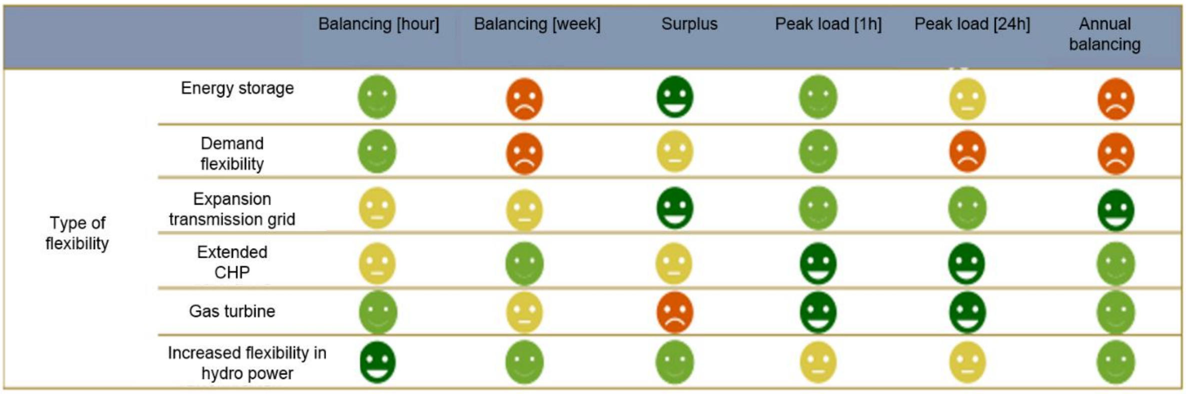

Figure 14 Different flexibility measures on different time scales (NEPP 2018a). Translated from Swedish to English[18].

Additionally, Figure 15 illustrates on which geographical system levels general types of flexibility measures are applicable. The figure shows that flexibility for transfer capacity on a regional and local level mainly is applicable on a time scale of minute to day. The need for flexibility for power on system level regards a shorter time frame, approximately sub-seconds to an hour. Thus, energy storage is a suitable option to provide flexibility for power and transfer capacity, as can be seen in Figure 14.

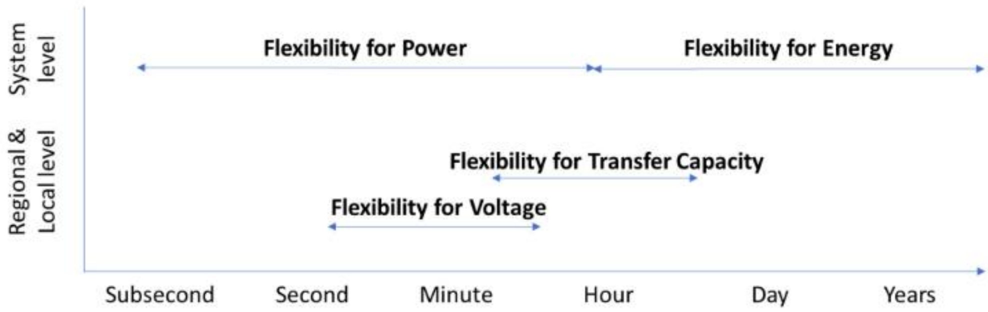

Figure 15 Flexibility needs on different system levels over time (Hillberg 2019).

Given the topic of this report, focus of this chapter will be on demand flexibility and how end customers with residential battery storage and self-production of electricity, commonly with

[18] CHP - Combined Heat and power

solar PV, can contribute to increased flexibility. One often highlighted possibility for addressing the problem of capacity and power shortage is that of utilizing already existing flexibility within the system. This can be achieved by incentivizing end customers to become more active in their own use of electricity and power through demand flexibility (Energimarknadsinspektionen 2017a).

5.2 *Demand Flexibility*

Demand flexibility is a flexibility measure that potentially could be of importance regarding shifting the demand for shorter periods of time, and is defined by Ei as:

> *"a voluntary change in the demand for electricity from the grid during shorter or longer periods, caused by some type of incentive".*
> (Energimarknadsinspektionen 2017a, p. 4.)

The different options of demand flexibility differ depending on who the consumer is and under what conditions the consumer needs electricity. Figure 16 shows these different cases. The first case (a) shows how consumers have the possibility to shift load to times of lower electricity prices. The second image (b) shows the option to lower load during peak load time while graph (c) shows how customers may increase their load during periods of low prices (Energimarknadsinspektionen 2017a).

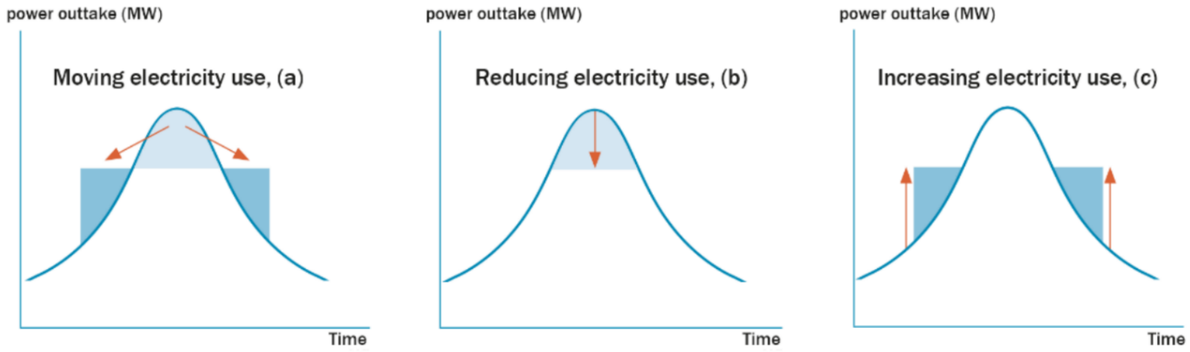

Figure 16 Types of demand flexibility (Energimarknadsinspektionen 2017a).

5.2.1 Benefits

According to Ei (2017a), demand flexibility could have several positive impacts on the system in terms of cost-efficiency, and point to the following factors:

- Contributing to maintaining frequency in the system
- Reducing the risk of power deficit
- Reducing price volatility and providing a more efficient use of production resources on the electricity market
- Contributing to more efficient network usage that may reduce losses, costs for overhead grids and the need for investments into new capacity in the electricity network (Energimarknadsinspektionen 2017a)

Ei also states that the actors on the electricity market that will face positive outcomes from an increased demand flexibility are consumers, grid operators, providers of energy services as well as producers of renewable electricity. Furthermore, electricity suppliers could be positively impacted by gaining knowledge of how their consumers use electricity. Positive outcomes of increased demand flexibility enable a more efficient use of resources, the possibility to avoid resource-heavy balancing actions, as well as avoiding local network issues.

As can be seen in the results from the performed interview study, see Chapter 8.3, many of the interviewees believe that demand flexibility could become increasingly important in the future and that, for the Swedish grid operators, could be important to work towards.

5.2.2 Barriers

In the same report, Ei further describes what currently are seen as barriers for increased customer participation on the electricity market. Some of those are, as mentioned, that customers do not have enough information nor interest to engage in demand flexibility. It is considered complicated and too large of an infringement on comfort. Another factor is that all consumers do not have access to hourly metering which is considered a requirement in order to utilize this flexibility measure. A third highlighted barrier is the fact that electricity customers find it difficult to compare grid tariffs. The report emphasizes that it is positive for demand flexibility that network operators offer a time-differentiated tariff along with a non-time-based tariff, but that it often is difficult for the customer to consider not only the choice of tariff but also the electricity supplier when comparing the optimal choice of subscription (Energimarknadsinspektionen 2017a).

Ei further concludes that hinderances for consumers to get paid for their flexibility in today's system are significant (Energimarknadsinspektionen 2016c). The discomfort that load shifting means for consumers, such as doing laundry during the night or moving other activities consuming electricity to hours when the grid is not very utilized, is still too high since the potential financial savings of doing so are negligible (Swedish Smartgrid 2019). Similar results are found in the interview study, see Chapter 8.3.

6 Challenges & Possibilities

This chapter describes current and future challenges and possibilities facing the Swedish power grid. As mentioned in Chapter 1, Sweco estimated in 2017 that the necessary investments for the Swedish power grid equates to approximately 1 500 billion SEK in order to adjust to a 100 % renewable electricity system in 2040 (Orring & Nohrstedt 2017). These are significant amounts and highlights the need for smart solutions and technology in order to postpone traditional grid investments. These investments normally amount to digging new cables, which is expensive and time-consuming. According to estimates from Svk, it takes approximately 10 years before a planned transmission grid cable is put into use (Ellevio 2019a). Power and capacity shortage are becoming real and urgent issues in certain areas in Sweden (Hardwick 2019). Additionally, for Sweden to reach 100 % renewable electricity production by 2040 an increase of solar and wind power is needed, as well as other possible sources like hydro power.

6.1 *Power and Capacity Shortage*

The definition of **power shortage** is that the amount of produced electricity cannot cover demand at a certain moment (Energimarknadsinspektionen 2018a, Ellevio 2019a). This can occur when for example several or all of the following circumstances apply:

- During cold winter days
- When no wind is blowing
- When there are restricted possibilities for importing electricity
- When nuclear power plants are not operating at full capacity

It is at these peak load hours that the problem of power shortage becomes real. During those times, Sweden has to import power from surrounding European countries or utilize the so called power reserve (Energimarknadsinspektionen 2018a, Ellevio 2019a).

The problem regarding **capacity shortage** lies in what is often described as bottlenecks within the grid and is something that often is highlighted in regard to new establishments such as data centres demanding large amounts of power, an increasing number of electric vehicles (EVs) and urbanization. These new establishments are not coordinated with how the grids were originally built, and therefore creates lack of power in certain regions. This is an issue on a local level, but also a large problem for the overhead national grid; there is just not enough room in the grid to transfer power from the northern parts of Sweden to growing cities further south (Åslund 2018, Ellevio 2019a).

SEA presents estimated future available power in an appendix to *Four Futures* (2017). The modelled numbers for the available power 2050 are here presented in Table 1. As can be seen, the available power will decrease in all future scenarios compared to 2014.

Table 1 Available power for SEA's four different future scenarios, and the benchmarked available power from 2014. Table based on data in Appendix "Key measures" to the report "Four futures" (2014).

	Forte	***Legato***	***Espressivo***	***Vivace***	***2014***
Available power [MW]	28 103	18 693	20 735	27 365	28 200

In NEPP:s *Two NEPP-scenarios* (2018b), the power demand in Sweden is presented, both for 2018 (grey line) and for the projected power profile for the two main scenarios Green Policy

Plus and Climate Policy Mix for 2040 (red line). As can be seen in Figure 17 the power demand [GW] is estimated to increase in the future, but further become more fluctuating, with foremost higher peaks. It is important to note that this is a projected prediction, and thus uncertain.

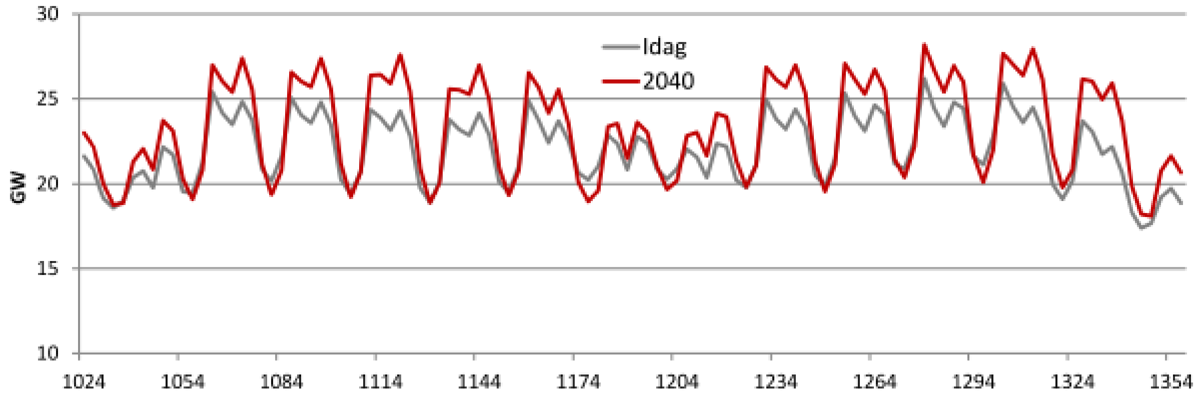

Figure 17 Power demand in Sweden for two weeks in February, as seen on the x-axis in hours. Actual values for 2018 (grey) and projected values for the main scenarios from NEPP 2040 (red) (NEPP 2018b).

With both modelled increased power demand as well as decreased available power in the future the problems regarding power and capacity shortages within the grid are not likely to disappear on their own and is thus of highest interest and concern.

6.2 *Customer Participation*

As mentioned, the current low level of customer activity and interest for demand flexibility depends on several different factors, such as an insufficient understanding of the subject and non-dynamic pricing structures for electricity, leading to low economic profit. Another obstacle is that customers feel that relevant subscriptions aimed at providing larger incentives for increased flexibility, are complex to understand and it is difficult to calculate the potential savings. Many customers are more interested in energy efficiency as a means to avoid increasing electricity costs (Energimarknadsinspektionen 2017a).

As described in Chapter 4.5, a rather small part of the total electricity cost is variable, which today does not incentivize customers to shift load. Ei is positive towards grid operators including a variable part in the grid fee, which could stimulate good behaviour among customers depending on design of tariffs. This would better reflect the actual cost of customers using the grid. Moreover, information is necessary regarding what possibilities customers have to impact their costs, savings and demand flexibility relating to a variable tariff. Tariff design needs to be clear and easy to understand for customers, in order to have any effect on customer behaviour (Energimarknadsinspektionen 2017a).

6.3 *Electric Vehicles*

The amount of EVs have increased significantly over the last couple of years in Sweden, as shown in Figure 18. The total number of EVs in the beginning of 2019 in Sweden was 71 189, with an increase of 52 % over the last year (Power Circle 2019). A prognosis for 2030 estimates a total penetration of 2.5 million chargeable vehicles, which correlates with the current fast increase. The rapid increase of EVs will have a predicted power requirement of approximately 7 TWh/year by 2050 in Sweden (NEPP 2019).

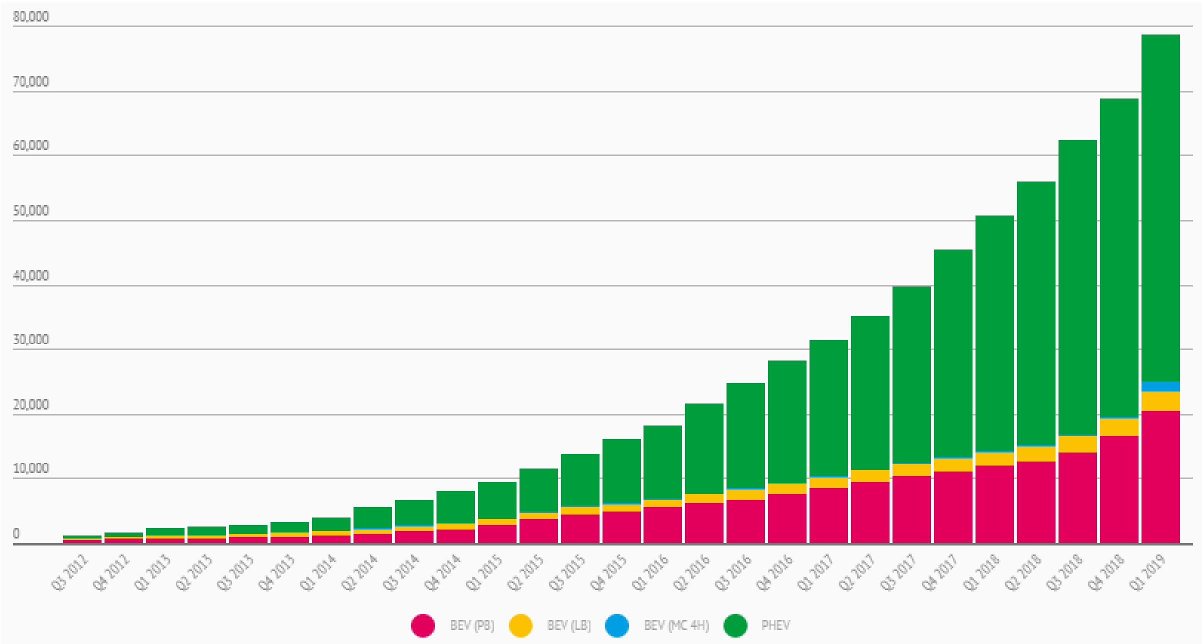

Figure 18 Chargeable vehicles[19] in Sweden between 2012 and 2019 (Elbilsstatistik.se 2019).

The increase of electric transportation has led to an additional need for power and electricity (Power Circle 2018, NEPP 2019). Since most EV owners will want to charge their EVs when they come home from work, when they arrive at work or over the night, this could produce a strain on the power grid at all levels and could likely contribute to issues regarding capacity and power shortage, especially in already strained regions. It might lead to both increased and new power peaks in the system (NEPP 2019). However, since more than 70 % of the EVs are parked at approximately the same time, there is a potential of steering the charge to times of low loads. EVs are further discussed as possible energy storages, but portable and not stationary. This is called vehicle-to-grid, meaning that the vehicle battery is discharging to the grid. If the charge or discharge is carried out in a smart way, peak loads can be reduced instead of increased on a system level. These charge and discharge cycles might lead to high state of charge (SoC) levels, and thus possible fast degradation of the battery lifetime. With future increased penetration of EVs, these batteries will have a potential to contribute to the power reserve.

The rapid increase of EVs have also resulted in cheaper batteries, foremost of lithium-ion (Li-ion) technology, due to both increased production and competition on the market. It has thus contributed with higher competition to the general market for battery storage as well (Power Circle 2018).

6.4 *Delivery Dependability*

The definition of energy security reads "*the uninterrupted availability of energy sources at an affordable price*", stated by the International Energy Agency (IEA) (2019b). In Sweden, delivery dependability could become increasingly critical with enlarged variable electricity production and relates in this context to the importance of customers having access to electricity at all times of demand (Energimarknadsinspektionen 2018b). Expansions and reinforcements are thus needed to allow for a joint European electricity market and grid as well as increased production of renewable energy. The intermittent production demands

[19] BEV = Battery Electric Vehicle, PHEV = Plug-in Hybrid Electric Vehicle, PB = private car, LB = Light Truck, MC = Motorcycle, 4H = Four-wheeler

flexible production and consumption and increase the strain on the electric grid (NEPP 2019). During days with low wind and solar, problems of delivery dependability could increase. Several projects to increase reliability and capacity in the Nordic grid are performed, such as new structures for regional electricity grids owned by Vattenfall Distribution and Ellevio in a collaboration with Svk and Sydvästlänken (Energimarknadsinspektionen 2018b). Sydvästlänken is a power line between southern and central Sweden to reduce transmission restrictions.

Another problem that arises with intermittent electricity production is that the production is not always in balance with the consumption. For a long time the focus in the Nordic electricity system have regarded energy and emission. However, with a shifting focus towards power instead of energy, e.g. with a larger implementation of power tariffs, the spotlight shifts to delivery dependability as one of the main decision making factors instead of emission reduction for changes in the Nordic electricity system (NEPP 2019).

6.5 *Hourly Metering*

According to Swedish legislation, customer electricity metering is obligatory. For 63 A and above, hourly metering is compulsory, while hourly or monthly metering can be applied for consumers with a fuse below 63 A. However, if the customer wants hourly metering the network operator has to install suitable metering (Energimarknadsinspektionen 2017a).

In order for consumers to exercise demand flexibility by load shifting leveling, access to hourly values is of utmost importance[20]. However, this might not be of interest for the customer per se but more for the so called aggregator in a future system. The Swedish grid operators might not have such a large interest in sub-hourly metering since it does not necessarily provide them with more data of interest. This is instead something that the electricity suppliers can have an interest in, since they can apply variable pricing for their customers.

6.6 *Aggregators*

The role of aggregators on the Swedish electricity market is not yet determined, but is something that receives large attention in the discussions regarding addressing challenges in the grid. Aggregators are highlighted as potentially important actors on a future electricity market, in order to provide flexibility to the system and decrease the need for consumers having to actively think about or adapt to questions regarding energy and power. The idea of aggregating capacity of several different electricity users and prosumers, and thereby liberating available flexibility in the system, is nothing new. Ei describes an aggregator as an actor on the electricity market that has the ability to combine the use or production of electricity of several customers in a group, and use that aggregated volume in order to release already existing flexibility within the system (Energimarknadsinspektionen 2017b). This could regard monitoring several residential battery units combined. An example of an aggregating model can be seen in Figure 19.

[20] Paul Göransson, Ellevio. Interview 2019-03-05.

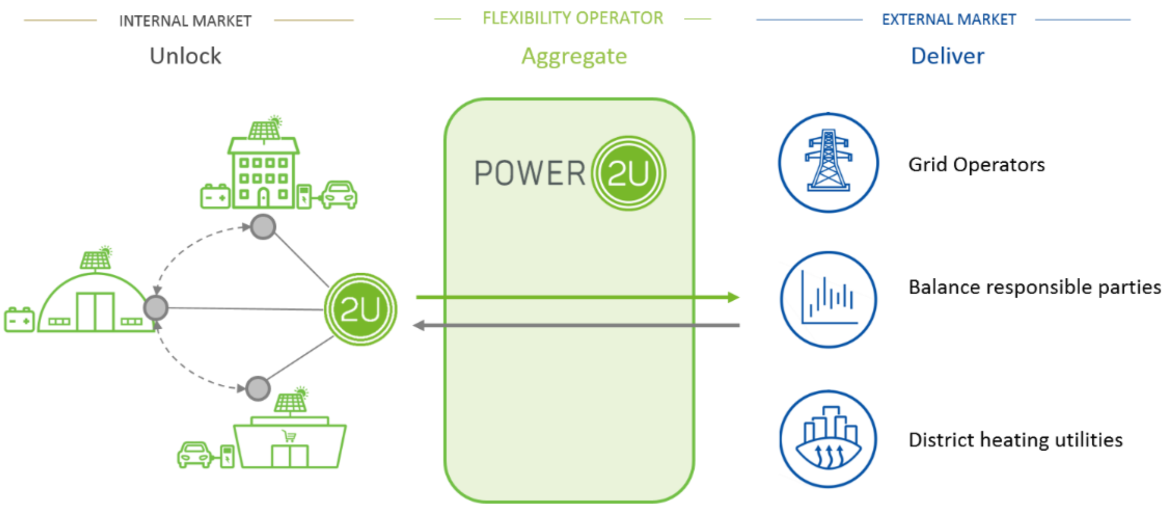

Figure 19 Aggregating model used by Power2U (Power2U n.d.).

There are only a few Swedish aggregators on the market today, such as Ngenic (Ngenic n.d.) and Power2U (Power2U n.d.). This is a line of business that is expected to grow in Sweden within the coming years, given that new market models are implemented since the economic profit is very limited at the moment for these type of actors (NEPP 2019). Clarified and reinforced regulations and legislations to enhance and simplify the aggregator model are needed in order for them to maximise their potential and facilitate demand flexibility (Energimarknadsinspektionen 2017a). As certain bid sizes are needed in order to participate on the flexibility market (more information in Chapter 4.4), the aggregator has the possibility to overcome this and other barriers caused by the current market regulations.

6.7 *Experimental Regulation*

One major issue with how the network regulation is set up today is the fact that the grid operators have very restricted options to try new solutions and experiment with new technology in order to address current issues of capacity and power shortage. This is partly due to the heavy regulation that also stops the grid operators from using economic means to try new solutions and technologies. Energy storage within the grids is one proposed solution to increase flexibility in the system, but there are still uncertainties regarding if grid operators have the right to own the batteries or instead only utilize the service that storage provides. Another important factor is that because network operators are heavily regulated by Ei, they cannot allocate the cost of experimental sandboxes[21] on their customers, since that is not allowed. In order for the Swedish grid operators to investigate the possibilities to strengthen their grids, economic funds are necessary[22].

6.8 *Digitalization*

Digitalization changes the prerequisites of how actors on the electricity market should act and how new systems should be built. Simultaneously it opens doors to new types of possibilities regarding smart metering of electricity and heat, charging of EVs as well as opens up for flexibility measures and improvements. This is possible due to Internet of Things (IoT), Artificial Intelligence (AI) and Blockchain techniques to mention a few. It further allows for closer collaborations between new and old actors involved in the electricity system such as network operators, car manufactures, battery producers, electricity suppliers, energy service providers, PV-producers, aggregators and end customers. With increased digitalization it is

[21] Possibility for grid operators to experiment regulatory.
[22] Anna Wolf, Power Circle. Interview 2019-03-23.

possible to address problems that arise with intermittent energy production such as flexibility issues, distribution problems, capacity and power shortages and increased wear and tear on the system with variable use. It can also help provide increased connections of the more and more decentralised systems and coupling between different relevant sectors. Continuous improvements, self-learning and self-healing systems will be possible with the help of AI. It can simultaneously increase the efficiency in electricity systems, as well as increase the capacity in the grid (Löfblad et al. 2019, NEPP 2019).

Another example of proposed measures towards increased digitalization is the continuous work towards a supplier centric model, as described in Chapter 4.5.3. Having access to data regarding the entire electricity system would positively impact the work towards a smarter Swedish power grid. It would allow for an increased number of energy services being made available (Svenska kraftnät 2019).

However, with these new possibilities and benefits of digitalization comes great responsibility and new risks. What happens with the customer data that is collected, who owns the data, how is it protected and how can the integrity of the consumer be secured? These questions and many more are important to answer for the involved actors on the electricity market in order to create a secure digital future (Holmström et al. 2018, NEPP 2019). Some of these questions are addressed below.

6.8.1 Cyber-Security

With a more digitalized electricity sector, the need for measures in regards to cyber-security is of utmost importance. In the past, the control systems for the electrical grid have been analogue and hardly accessible for the surrounding world, but with increasing amounts of smart and connected components in the electrical grid, the exposure and risk for hacker attacks increases (Holmström et al. 2018). Due to increasing digitalization with higher need of well-functioning IT-systems, the consequences if something happens also increases simultaneously (Löfblad et al. 2019). Thus, the need for cyber-security intensifies. An increased need for security in information and network systems regarding energy supply is one of seven designated critical areas. Hacker attacks that shut down the electricity supply have been seen several times in Ukraine. Later on, several more cyber-attacks in Europe and USA have been registered (Holmström et al. 2018). These attacks have used malware to get remote access to the electricity companies' computers and systems, by using for example viruses and harmful codes. In order to handle the growing problems, the NIS-directive[23] was adopted in the EU 2016 and took effect in Sweden 2018, where agreements regarding mutual actions and requirements such as security measures, surveillance and reporting of incidents. Continuous and structured security work is necessary both between actors and within systems and organisations to gain a satisfactory level of security of the whole electric grid.

6.8.2 Customer Integrity

With an increased digitalized energy sector with more data available and needed, the question regarding integrity and how assumptions can be drawn from analyzing a customer's load profile, has become a topic of interest. Hourly metering is today a requirement for providing flexibility measures, as mentioned earlier in Chapter 6.5 and discussed further in Chapter 8.3, and concerns are raised regarding the need for real-time metering in order to fully take advantage of new market models such as aggregating services. More available data is a necessity in order to allow such new market models and for consumers to become a more

[23] Directive on security of network and information systems

integrated part of the electricity system, which in turn will provide more flexibility (Power Circle 2018). However, how companies act and use customer data can affect the company's reputation, image and credibility (Löfblad et al. 2019). If the company does not take responsibility for their customer data or if the data is exploited, the trust and relationship with the customers could be harmed as well. This is for example what happened with Facebook, which now has the lowest trust of all major tech companies regarding safeguarding user data (Vanian 2018).

6.9 *More Batteries in the System*

An additional flexibility measure on a local scale are batteries (Pavarini 2019). Residential battery storage could act in alleviating ways in connection to local grids at times of high usage, and increasingly so if more system services are considered (Energimarknadsinspektionen 2016b). How this could be possible within the coming years is described in the next chapter.

7 Battery Storage

This chapter presents short introductory information on energy and battery storage, its areas of usage as well as difficulties and possibilities with increased implementation in Sweden. The idea behind energy storage is storing energy during periods of time when demand is low, allowing for a temporal imbalance between supply and demand. Certain storage technologies are better for long-term storage while others are more suitable in short term. Large scale energy storage options include pumped hydro and compressed air energy storage (CAES). One storage option for short-term is electrical energy storage, or batteries (International Energy Agency 2019a).

7.1 *Batteries*

Batteries are normally defined as devices transforming chemical energy into electrical energy through electrochemical reactions. A battery consists of one or more cells that can store energy and release it in form of electricity when appliances are in need of current. The cells can be connected in series or in parallel. The battery itself has an anode and a cathode, negative and positive with a separator and electrolyte acting as a catalyst (Battery University 2019b). The lifetime of a battery is usually determined by the amount of cycles that can be performed, i.e. the number of times the battery can be charged and discharged[24].

Figure 20 shows an annual deployment forecast for different types of energy storage in the US. The total market was estimated to double 2018 - 2019 and almost triple 2019 - 2020 (Wood Mackenzie Power & Renewables 2019). The residential storage scale of batteries increased the delivery of power with 350 % between 2017 and 2018 in USA (Spector 2019).

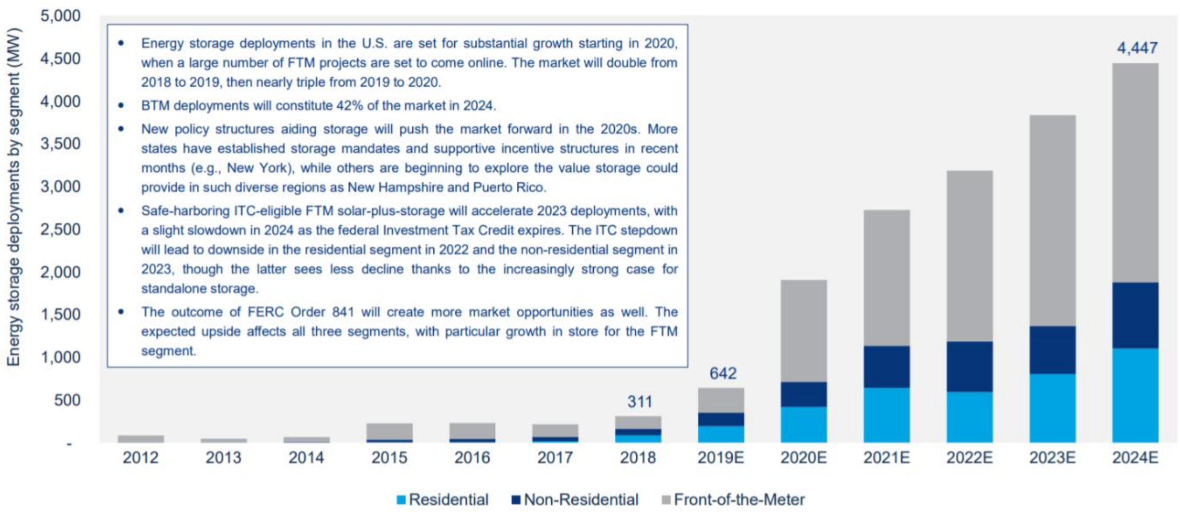

Figure 20 Annual deployment forecast of U.S energy storage, divided in sectors of residential, non-residential and in-front-of-the-meter (Wood Mackenzie Power & Renewables 2019).

7.1.1 Battery Storage Systems

Battery storage needs smart systems that optimize when the battery should be charged and discharged, which is acquired through a battery management system (BMS). The BMS fills several different functions, such as controlling the surrounding environment of the battery and securing that charging and discharging occurs within set limits. When the battery is operating outside of its set conditions, the BMS is designed to notify the overhead system.

[24] Peter Thelin, Nilar. Interview 2019-03-19.

The Energy Management System (EMS) allows the battery to interact with other electric appliances in its setting (Nilar 2017).

7.2 *Battery Types*

There are many different types of batteries available on the residential battery storage market and four of the technologies are briefly described in this section. These types are all rechargeable and commonly used in combination with solar PV production (Pickerel 2018).

Most home storage units available today are built with **Li-ion** technology (Pickerel 2018). This type of battery is light which is one reason why they are common options for EV batteries and have a longer life length than lead **acid** batteries. In Figure 21 it can be seen that Li-ion batteries generally have a small size and weight, and thus higher energy density. This type of battery is further the most common battery to use in combination with solar PV due to its long cycle life as well as an efficient charge-discharge rate. Li-ion batteries require relatively low maintenance. In addition to lithium, materials such as cobalt, manganese and nickel could be included. The two most common types of Li-ion batteries are nickel manganese cobalt oxide (NMC) and lithium iron phosphate (LFP). IEA highlights the potential issue of a too rapid ramp-up of Li-ion battery production within the coming years as a possible problem (International Energy Agency 2019a). This could further be affected by the likely increase of EV batteries as well as an increased utilization of grid-based batteries.

Lead acid batteries are the oldest rechargeable batteries and have relatively low cost. They are commonly used in home storage units and have a comparatively short depth of discharge (DoD). This type of battery typically has a low energy density, see Figure 21, and may need refilling of its acidic electrolyte after some time (Pickerel 2018).

Flow batteries consist of two tanks containing electrolytes which are separated by a membrane, and works similarly to a fuel cell. The liquids in the two tanks never interact in any other way than that the electric current travels through the membrane. This type of battery does not require a high amount of maintenance (Pickerel 2018).

Common types of **nickel batteries** are nickel-cadmium (NiCd) and nickel-metal-hydride (NiMH). NiCd batteries have been used for more than a hundred years while NiMH batteries were introduced in the end of the 20^{th} century (Battery University 2019a). Nickel batteries have a relatively high performance at low temperatures and are considered safer than Li-ion batteries with regards to for example transportation (Nilar 2017). This type of battery has a relatively low energy density, as seen in Figure 21.

Figure 21 shows different battery technologies and their correlation between size and weight.

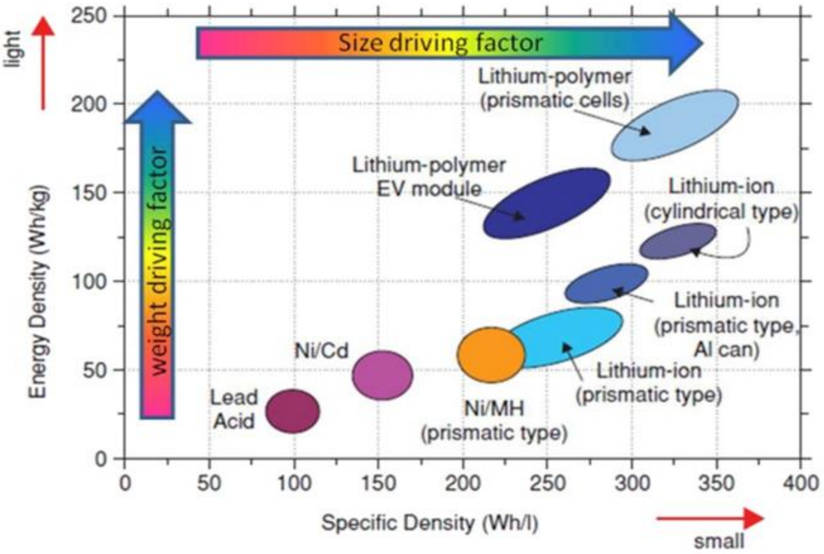

Figure 21 Different types of batteries based on their energy density and specific density (Abada et al. 2016).

7.3 *Benefits*

As earlier described, see Chapter 6.9, utilizing batteries in the energy system for flexibility reasons is likely to be increasingly common due to the many services the technology can provide. Batteries can be used on transmission level, distribution level or on customer level BTM. Among services that battery storage can provide for ISO/RTO[25] services, services such as black starts, voltage support, frequency regulation and energy arbitrage are commonly mentioned. On a utility scale, services provided by use of battery storage are resource adequacy, transmission deferral and congestion relief, as well as distribution deferral (Fitzgerald et al. 2015). Ei (2016b) describes the different system benefits with batteries in different parts of the power system in Table 2.

[25] Independent system operators/Regional transmission organizations

Table 2 System benefits of batteries in different parts of the electricity system. Blue markings mean that the services are dependent on location within the system. (Energimarknadsinspektionen 2016b). Table translated from Swedish to English.

Production	***Transmission and system responsibility***	***Distribution***	***Consumption***
Possibility of arbitrage profits.	System services for system stability (inertia etc.)	Contribute to managing stability problems.	Cost-optimization from hourly pricing or similar.
Integration of battery storage in wind and solar power plants (capacity firmness).	System services for frequency stance, for example spinning reserves.	Dynamic local voltage stance.	Lowered power outtake at peak load – lower energy and/or grid fee cost (or lowered tariff cost).
Battery storage as alternative to curtailment of variable production at low demand.	Bids and calls on the Balance market (primary, secondary and tertiary reserves).	Improved electricity quality and reactive power consumption etc.	Increased use of local self-production from for example solar PV.
Black-start of conventional power production.	Facilitate congestion management and postpone new grid investments.	Facilitate congestion management and postpone new grid investments.	Own reserve power and possibility to handle certain requirements on electricity quality.
		Possibility of planned island-operation during blackouts.	Support to local micro grids in buildings or local areas.

Table 2 highlights the different benefits batteries in separate parts of the power system can provide. Since the thesis mainly regards residential battery storage, benefits on the consumption and distribution side are focused on within this chapter.

7.3.1 Residential Battery Storage

According to Fitzgerald et al. (2015) there are four major areas for which residential battery storage could provide services to the owner of the storage. They also conclude that the further down in the system the battery storage is placed, the more value can it provide to the system. These four benefits are described as:

- Time-of-use bill management
- Increased PV self-consumption
- Demand charge reduction
- Backup power (Fitzgerald et al. 2015)

Time-of-use bill management regards the opportunity for an electricity customer to shift their usage during the day, and therefore take advantage of the volatility of the electricity price. Battery storage could also allow for a self-producer, usually of PV production, to use more of the produced electricity instead of selling excess production to an electricity supplier. Demand charge reductions by cutting power peaks as well as backup power during grid failures are further possible outcomes of battery storage (Fitzgerald et al. 2015).

7.3.2 PV & Batteries

As described in the previous chapter, by adding a battery to an existing PV system the micro producer may use more of the self-produced electricity instead of selling it on the wholesale market for a low price, as well as using the difference in electricity price over the day. The market for PV installations for private customers in Sweden has increased largely within the last couple of years. One important factor connected to this is the very well utilised governmental subsidy regarding investment of solar power for self-production. From January 1st 2018 the subsidy covers 30 % of the investment costs up to a total of 37 000 SEK + VAT per installed kW electric power. This incentive was introduced in 2009. From May 8th 2019 the solar subsidy was lowered to 20 % of the investment cost (Wallnér 2019).

The production rate of solar PV electricity is season-based, meaning that in Sweden the largest production of solar electricity occurs during spring and summer. The production further varies over the course of the day, with electricity production during the day and none during the night.

7.4 *Battery Economics*

The economics of battery storage depends on several factors, such as system settings, if storage is combined with micro-production, potential up-scaling of production as well as future cost developments of storage.

By utilization of **battery storage with PV**, the economic benefit for customers to use more of their own produced electricity, and thereby avoid purchasing that amount of electricity from the grid, increases. Additionally, with increased implementation of power tariffs for Swedish electricity consumers, the economic benefit of a residential battery storage is estimated to increase since it provides an opportunity for customers to cut power peaks and lower their demand charge (Power Circle 2016).

The idea of utilizing **battery storage without PV** production is not economically profitable today. For some customers however, a backup solution such as battery storage could be of absolute necessity considering blackouts in exposed areas of the grid. Investing in battery storage mainly for arbitrage reasons, could further be of interest in the coming years. Considering the likely possibility of a more variable electricity price due to increased penetration of variable renewable electricity, the idea of charging the battery from the grid during times of low rates, for example at high wind power production, and feeding it back to the grid when rates have increased could become a possibility. However, with today's low electricity rates and high costs of battery storage, this is not economically profitable[26].

7.4.1 Cost Development

The battery costs for home usage has significantly declined within the last couple of years which is one of the reasons why this technology has potential of increasing significantly (Frankel & Wagner 2017). According to a Bloomberg report (2019), LCOE of Li-ion batteries has fallen 76 % since 2012. More recently, since the first half of 2018 it has decreased 35 % and now amounts to 187 USD/MWh[27]. This significant decrease in LCOE for batteries have the potential to allow this technology to become a viable option in providing necessary flexibility in a renewable electricity system. However, as Green Tech Media [28] points out regarding the Bloomberg report, battery LCOE is still significantly higher compared to solar and on- or offshore wind (St. John 2019). The LCOE reduction, both

[26] Johan Fält, SEOM. Interview 2019-02-21.
[27] It is estimated that 1 USD = 10 SEK
[28] Media company that provides market research relating to green technology

historical and predicted within the close future, for onshore wind, offshore wind, PV and Li-ion battery storage can be seen in Figure 22.

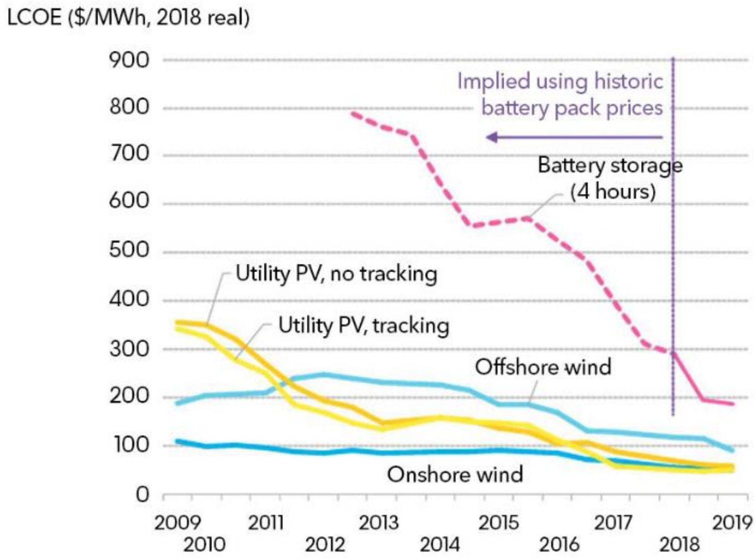

Figure 22 Global benchmark LCOE for PV, wind and batteries (Henze 2019).

Pavarini (2019) claims that costs for both small-scale and utility-scale battery storage systems will continue to fall and that a four-hour battery is projected to cost 220 USD/kWh in 2040 compared to today's price of 400 USD/kWh, as seen in Figure 23. The battery storage cost can decline even more if one considers secondary life for batteries as well as state-of-the-art reduction in battery system costs. The battery cost would under these assumptions be 70 % less expensive 2040 compared to today.

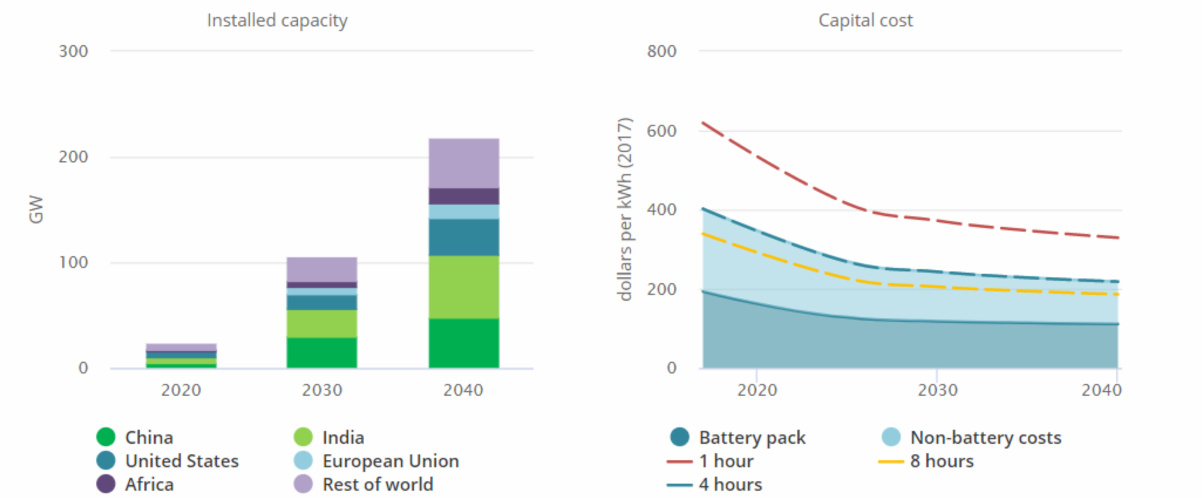

Figure 23 The projected deployment and capital cost of utility-scale battery storage according to the New Policies Scenario from IEA (Pavarini 2019).

Discussions regarding ingoing materials of battery storage systems, such as lithium and cobalt, and whether or not the reserves will last and under what circumstances they are mined, are commonly heard today (International Energy Agency 2019a). However, it is expected that there are enough reserves of the critical materials, but rather that the problem lies within the fast production growth of batteries and thus that the supply of lithium and cobalt will be the real challenge. Due to these problems the price of battery storages, especially Li-ion, might become more dependent on the price for the active materials.

However, prices for both cobalt and lithium increased substantially during 2017, but that gave no substantial effect on the overall battery storage prices. Between 2016 and 2017 battery storage prices fell by 22 %. According to Wood Mackenzie (2019), battery rack prices will go below 150 USD/kWh in just a few years, see Figure 24.

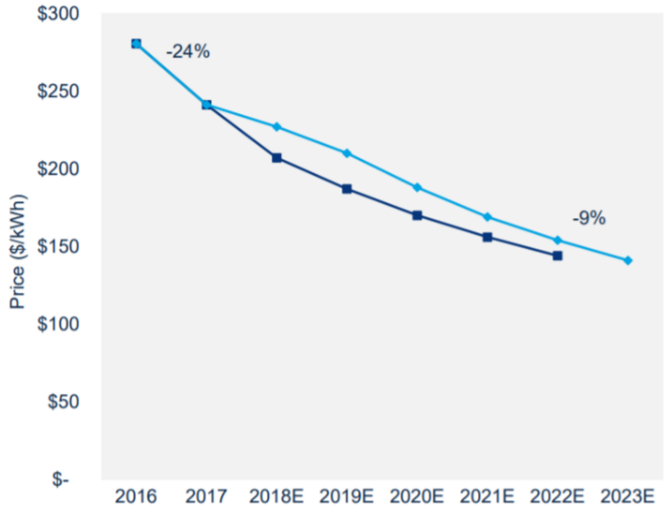

Figure 24 Forecast of battery rack prices in USA. Dark blue line is an older forecast and light blue line a newer forecast (Wood Mackenzie Power & Renewables 2019).

7.5 *Policy Instruments*

The Swedish government subsidizes energy storage today by offering a subsidy which covers parts of the investment costs, as further described in this chapter.

7.5.1 Investment Subsidy

Since November 2016, an energy storage subsidy is available for customers with energy storage in combination with self-production of electricity. The subsidy covers 60 % of the investment cost with a maximum of 50 000 SEK. The idea behind the subsidy is to provide an incentive for micro-producers, commonly within PV production, to invest in energy storage. This subsidy is applicable for producers having invested in storage within the time frame of January 1st 2016 and December 31st 2019 (Energimyndigheten 2018). According to SEA, most applicants for the subsidy for energy storage install a battery in combination with PV production.

According to Lars Karlbom[29] at SEA however, the battery storage subsidy has so far been modestly utilized compared to the solar subsidy. From the introduction of the energy storage subsidy, approximately 26 million SEK in subsidies have been granted, which is considered little in comparison to the solar subsidy. The three counties that have received the largest amounts of subsidies for energy storage are Skåne, Västra Götaland and Stockholm.

7.5.2 Regulatory Proposals

According to a recent governmental investigation, SOU 2018:76, today's regulation of the energy storage subsidy does not allow for all potential smaller participants on the electricity market to utilise it. These mainly refer to households, smaller companies as well as private housing cooperatives (Brf:s). Further issues regarding how the subsidy is designed today is

[29] Lars Karlbom, SEA. Information obtained via e-mail 2019-03-20.

that few of the additional advantages that come with residential battery storage are accounted for, and only balancing of self-production is accounted for when applying for the subsidy.

In order to allow for more possible beneficiaries of the energy storage subsidy, SOU 2018:76 proposes that the requirement of self-production of electricity is removed. It further proposes that the maximum subsidy is increased from 50 000 SEK to 150 000 SEK, with the intention to include additional possible applicants, such as municipalities and companies. The considered time period for the subsidy is recommended to be extended to 2022.

An additional proposition on the matter of energy storage in SOU 2018:76 regards removal of dual taxation for battery storage. The owner of battery storage is required to pay energy tax for the electricity passing through the battery, not considering the fact that the battery itself does not consume nor produce any electricity. SOU 2018:76 proposes that the energy tax on electricity paid by owners of battery storage for the electricity passing to and from the storage, is to be refunded. This refunding of the energy tax is suggested to apply for companies as well as for private citizens. The refunding is applicable when the stored electricity is returned to the grid.

Another proposition in SOU 2018:76 is that battery storage should be clearly described and defined in the Swedish Law of Electricity[30]. This is something that is inadequate today. A clear definition of electrical energy storage in the law would clarify the meaning of such storage technology, and thereby avoid unnecessary misunderstandings. The legislative proposals were published in late 2018 and have to this day not been adopted.

[30] Ellagen

8 Interview Study

The aim of the interview study has been to gain insight from different knowledgeable actors in the electricity system and collect information on power tariffs, demand flexibility and its potential impacts on the market for residential battery storage. It has further been intended to gain inside information on the general ideas and opinions within the business in order to analyse how power tariffs could affect residential battery storage.

8.1 *Method*

Since the thesis aims to highlight potential impacts of the introduction of power tariffs on economic incentives for customers to invest in battery storage, representatives at grid operators Vattenfall Distribution, Ellevio, SEOM and Sala-Heby Energi Elnät were interviewed. SEOM were first with introducing power tariffs in their tariff portfolio, in 2001, and were included in the interview study in order to contribute with experiences and knowledge on this topic, as well as network operator Sala-Heby Energi Elnät that also utilizes power tariffs in their grid fee. Vattenfall Distribution has released plans to introduce this type of tariff for their small customers segment in 2020 and also Ellevio has started to investigate possibilities to introduce a power tariff. In order to gain further knowledge on the government's standpoint on batteries as well as power tariffs, a representative of the Swedish Ministry of Environment and Energy (MEE) was interviewed. Anna Wolf, Power Circle, was interviewed as knowledgeable within energy systems and smart grids.

The interviews were carried out orally in Swedish, in a semi-structured way. The interviewees were allowed to see the questions on beforehand and the interviews took place at respective informants' location, except Sala-Heby Energi Elnät where answers were provided via e-mail. Follow-up questions were asked in order for the interviewee to clarify or elaborate further. The interviews were recorded. After the interviews, the answers were written down, translated from Swedish to English and summarized to a running text in order to provide the reader with an opportunity to see similarities and differences of the answers. All interviewees were given the opportunity to read their answers and have given approval of publication of their answers and quotes. The questions asked can be found in Appendix A.

8.2 *Interviewees*

The interviewees are presented in Table 3, along with information regarding their respective positions and companies or organisations that they work for. The interviewed actors were chosen from their expertise and with the intention of providing answers thoroughly in regards to power tariffs, flexibility in the power system and battery storage.

Table 3 Interviewees.

	Interviewee	*Company/Organisation*	*Position*
1.	Paul Göransson	Ellevio AB	Senior Price and Product Specialist
2.	Thorstein Watne Mona Sinclair Anna Nilsson[a]	Vattenfall Distribution Sweden	Business Strategist Business Analyst Business Analyst
3.	Filip Vestling	Ministry of Environment and Energy (MEE)	Head of Section
4.	Oscar Willén[a]	Sala-Heby Energi Elnät	Power Supply Engineer
5.	Anna Wolf[b]	Power Circle	Policy Officer Energy Systems and Smart Grids
6.	Johan Fält	SEOM	Electricity Business Unit Director

[a] Answers from Anna Nilsson and Oscar Willén were obtained at a later stage via e-mail.
[b] Answers provided by Anna Wolf, Power Circle, are to be considered her own thoughts and ideas and do not represent the opinions of Power Circle.

Since the authors wished to gain specific knowledge regarding different tariff structures and designs, the interviewees at the grid operators were asked detailed questions regarding this. These questions therefore were not asked to the remaining interviewees. Further, in order to gain information regarding the future of the battery storage subsidy discussed in SOU 2018:76, the representative for MEE was asked specific questions regarding this.

8.2.1 Information About Companies and Organizations

SEOM is located in Sollentuna north of Stockholm and has approximately 29 000 electricity customers. Ellevio has approximately 1 million customers and are mostly present in the Stockholm region, Dalarna, Hälsingland, Gästrikland, Värmland, Närke and Bohuslän (Ellevio 2019b). Vattenfall Distribution provides approximately 900 000 customers with electricity (Vattenfall Distribution 2019b) and administrates local grids in western, eastern and northern parts of the country. Sala-Heby Energi Elnät is a local grid operator that has had power tariffs since 2009 and have a similar tariff structure to SEOM. They own local grids mainly in the municipalities Sala and Heby located in SE3 (Sala-Heby Energi Elnät n.d.).

Power Circle is an interest organization with company members from the energy sector and focuses on smart grids, electrification of the transport sector and charging infrastructure among other areas. The Ministry of Environment and Energy is one of the Swedish government’s departments working with issues regarding energy and environment. During the course of the work of the report, this department went through a re-organization and is currently divided into an environmental department belonging to the Ministry of the Environment, while the energy division instead belongs to the Ministry of Infrastructure (Regeringskansliet 2019b, Regeringskansliet 2019a). However, this department is still referred to as the Ministry of Environment and Energy, or MEE, in this report.

8.2.2 Tariff Design

SEOM has had power tariffs as part of their grid fee since 2001. The power tariff is differentiated between high and low peak months[31] and is applied during 07-19 o'clock weekdays, with a duplication in price during peak months. SEOM:s tariff is determined by a mean value of the three highest power peaks measured over the course of each month. Sala-Heby Energi Elnät also utilizes power tariffs from 07-19 o'clock on weekdays and the tariff differs more than double in price per kW depending on high or low peak months. The tariff is determined by a mean value of the three highest power peaks per month.

Vattenfall Distribution has announced that they will introduce power tariffs for their small customer segment during 2020 and Ellevio is considering implementing a similar tariff within the coming years. Paul Göransson, Ellevio, mentions that they today consider a power tariff which is constant over the course of the day and says that such a design would act in a load levelling way instead of simply shifting load to hours with a lower price. Vattenfall Distribution's power tariff will be constant over the course of the day but most likely be calculated as a mean of a number of peak measurements from different days. They currently aim at measuring the five highest power peaks over the course of one month in order to decrease the importance of a single largest value.The energy fee could be time-differentiated or constant over the course of the day, the customer is allowed to choose between the two. The current fuse subscription for the small customer segment (16 – 63 A), which accounts to the fixed fee, will be phased out during the coming years. Ellevio has not released information regarding a potential design of their power tariff structure.

It should be mentioned that when tariffs are mentioned in the interview study, it is implied that it regards power tariffs for the small customer segment if nothing else is specified.

8.3 *Results*

The results from the interview study is presented in this section. The interview answers are divided in the following categories: Power and capacity shortage (8.3.1), Tariffs (8.3.2), Batteries and tariffs (8.3.3), Regulation (8.3.4) and Battery storage (8.3.5) in order to make the results accessible to the reader and allow for comparison of the answers. The questions are numbered.

8.3.1 Power and Capacity Shortage

1. *Do you experience power or capacity shortage in your or the Swedish power grid?*

Among the interviewed grid operators, both Ellevio and Vattenfall Distribution agree to a certain level that capacity shortage is a problem in their respective grids. Paul Göransson, Ellevio, explains that they do experience capacity shortage on certain levels today. This is exacerbated due to the uncertainties regarding the future of certain power plants in their geographical region. Ellevio further faces shortages in the Stockholm region, where residential areas expand more than estimated. According to Göransson, there is also shortage of capacity at certain tight sections in the grid, which likely will be magnified and become an urgent problem considering an increased penetration of EVs.

Thorstein Watne, Vattenfall Distribution, mentions that they have problems in the areas of Uppsala, southern parts of Stockholm and Västerås to mention a few. The problem is caused

[31] High peak months are April to October, low peak months are November to March.

by Vattenfall Distribution not getting permission from Svk to upgrade their subscription of power from the transmission grid. Hence, it is not beneficial for Vattenfall Distribution to extend their own regional grids. Grid operator SEOM does not, according to electricity network manager Johan Fält, face shortages in their local grid. According to Fält, the reason is that SEOM has planned for, and thus have a subscription for, higher power than what is currently necessary. Another reason could be that Sollentuna municipality does not have any big industries since the land is too expensive. Anna Wolf, Power Circle, points to that local capacity shortages within certain metropolitan areas such as Uppsala and Västerås today are acute. This can further be seen in Stockholm and Gothenburg. Given the expected increased quantity of EVs, that likely will create new power peaks that can be troublesome to solve locally, the power grids will see continuous local power problems if reinforcements are not made.

2. *Which actions do you consider important in order to encourage small-scale consumers to change their load patterns and increase demand flexibility in Sweden?*

Demand flexibility is a term that is commonly mentioned today as an action towards providing flexibility within the Swedish electricity system. Grid operators could make several different measures towards encouraging their customers towards this. According to Paul Göransson, Ellevio, the important thing for them as grid operator is to incentivize good behavior by the customer. This simply means that a customer with high peak load pays a larger amount than a customer with lower power peaks. This measure should provide incentives for investing in demand flexibility, for example smart equipment for monitoring maximum power usage. Thorstein Watne, Vattenfall Distribution mentions that important measures are to make sure that customers actually have a possibility to impact their electricity consumption, both behaviorally and with smart technology, and understand both *why* and *how* this can be achieved. Additionally, the customers' total electricity cost should further be designed in such a way that the customer can make savings if he or she load shifts. According to Anna Wolf, the most important measure is for customers to face a more variable electricity price. It must further be combined with some type of new market, some form of aggregator service. Wolf distinctly highlights the need for automatization and further mentions that she thinks power tariffs are too broad an instrument and that all types of flexibility must in some way be made lucrative. One precondition for successful use of aggregators and automatic systems is that this type of equipment is online and regulated by a third part.

> *The most important measure is to combine power tariffs with prohibiting fixed rate deals for private customers, since the customers need to feel the impact of high and low prices and how they can benefit from it.''*[32]

8.3.2 Tariffs

3. *Do you provide incentives for your customers to shift load? If so, how?*

According to Paul Göransson, Ellevio, demand flexibility is something that should be achieved since it could be of importance for the future electricity system. He does however mention that there is no exact knowledge today regarding the impacts that demand flexibility actually could have on individual customers. He further mentions that Ellevio today does not actively act to affect the load patterns of their customers, but emphasizes that demand

[32] Johan Fält, SEOM. Translated from Swedish to English.

flexibility could become increasingly important in the coming years with a larger amount of intermittent electricity production. The closest to this type of action is that Ellevio has implemented a power tariff for customers with a power fuse over 63 A. This is combined with a time-differentiated subscription. This is something that also Vattenfall Distribution has implemented for larger customers.

> *"Instantaneous capacity is something that will have to be priced in the future when we do not have any planned production. Then capacity will be the factor that set the limit – not the energy over the year."*[33]

Thorstein Watne, Vattenfall Distribution, mentions the soon introduced power tariff as an example of Vattenfall Distribution working towards higher demand flexibility. At SEOM, power tariffs are applied during 07-19 on weekdays but Johan Fält says that SEOM thereby misses an important aspect being that the consumption will need to increase during some days to be called real demand flexibility. Filip Vestling at MEE comments that electricity would need to become much more expensive and that it would need to be simpler for customers to engage. He highlights that today, very little effort is needed to change the load pattern of a customer, although almost nothing is to gain from it economically.

4. *What reasons do you have to introduce power tariffs?*

SEOM was the first Swedish network operator to introduce power tariffs in 2001. According to Johan Fält, there were hardly any incentives or demand to do so at the time. Paul Göransson, Ellevio, mentions that among the reasons to introduce power tariffs, one is to positively affect demand flexibility among customers but that it depends on how the tariff is designed. He also mentions that Ellevio wishes for the future power tariffs to have a load leveling effect instead of a load shifting such. This means that power peaks should not be shifted to other times of the day, which could be the case with time-differentiated tariffs. Additionally, he believes that the implementation of tariffs will not have a substantial effect on Ellevio economically but that a successful result of the power tariffs, leading to lowered power peaks, could lead to less future investment needs for Ellevio. This in turn provides socio-economic savings, according to Paul Göransson. Thorstein Watne and Mona Sinclair mention that the reason for an introduction of power tariffs is that it is needed for the grid, due to power shortage. They say that they believe it is beneficial for them to introduce the tariffs before a supplier centric model is introduced, likely around 2022, since the electricity supplier then will take over all contact with the customer. Thorstein Watne mentions that they are afraid that this will disfavour grid operators. Anna Nilsson elaborates further that this perhaps primarily will be the case since it will become increasingly difficult for the grid operators to communicate questions regarding tariffs when the customer's first hand contact will be with the electricity suppliers. Moreover, Vattenfall Distribution wants to introduce power tariffs in the beginning of the next regulation period.

5. *What arguments for and against a larger implementation of power tariffs do you see?*

Grid operator SEOM has seen positive outcomes from the introduction of power tariffs. Johan Fält mentions that the income for them as utility becomes more stable, that the customers have adapted to the new price structure and that they find it easier to embrace changes for increased energy efficiency. Paul Göransson, Ellevio, says that the proposed

[33] Paul Göransson, Ellevio. Translated from Swedish to English.

problem of customers in general not understanding the difference between energy and power not necessarily has to be a problem, but rather a challenge. It is a matter of explaining everything simple and clear to the customer. Regarding energy, the customer simply should not run all their electric equipment for a long time and for power, they should not run all their electric equipment at the same time. It is additionally important not to have too many complicated moving parts [in the tariff] which could make it difficult for the customer to understand how to work with the tariff, not against it. The communication with customers will be the most important part of the coming pilot studies, according to Göransson. He adds that he thinks that the power tariffs can provide larger flexibility in the system, given that aggregators are allowed to establish themselves on the market. Filip Vestling at MEE agrees that power tariffs certainly could provide larger incentives for selling flexibility. Anna Wolf highlights that the power tariffs are one possible measure that grid operators have to access larger flexibility, but that it is not precise enough an instrument. Vattenfall Distribution regards power tariffs to be one measure towards preventing capacity shortage in their grids. Both Watne and Sinclair believe that the transition towards power tariffs will be pleasant for most customers, as long as the change is smooth and not too large. Mona Sinclair adds that some customers will always face disadvantages when changes are made, and they will react. Vattenfall Distribution, similar to Ellevio, mentions that hourly metering is currently enough from their perspective. Watne says that quarterly metering for example would rather give a deceptive response since small actions could make a high impact on peak power. According to Filip Vestling at MEE, one important challenge is providing grid owners with sufficient economic incentives, in order to account for the increased administration. He further mentions that the metering needs to be as exact as possible, as well as the clearing[34]. Anna Wolf highlights important challenges as how the laws, regulations and power system are formed regarding providing playroom for the grid operators to experiment. This could mean problems for the grid operators if they introduce something that is not working sufficient or makes the system fail, which is one reason to why they are risk averse. Wolf mentions the need for more tests and that funding could come from governmental support system for grid operators to apply for money.

6. *Have you received or noticed any interest from customers regarding implementation of power tariffs?*

Johan Fält mentions that initially after that SEOM introduced tariffs in 2001, some customers considered the tariffs complicated. On a follow-up questions to SEOM, regarding whether or not they have seen that customers connected to their grid have shown an increased interest and activity as electricity customers with power tariffs, Fält says that is not the case. He mentions that interest has been slight regarding load shifting. Also grid operator Sala-Heby Energi Elnät, a network operator that introduced power tariffs in 2009, answers similarly to SEOM. According to Oscar Willén, power supply engineer at Sala-Heby Energi Elnät, they have seen that the highest power outtake for the average customer decreases yearly. Willén mentions that they have had approximately the same highest power outtake this year as in 2014, even though the amount of customers has increased significantly.

Neither Ellevio nor Vattenfall Distribution have noticed an interest from their customers regarding the potential introduction of power tariffs. Rather few customers are aware of the

[34] A clearing is received on the electricity bill and regards the difference between the estimated and actual electricity use (GodEl 2019).

changes. Paul Göransson mentions that the organization Villaägarna spoke out on behalf of their members with skepticism against Vattenfall’s press release regarding their plans on power tariffs, which is confirmed by Thorstein Watne. Anna Wolf, Power Circle, says that they have not heard especially from consumers regarding this, but that they are seeing that the grid operators are starting to experiment with this type of tariff.

7. Do you see a potential conflict between power tariffs in combination with intermittent electricity production?

It could seem that a tariff that covers the bigger part of the day could act in opposition to intermittent electricity production. Paul Göransson, Ellevio, confirms that it could be a problem with reverse feed if too much is produced by solar PV among smaller customers during the day. However, according to Paul this is mainly a technical issue. Johan Fält at SEOM, comments that he does not see it as a problem, since the income for grid operators is regulated by law, and thus the level of the tariff will change accordingly to that constrain and to the market. Thorstein Watne, Vattenfall Distribution, mentions that it is not possible to disregard that their grid tariff from time to time can give opposite signals as electricity rates. This is due that when production of electricity is high it is beneficial if customers are incentivised to purchase at that time, given that the grid is not highly strained. Filip Vestling, MEE, mentions that they have troubles seeing that power tariffs would amend to larger problems with regards to intermittent electricity production. They are often satisfied when people pay for the strain that they put on the grids and note that they want stability in the grids.

8. Could power tariffs affect demand flexibility in Sweden?

Johan Fält, SEOM, says that the power tariffs only will affect the demand flexibility on the margin and that it is important not to miss that customers will need to be able to purchase cheap electricity during high production of e.g. wind and solar power without getting punished by the power tariffs. Regarding whether or not power tariffs have had an effect on demand flexibility for grid operator Sala-Heby Energi Elnät, Oscar Willén says that it is difficult to say and that some customers are very good adaptors while others do not wish to adjust at all. Paul Göransson, Ellevio, believes demand flexibility will become more and more important in Sweden and that the capacity market will play a large role. It is the capacity side that they really work towards, the energy fee could just cover losses. Vattenfall Distribution claims that the power tariffs will provide their customers with a larger possibility to affect their grid fee costs compared to today’s fuse subscription since the variable part of the tariff increases. This way the information to the customers regarding how the tariff works will be important in order for the customers to understand when they can make economic savings by lowering their power peaks and smoothen out their load. Filip Vestling at MEE believes that an implementation of power tariffs within the larger distribution companies could likely give economic incentives for customers to shift their load according to the tariffs. The problem with demand flexibility is that customers are not aware of it and that there today is not enough money to save. They are positive to grid operators moving in this direction. Anna Wolf, Power Circle, agrees that the tariffs will increase the profitability of demand flexibility for the customer, but poses the question whether or not it is even necessary for the customer to be active regarding their consumption.

"The power tariffs could today be an incentive to invest in a controllable system, or set up an algorithm at home, but not for me as customer to always shift when I turn on my dishwasher." [35]

Wolf still believes that the system needs processes for consumers to be flexible and that a larger introduction of power tariffs will still mean that it is too cheap to be an inactive customer. Wolf highlights the future role of aggregators acting to control several different customers without decreased comfort for the customer. She thinks that power tariffs can possibly partly contribute to demand flexibility but that it will not be enough. Additionally, Wolf mentions that for customers to at all consider making active choices regarding their electricity and power consumption in their daily life, a higher electricity price is necessary. Oscar Willén, Sala-Heby Energi Elnät, claims that Vattenfall Distribution and Ellevio's future introduction of power tariffs likely will have an effect on demand flexibility in Sweden and says;

"Since power is something that most customers do not know anything about, it is likely that if two of the largest Swedish grid operators introduce power tariffs, power will become more relevant." [36]

And adds further;

"Approximately 40% of our customers say that they understand our power tariff. If, after the introduction of power tariffs [among Vattenfall Distribution and Ellevio], the percentage is the same – that means that a large part of the population understand what power actually is. That further means that these customers also understand that they can shift their power outtakes to times when it is less costly, and that there is more reason for demand flexibility." [37]

9. *Will power tariffs affect you as grid operator in the electricity system economically?*

SEOM has seen an effect of more stable income and says that the customers often tend to have a few hours with high power outtake even though it is a warmer month than normally. Ellevio and Vattenfall Distribution claim that they are unlikely to make an economic profit from implementing power tariffs due to the regulation from Ei[38]. However, Paul Göransson at Ellevio mentions that if they in the long run can keep the peak power lower, that means that Ellevio can keep socioeconomic costs down to manage the grid since they can invest less. If the regulation does not change, hardly any economic changes will be seen. Vattenfall Distribution confirms that the tariffs will not necessarily have a positive impact on Vattenfall economically due to the income regulation from Ei. They add that implementing power tariffs early in the new regulation period will allow for corrections to be made early on.

10. *Will power tariffs influence how the Swedish electricity grids are built in the future?*

[35] Anna Wolf, Power Circle. Translated from Swedish to English.
[36] Oscar Willén, Sala-Heby Energi Elnät. Translated from Swedish to English.
[37] Oscar Willén, Sala-Heby Energi Elnät. Translated from Swedish to English.
[38] Ei allows the grid operators to cover their costs by taking in appropriate revenues.

Johan Fält, SEOM says that one change could be that they will need to replace all small fuses in the grid (16-20A). Paul Göransson at Ellevio thinks that power tariffs could potentially change how power grids are designed in the future since it could change the power profile and would also allow for Ellevio avoid having to build for such large power peaks as today. This is something that further will be enunciated by future increased penetration of EVs. Vattenfall Distribution imagines that the largest positive change would be if the power tariffs would enable them to lower their subscription against the transmission grid and manage on a lower total capacity. Mona Sinclair mentions that this is a way to allow the customers to do something and shift load and not just pay. Thorstein Watne also adds that having active customers can allow them to avoid future investments by utilizing flexibility. Anna Wolf, Power Circle, does not necessarily think that the tariffs alone will provide a large change for the construction of power grids. However, she agrees that they together with other measures can make a potential difference regarding that they could contribute to the possibility to postpone investments for some time, depending on tariff design.

8.3.3 Batteries and tariffs

11. Do you see a need for residential battery storage for you as an actor on the electricity market?

Neither SEOM, Ellevio or Vattenfall Distribution would benefit directly from their customers investing in residential battery storage. Ellevio and Vattenfall Distribution point to the benefit for them as grid operators of potentially utilizing larger batteries in the grid while the representatives for Vattenfall Distribution mention that customers sensitive to blackouts would benefit from battery storage. MEE considers residential battery storage one solution to promote flexibility in the system. From their perspective, more batteries in the system in order to increase demand flexibility is the only interesting aspect for them, not that the customers may lower their demand charge by using batteries.

12. Do you see increased system benefits with residential battery storage?

Paul Göransson, Ellevio, mentions that he sees more system services other than power conditioning or smoothing. Those however mainly apply higher up in the transmission grids. Smaller batteries in combination with a larger system could contribute to changes in the system at large, through an aggregator. Johan Fält at SEOM sees large benefits at customer level, but that it is up to the customers themselves to obtain these benefits such as subscribing to the available time-differentiated tariff and defining their monthly peak loads. MEE is positive to any measures that can balance the use in the grid over the day and over the year. They are examining whether one could receive payment for additional system services which, according to Filip Vestling, faces no barriers today but also no economic incentives. Vattenfall Distribution has no comment on system benefits of residential battery storage, nor has Anna Wolf.

Considering battery storage in front of the meter, Filip Vestling at MEE mentions that large scale energy storage in the grid could certainly contribute with system services, especially in the short term and in SE4. Since grid operators only are allowed to own and use battery storage under special circumstances, one possibility could be that electricity suppliers own the storages and sells capacity as a service to the grid operators. Anna Wolf agrees, but states that not many studies have been performed on this subject yet. Wolf thinks that large scale storage solutions in the grid mostly would be beneficial for quickly taking action and temporarily solving bottlenecks in the grid. As of today, she still believes that it is cheaper with ordinary grid extensions such as building new power lines but that these ordinary actions often take a long time to implement. With decreasing battery prices and a market for system benefits such as capacity trading on a flexibility or balance market, there might be a real business case.

13. Could power tariffs be seen as an incentive to use residential battery storage?

All interviewees agree that power tariffs could be an incentive for customers to use residential battery storage. Thorstein Watne, Vattenfall Distribution, claims that it provides the customer with a possibility to even out their power outtake and cut power peaks, which gives a reduction of the demand charge. Filip Vestling, MEE, mentions that there is potential for the power tariffs to incentivise a battery where one could purchase electricity during times of lower tariffs. Wolf, Power Circle, agrees that it certainly could be, providing a large enough price difference at different times. The potential incentive for batteries is especially linked to for example EV charging and PV production and/or other loads that are shiftable, for example households with heat pumps. Paul Göransson at Ellevio states that the battery units are too expensive today and that bulk production is required in order to bring the prices down.

Oscar Willén, Sala-Heby Energi Elnät, mentions that they have not yet seen an increased interest among their electricity customers to invest in battery storage after the implementation of power tariffs among their small customer segment. He does however claim that an increased use of power tariffs among the larger Swedish grid operators could affect the profitability of residential battery storage among electricity customers. Willén says that residential battery storage thereby is likely to become more commercially viable.

14. Do you see a possible role for an aggregator in order to increase flexibility?

Many of the interviewees highlight the future role of aggregators on the Swedish electricity market. Allowing for aggregators to control and operate several battery units would provide the aggregator with a noticeable flexible capacity which could have an impact on the electricity system. Paul Göransson, Ellevio mentions that the role of aggregators in Sweden today is not completely decided or implemented but could be of interest in the future. A larger implementation of aggregators on the market would likely be an indirect advantage for Ellevio due to a more stable power outtake from their customers, which would allow them to plan the distribution in a more safe and economically profitable way in the long term. Vattenfall Distribution further claims that the future of aggregators is positive but that it all depends on the price of the service they provide. The MEE adds that the aggregators that are currently discussed should be able to make a difference regarding the customer will to change its consumption, since it will simplify the action.

"Today there still seems to be no market for aggregators who come in and buy large amounts of flexibility, but it would certainly make it very easy for the customer." [39]

[39] Filip Vestling, Ministry of Environment and Energy. Translated from English to Swedish.

8.3.4 Regulation

15. Which policy measures would have the largest effect regarding battery storage, and which are currently the main regulatory obstacles?

Filip Vestling at MEE says that the most effective tool for promoting batteries in the system would be obligation. However, it might not be the best solution when other aspects such as rule of law and what type of solution and goal are intended. A problem that both Filip Vestling as well as Johan Fält at SEOM clearly consider, is that the subsidy for battery storage today sets the market price for residential battery storage. Vestling says that there is always a risk that the market develops around a subsidy like this. Johan Fält also mentions the dual taxation on battery storage as a problem. Anna Wolf mentions that it is hard to point to certain policy instruments that would have a large effect, but that the market for these type of support services needs to mature. However, changes regarding grid regulations most certainly are needed to enable and encourage grid operators to procure support services. Some regulatory obstacles are that the current legal framework is based on the old energy system consisting of only producers, a grid and consumers. It needs to be updated so it is relevant for how the energy system functions today. Moreover, it would also be useful with a clear definition of electric energy storage, and modifications of rules and regulations like the entire electricity tax are needed. Considering the customer perspective, Anna Wolf thinks there today are too few, and too small, economic incentives for it to be economically beneficial to load shift from times with high rates to low. Thus, it must be allowed for some kind of connecting actor that can buy this support service from its customers, accumulate it and sell it at larger scale to the grid operators.

> *"The possibility of batteries by end customers is that they can be used for so many different things, but the obstacle is that there are so many different markets and no actor acting on all these markets. One cannot expect customers to manage all of that on their own."*[40]

Wolf also thinks that it is an interesting paradox that if you are to buy a stationary battery today it is cheaper to instead buy an EV to fill the same function, and thus one could argue that the market for stationary batteries is not mature. The price of EVs is increasingly forced since they must compete with fossil-fueled cars. That means that there should be a possibility to lower costs for stationary battery storages as well.

16. What are your thoughts on the current subsidy for battery storage and its effect on the market price of stationary batteries?

Johan Fält at SEOM says the current battery storage subsidy basically sets the market price for batteries where customers rarely know exactly what qualities they pay for. The same lack of thorough knowledge goes for the solar PV retailers that have started to offer a combined PV and storage system, which is problematic. Whether if the proposition for an extended subsidy[41] will go through or not, Filip Vestling at MEE cannot tell, but that it will be decided during the Spring of 2019. Anna Wolf states that an extended subsidy could be useful for batteries that are to be located in places with certain distinct peaks, for example where it is obvious that employers with EVs will arrive at a certain time at work every morning. However, the subsidy should be disconnected to the demand of self-production of energy.

[40] Anna Wolf, Power Circle. Translated from Swedish to English.
[41] Increase to a maximum of 150 000 SEK and increased availability for larger customers to apply.

Wolf also says that it is slightly ironic that there is a support system for local solar PV production where one receives payment for every kWh produced as well as tax reduction, and at the same time to have a subsidy for a battery storage – those actions point in opposite directions.

17. What do you think of the guidelines from Ei regarding power tariffs today?

Both Vattenfall Distribution and Ellevio think that the current guidelines so far from Ei regarding power tariffs are still slightly unclear. According to Vattenfall Distribution, Ei have stated two things so far; that they will try to have similar requirements on all grid operators in order to send the same signals throughout the whole system, and that they prefer a time-differentiated power tariff. SEOM thinks that Ei needs to take a wider stance and forbid fixed prices on energy for private customers. However, Ei has been given authorization which allows them to complete the guidelines for how tariffs are to be designed. This project will last until February 2020. Neither Anna Wolf nor the MEE have any standpoints regarding this. Anna Wolf, however, mentions that the grid operators should be given the right to experiment with diverse tariffs and have the opportunity to design different offers to separate customers groups, such as a specific tariff for customers with a stationary battery storage and/or an EV.

8.3.5 Battery Storage

18. Could an increased use of residential battery storage benefit you as an actor on the electricity market?

Since grid operators are natural monopolists, Johan Fält at SEOM claims that they should not be part of the discussion regarding residential battery storage. However, both Vattenfall Distribution and Ellevio see indirect positive effects from an increase in residential battery storage by their customers, such as increased more levelized and stable power outtake from their customers. Thus, it will become easier for Ellevio and Vattenfall Distribution to plan their distribution better. Ellevio states that for this to be possible some sort of aggregator is required, that can operate several battery storage units together and thereby create a significant capacity for flexibility. Neither Ellevio nor Vattenfall Distribution see any greater economic impact for them with an increase of residential battery storage. Wolf also says that the grid operators, as well as local electricity producers with larger economic potential for storing their energy rather than selling it back to the grid, will see the largest positive impact of more batteries. Locally in weak grids where there are high power peaks, such as parking garages where many EVs will be charged, there are also needs for increased use of batteries. However, Anna Wolf as well as Paul Göransson state that residential battery storage is a type of short-time storage suited for use on a daily basis and thus only applicable for shifting load for a few hours and not an option for longer shifting or seasonal storage.

19. What are your thoughts on residential battery storage in Sweden within the coming years?

All interviewed actors say that the penetration of residential battery storage in the future will depend on several factors, such as price development of batteries. Paul Göransson, Filip Vestling and Anna Wolf all mention that the economic incentives will increase with increasingly volatile electricity prices and more capacity-based power tariffs. Without new dynamic pricing models it will be hard for batteries to become feasible by only a decreased battery price. Anna Wolf thinks that it will never be profitable and interesting enough for individual customers to invest in residential battery storage and work towards flexibility by shifting their power use, but that this needs to happen automatically with help of aggregators. Both Anna Wolf and Thorstein Watne mention that flexibility in the electricity system is needed already today and that batteries are a part of the solution towards power shifting and levelling as well as for other system services. Other technologies that Anna Wolf mentions are smart metering and regulation, in addition to more automatization.

Wolf and Fält also mention the penetration of EV batteries as a potential source for storing capacity. Johan Fält, SEOM, believes that EV battery storage will become more common than stationary battery storage since they will be multifunctional and thus more profitable. Larger stationary batteries will not be likely in buildings in bigger cities due to the high price of housing in for example apartment buildings, and thus an installation of such batteries would become very expensive. He further mentions the likely increased price variations of electricity, due to increased amounts of wind power and other intermittent power sources in the system.

Anna Wolf rather believes that the penetration of EV batteries versus stationary battery storage will depend on how the market evolves generally and how well vehicle-to-grid solutions are implemented. She thinks that there will have to be a combination, that we will use all resources available in a smart way. Another challenge that Wolf mentions regarding the development of future smart grids is the integrity of customers and cyber-security. Increased customer data collection is almost a necessity for development of the grids, but it will thereby also be possible to tell almost anything about the individual customer and its habits. This is something that the grid owners are starting to become aware of.

Also Filip Vestling at MEE mentions EV batteries as a mean to store energy and contribute to grid benefits. Contrary to Johan Fält, Filip Vestling sees a problem with people's willingness to let a third part control the charging of their EV, and that people will want to know that their EV is charged when they intend to use it. Vestling also says that the EV battery would rather contribute to negative grid services, since the car most of the day will not be home and thus not able to store energy from residential PV-production. Wolf thinks that the largest competitor to stationary batteries are vehicle-to-grid from EV.

> *"Depending on how quickly we receive electric vehicles into the system, and to what extent people are willing to use them to contribute to the system balance, will probably determine the market development of stationary batteries."* [42]

20. Are there other systems than batteries that you see as possible for use of local energy storage?

Paul Göransson, Filip Vestling and Anna Wolf mention heat storage as another possible storage technology. Traditional hot water accumulation, heat storage in air or heat storage in the ground are discussed, whereas some already exist and are used, other techniques are under development. Paul Göransson, Ellevio, says that while not discussed in general while discussing the electricity market and grid, the major portion of possible flexibility is in heating. Johan Fält, SEOM, says that the combination with other energy systems such as

[42] Anna Wolf, Power Circle. Translated from Swedish to English.

accumulation tanks and EV batteries that can be used both for charge and discharge to the grid are other options. Vattenfall Distribution claims that there is an abundance of possible energy storage techniques that customers can use, but that it does not matter to them as grid owners which technique their customers use as long as it is not interfering negatively with the grid and affect the quality of electricity. Anna Wolf answers the question with the following quote:

> *"No, not that could be implemented on the customer side. The thing about batteries is that you can do a lot of things with them, it is a very flexible resource."* [43]

[43] Anna Wolf, Power Circle. Translated from Swedish to English.

9 Technoeconomic Case Study

In addition to the literature and interview study, a technoeconomic case study is performed focusing on economic calculations for residential battery storage. The case study intends to provide examples of economic viability regarding a potentially changed economic incentive for residential battery storage investments for customers with battery, solar PV and power tariffs. A small battery of 6 kWh combined with a solar PV system of 6 kW are simulated.

The case study presents costs and potential economic benefits that a battery can provide by lowering a consumer's power peaks. It further presents payback periods for battery and PV system installations for a Case Present (set in 2018) and a Case Future (set in 2030).

Chapter 9 is divided into several parts, where the method is presented initially and includes input data and assumptions. Thereafter a description of the foundations of the case is presented, followed by economic parameters used for Case Present and Case Future respectively. Calculations and results are presented together and include total cost for the considered household without system, economic savings with system as well as discounted payback periods for both Case Present and Case Future. Lastly a sensitivity analysis included, aimed at displaying high impact parameters regarding the discounted payback periods.

9.1 *Method & Case Description*

The technical calculations and simulations have been performed in the simulation tool System Advisor Model (SAM) and economic calculations in Excel. Information regarding utilized price information from grid operators SEOM and Vattenfall Distribution are presented in Appendix B. Information regarding SAM and how the simulations have been performed are found in Appendix C. Price information regarding used electricity rates, energy tax on electricity and estimated future grid fees are found in Appendix D.

The case study regards utilization of a 6 kWh battery that is considered subsidy-optimized[44]. Considered grid fees belong to network operators SEOM[45] and Vattenfall Distribution[46] in SE3. SEOM's price structure contains a fixed fee (SEK/yr) and a power tariff (kW/month). Vattenfall Distribution's provided price structure for grid fees is currently being reconstructed and data used for the case study is preliminary. Their preliminary grid fee consists of a fixed component, an energy component and a power component, seen earlier in Figure 10 in Chapter 4.5.2.

The chosen battery simulated is a Li-ion battery. The battery is in a setting of a one-family house with a set roof-mounted PV-production of 6 kW. The battery is optimized to cut power peaks by using an automated dispatch model in SAM where the peak load reduction is the main focus. How the simulation model is optimized can be studied in Appendix C. In SAM the battery is in a setting with PV production, and in regards to time restrictions for this report the possibility to simulate separate peak shaving contributions of battery and PV respectively was unavailable. The considered time spans studied are one contemporary scenario with data from 2018, called Case Present, and one future scenario set in 2030, called Case Future, with estimated parameters.

[44] The current energy storage subsidy sets the market price for residential battery storage. Since current subsidy is 60 % of the investment cost, with a maximum of 50 000 SEK, a subsidy-optimized battery storage has a market price of approximately 82 000 SEK. Market price restrictions limit the parameters of the battery storage.
[45] Prices accessible on SEOM:s website.
[46] Prices obtained from Thorstein Watne, Vattenfall Distribution via e-mail, 2019-04-24.

9.2 *Input Data & Assumptions*

Used load data regards a one-family household in Northern Sweden with electrical heating. The data is from 2018 and is assumed to be a normal load curve for a one family-household. Obtained load curve relates to a house in northern Sweden (SE1) while solar data, spot prices and electricity prices used relates to the Stockholm region (SE3). This is due to availability of data as well as geographic restrictions of network operators utilizing power tariffs.

The size of PV system was chosen without optimization with regards to the size of the battery. However, a qualified guess of the size of the PV system has been done in combination with reiterated tests in SAM on the performance of the total battery + PV system, resulting in a PV system of 6 kW combined with the battery of 6 kWh.

Technical data used in SAM for both Case Present and Case Future, regarding PV and battery system, as well as information on electricity consumption and geographic location, is presented in Table 4.

Table 4 Technical data.

Technical data	
Year	2018
Estimated lifetime battery [yr]	15
Estimated lifetime solar PV [yr]	25
Location solar data[a]	Stockholm
Degradation rate [%]	0
PV module efficiency[b] [%]	13.5
Geographic area for system installation	Stockholm, SE3
Annual electricity consumption [kWh/yr]	24 088
System location	SE3
Installed battery capacity [kWh]	6
Installed PV capacity [kW]	6

[a] Data obtained for lat. 59.335 and long. 18.063 (Stockholm), from European Commission's Photovoltaic Geographical Information System (PVGIS) and regards a typical metrological year from 2007 to 2016.

[b] At solar irradiance of 1 000 W/m^2

Table 5 presents ingoing **financial data** used for the economic calculations in Excel. All prices used in the economic calculations include VAT, except for Nord Pool's spot prices where this is not applicable.

Table 5 Financial data for the two cases.

Price data	***2018***	***2030***
VAT	25 %	25 %
Energy tax on electricity [SEK/kWh]	0.41	0.5
Tax reduction on excess generation [SEK/kWh]	0.6	0.6
Grid service on excess generation [SEK/kWh]	0.05	0.05
O&M[a]-costs [SEK]	0	0
Discount rate[b] (real) [%]	5	5

[a] Operation and Maintenance

[b] The real discount rate refers to what required rate of return the investor has, without consideration to monetary inflation

It is assumed that the modelled battery storage is charged and discharged optimally. Both SEOM and Vattenfall Distribution charge their customers a power charge based on a certain number of power peaks per month. This is disregarded within the modelling. Instead the single highest power peak per month is considered. For the future scenario of 2030 it is assumed that the battery + PV system will have the same technical qualities as today, and thus the performance will be the same.

The investment cost of the subsidy-optimized battery storage of 6 kWh includes inverter as well as both BMS and EMS. Table 6 includes investment costs for Case Present and Case Future, for both PV as well as battery with and without subsidy. Costs for battery storage are obtained from Nilar while costs for PV is estimated from Vattenfall's[47] available solar PV packages (Vattenfall n.d.). It is assumed that both investments are made with full subsidy.

Table 6 Applied costs for PV and Battery.

	System component	***Investment cost [SEK]***	***Available subsidy***	***Maximum subsidy***	***Investment cost with full subsidy [SEK]***
2018	**Solar PV, 6kW**	140 000	30 %[a]	37 000 SEK/kW	98 000
	Battery storage, 6kWh	82 600[b]	60 %	50 000 SEK	32 600
2030	**Solar PV, 6kW**	84 000	0 %	0 SEK	84 000
	Battery storage, 6kWh	15 000	0 %	0 SEK	15 000

[a] The subsidy has been revised 2019 and is currently at 20 %

[b] Price from Nilar and Ferroamp collaboration

[47] Vattenfall regards the part of the company that supplies electricity, whilst Vattenfall Distribution regards the part that distributes electricity and maintain their grids.

Additional technical input data for the battery and PV used in the simulations in SAM are found in Appendix C.

Used load data is depersonalized and regards a one-family house in the northern parts of Sweden[48], see Figure 25. This building has a yearly electricity consumption of 24 088 kWh with electric heating. The consumption for this type of household is considered normal, see Chapter 4.5. Figure 25 clearly shows the power peaks, visible as blue spikes. The changing general consumption depending on the seasonal variation between winter and summer is also possible to detect, where the summer months have a lower load of 0.5-5 kW on average, and the winter months have a higher demand of approximately 2-8 kW.

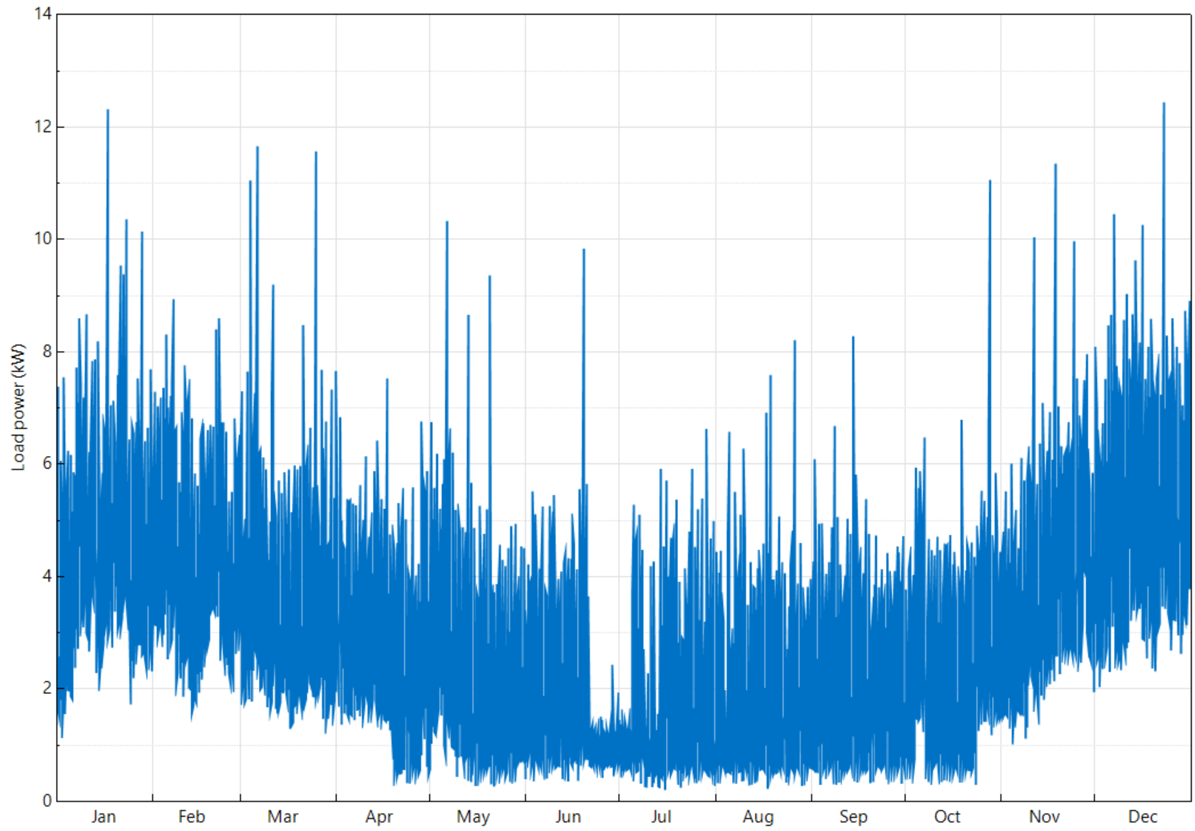

Figure 25 Load curve for a one-family house with electrical heating in Sweden 2018, based on data provided by Vattenfall Distribution.

9.3 *Economic Parameters 2018*

In this chapter the economic parameters that are considered for Case Present are described. The evaluated parameters are solar PV prices, battery prices, battery storage subsidy, grid fees, electricity rates and energy tax on electricity. Some of these parameters are presented in Chapter 9.2. As earlier stated, VAT is considered for all prices used in the calculations except for Nord Pool's spot prices where it is not applicable.

Solar PV prices

The price of solar PV is set to 140 000 SEK. With a 2018 solar subsidy of 30 %, the investment of solar PV is set to 98 000 SEK.

[48] Data obtained from Mona Sinclair, Vattenfall Distribution via e-mail 2019-03-21.

Battery prices
The battery price is set to 82 600 SEK, with an investment of 32 600 SEK after applied subsidy. That results in a price of 5 430 SEK/kWh for the 6 kWh-battery storage system.

Battery storage subsidy
The current battery storage subsidy is used for the battery system for Case Present, allowing applicants to subsidize 50 000 SEK of the investment cost.

Grid fees
SEOM's current grid fee and Vattenfall Distribution's preliminary grid fee are used, which can be found in Appendix B.

Electricity rates
Hourly prices from Nord Pool's spot market are used in order to estimate the total savings for the considered household. The spot prices are used for the surplus electricity produced and sold from the PV system. Figure 27, see Appendix D, shows weekly spot prices[49] for 2018, as well as significantly lower spot prices 2017. Data applies to SE3.

For the purchased electricity to the studied household, Vattenfall's variable electricity rates for 2018 in SE3 are used. This is considered adequate to apply, since it is possible for the customer to choose its own electricity supplier. The variable electricity rate includes Vattenfall's acquisition value, Nord Pool's spot prices, VAT, the cost for REC:s and Vattenfall's supplement charge. Energy tax on electricity and annual fee are not included (Vattenfall 2019a). The price development for monthly variable electricity rates for Vattenfall in SE3 2016 - 2018 can be seen in Figure 28 in Appendix D.

Energy tax on electricity
The energy tax used for Case Present 2018 is 0.41 SEK/kWh, including VAT (Konsumenternas Energimarknadsbyrå 2019c).

9.4 *Economic Parameters 2030*

In this chapter the economic parameters that are used in the financial calculations in Excel for Case Future are stated. The evaluated parameters are the same as for Case Present. As stated before, VAT is considered for all prices used in the calculations in Case Future as well, except for Nord Pool's spot prices where it is not applicable. VAT is assumed to be the same 2030 as in 2018, thus 25 %.

Solar PV prices
Solar PV prices are assumed to continue to decrease. In this scenario it is assumed that PV prices have dropped by 40 % by 2030 compared to today's prices, and will thus be 84 000 SEK for a 6 kW system. Moreover, it is assumed that the 2018 solar subsidy no longer is applicable, neither is any other type of solar subsidy for residential customers.

Battery prices
As described earlier in Chapter 7.4, see Figure 24 among others, battery storage prices are estimated to drop significantly in price within the coming years. Figure 24 estimates that

[49] Spot prices do not include prices for REC:s, supplement charges from the electricity supplier, VAT or energy tax (Nord Pool 2017).

battery storage prices will have dropped to 250 USD/kWh in the year of 2030. For the future scenario, it is thus estimated that battery storage prices will be 250 USD/kWh, i.e. 2 500 SEK/kWh and 15 000 SEK for a 6 kWh battery storage.

Battery storage subsidy
It is assumed that today's battery storage subsidy is no longer applied, and that no other battery storage subsidy is available for residential customers.

Grid fees
With the significant investment needs facing the Swedish power grid, in addition to the historic price increase of grid fees, the assumption is made that Swedish grid fees will continue to increase during the coming years. The estimated increase is based on calculations where it is assumed that the coming increase will be somewhat linear with the historic grid fee increase. Increase of grid fee is set to 40 %, and is evenly distributed over the different components of the grid fee for SEOM and Vattenfall Distribution, see Figure 10 in Chapter 4.5.2. Calculations of the estimations are found in Appendix D.

Electricity rates
Based on the information gathered in the literature study, the electricity price in Sweden is expected to increase in variability and price. However, the studied estimates of future electricity prices in year 2030 from SEA (*Four* futures) and NEPP (*Two NEPP-scenarios*), referred to in Chapter 4.7.3, do actually show a small decrease in electricity rates compared to the actual electricity prices of 2018. Nevertheless, it is important to note that the prices for 2018 are to be considered high compared to earlier years, see Figure 27 in Appendix D. The insignificant decrease in electricity price between estimations for 2030 and actual prices for 2018 is probably due to the unexpectedly high rates of 2018, partly relating to a dry summer 2018. A combination of the estimated values from NEPP and SEA are still used for the simulations of this future scenario. The future estimated electricity rate for both bought and sold electricity is set to 0.65 SEK/kWh.

Since the estimated future electricity price is uncertain, no price difference will be made between the electricity that is bought and that is sold. This thus differs from Case Present, where Nord Pool's spot prices are used for sold electricity and Vattenfall's variable electricity rate is used for purchased electricity. The purchased electricity has a higher price today than sold electricity, see Figure 27 and Figure 28 in Appendix D.

Energy tax on electricity
It is assumed that the energy tax on electricity continues to increase, as it has done during the last couple of decades in Sweden, see Figure 29, Appendix D. The figure shows a nominal increase of pricing. A qualitative estimation of the increase is made based on the previous increase, however without consideration to monetary inflation. Energy tax on electricity is set to 0.5 SEK/kWh 2030, including VAT.

9.5 *Calculations and Results*

In this chapter results from the simulations in SAM, calculations in Excel as well as the correlating results are presented for Case Present and Case Future.

9.5.1 Power Peak Shaving

Table 7 shows the demand peaks with and without the installed battery + PV system. Maximum peak shavings, reduced power peaks, have been iterated in SAM, see Appendix C for further explanation.

Table 7 Power peaks [kW] with and without battery + PV system, as well as peak shaving for a one-family household. Peak shavings based on iterations and optimization in SAM. Data in kW for 2018.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Power peak without system [kW]	12.1	8.7	11.5	7.5	10.1	9.6	6.4	8.0	8.1	10.9	11.1	12.2
Power peak with system [kW]	9.2	6.5	7.5	4.3	6.7	5.1	2.9	5.3	4.1	6.9	7.6	8.6
Peak shaving [kW]	2.9	2.2	4.0	3.2	3.4	4.5	3.5	2.7	4.0	4.0	3.5	3.6

Since monthly power load peaks do not always correlate within the timeframe of SEOM's time-differentiated power tariff, alternative power peaks that occurred within the considered timeframe, during 07-19 on weekdays, were instead identified. With these alternative power peaks, correlating maximum peak shaving was calculated for SEOM, see Table 8. This peak shaving is used in the economic calculations to evaluate the profitability of the battery + PV system.

Table 8 Power peak and peak shaving when SEOM's timeframe for applied power tariffs are considered. Data in kW for 2018.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Power peak within time frame, without system[kW]	12.1	8.4	11.5	7.3	6.4	5.0	5.5	6.7	5.2	6.6	7.8	10.2
Peak shaving [kW]	2.9	1.9	4.0	3.0	0.1	3.8	2.6	1.4	1.1	0	0.2	1.6

9.5.2 Case Present

This chapter includes calculations and results for Case Present.

Economic Costs without System

The total electricity cost without the battery + PV system were obtained by summarizing the costs of the fixed grid fee, demand charge and/or energy fee, the electricity rate and tax and VAT. The total electricity cost with SEOM's power tariff results in **35 400** SEK per year.

With Vattenfall Distribution’s grid fee the total cost is calculated to **44 800** SEK per year, thus higher than SEOM’s total cost. This can be seen in Table 9.

Table 9 Costs per year without system and with SEOM and Vattenfall Distribution’s grid fees respectively. Prices in SEK/year.

	Fixed grid fee	***Power tariff and Energy fee***		***Electricity rate costs***	***Energy tax on electricity***	***TOTAL COSTS***
SEOM	1530	Power tariff[a] 7560		16 340	9 970	**35 400 SEK/yr**
Vattenfall Distribution	2400	Power tariff 7900	Energy fee 8190	16 340	9 970	**44 800 SEK/yr**

[a] Time-differentiated

Economic Savings with System

The total yearly savings were calculated by adding saved costs for decreased demand charge, income from selling excess generation, tax reduction and grid services, reduction of electricity rate costs and reduction of corresponding tax and VAT. The total economic saving with SEOM’s grid fee amounts to **10 610** SEK per year, considering time-differentiation of the power tariff. With Vattenfall Distribution’s grid fee the total savings with the system amounts to **13 640** SEK per year, see Table 10.

Table 10 Economic savings per year with battery + PV system and SEOM and Vattenfall Distribution’s grid fees respectively. Prices in SEK/year.

	Peak shaving savings of grid fee		***Selling of excess generation***	***Tax reduction and grid services***	***Reduction of electricity rate costs***	***Reduction of tax on electricity***	***TOTAL SAVINGS***
SEOM	Power tariff[a] 1 750		1 340	1 080	4 050	2 390	**10 610 SEK/yr**
Vattenfall Distribution	Power tariff 2 820	Energy fee 1 960	1 340	1 080	4 050	2 390	**13 640 SEK/yr**

[a] Time-differentiated

The savings regarding lowered demand charge were obtained by calculating the difference in peak load with and without system and multiplying it with applied power tariff for SEOM and Vattenfall Distribution respectively. Price information regarding grid fees are found in Table 17, Appendix B. For SEOM, the applied peak shaving within the time frame were used, see Table 8. Since Vattenfall Distribution does not apply a time-differentiated power tariff, the original power peaks could be used, see Table 7 above. However, Vattenfall Distribution applies an energy fee in their grid fee. The energy fee savings are calculated by multiplying the Enkeltariff with the difference in monthly electricity load with and without battery + PV system. The total demand charge savings from peak shaving is **1 750** SEK for SEOM and **2 820** SEK for the power tariff and **1 960** SEK for the energy fee savings, thus totally **4 780** SEK in peak shaving savings for Vattenfall Distribution.

Calculations regarding selling of excess generation are obtained by multiplying the excess generation combined with the hourly spot prices from Nord Pool for 2018 for SE3, seen in

Figure 27, Appendix D. The savings from excess generation are the same for Vattenfall Distribution and SEOM and adds up to **1 340** SEK for a year.

Savings from tax reduction due to excess generation and grid services are calculated by multiplying these two values separately, see Table 5, with the annual excess generation of 1 667 kWh for year 1. The total savings from tax reduction and grid services are calculated to **1 080** SEK for a year and are the same for both SEOM and Vattenfall Distribution.

The savings in electricity rate costs are calculated by using the variable electricity rate from Vattenfall in SE3 for 2018, monthly data found in Figure 28, Appendix D. The variable electricity rates were multiplied with the monthly electricity saving from battery + PV system for 2018. This accumulates to an economic saving of **4 050** SEK for 2018 and is the same for both SEOM and Vattenfall Distribution.

The reduction of tax and VAT on electricity is calculated by taking the annual reduction in electricity needed with the system compared to without system, obtained to 5 766 kWh in SAM. This is then multiplied with the energy tax on electricity, including VAT, of 0.4138 SEK/kWh for 2018. The acquired saving is **2 390** SEK for the first year, the same for both SEOM and Vattenfall Distribution.

Due to SEOM's time-differentiated power tariff, the considered peak shaving will be different depending on if the time-differentiation is considered or not, as earlier described. Table 11 shows the difference in savings between the case with and without consideration to time-differentiation. However, the yearly difference in low and high load is still included in these results. It is clear that the savings would increase if the time-differentiation was not considered. It is thus possible to say that several of the power peaks for the studied load curve are outside of the time span, either during weekends or during the night hours (19-07).

Table 11 Savings from peak shaving with system, with and without consideration to SEOM's time-differentiated power tariff, [SEK/year].

Demand charge savings with and without time-differentiation SEOM	
Savings with time-differentiation	1 750 [SEK/year]
Savings without time-differentiation	3 060 [SEK/year]

Discounted Payback Periods

The discounted payback period were calculated based on the cumulative annual savings from applying the battery + PV system and the cumulative annual costs, as well as a discount rate of 5 %. Table 12 shows discounted payback periods with both SEOM and Vattenfall Distribution's grid fees presented. For applied equation and further explanation, see Appendix D.

Table 12 Discounted payback periods for Case Present.

Discounted payback periods Case Present	*SEOM [years]*	*Vattenfall Distribution [years]*
Battery with subsidy + PV with subsidy	19.6[a]	13.3
Battery without subsidy + PV with subsidy	38.9 [a]	22.2 [a]
Battery with subsidy + no PV costs	3.4	2.6
Battery without subsidy + no PV costs	10.1	7.4

[a] Since these payback periods are longer than the set lifetime of the battery, none of them are possible to achieve. The economic calculation is thus not justified for these cases.

As can be seen in Table 12, the payback periods are generally shorter for Vattenfall Distribution's grid fees, both with and without considering the battery subsidy and the PV costs. It can also be seen that discounted payback periods significantly differ if the battery subsidy is considered or not, as well as if the PV installation cost is considered. If the PV installation cost is not considered it is important to note that all savings from the system will be allocated to the battery, even if they might derive from the PV production.

9.5.3 Case Future

The total savings for Case Future 2030 were calculated the same way as for the present scenario, except that estimated values of 2030 were used in the calculations, found in Chapter 9.4.

Economic Costs without System

The total cost for Case Future, without battery + PV system but otherwise with the same prerequisites as for Case Present, i.e. the same weather and load data, is obtained the same way as for Case Present. The total cost with SEOM's grid fee accounts to **40 420** SEK per year. With Vattenfall Distribution's grid fee the total cost is calculated to **53 590** SEK per year, and thus higher than total cost of SEOM. This is presented in Table 13.

Table 13 Total cost calculations per year for Case Future, without system and with SEOM's and Vattenfall Distribution's grid fees respectively. Prices in SEK/year.

<table>
<tr><th></th><th>Fixed grid fee</th><th colspan="2">Power tariffs and Energy fee</th><th>Electricity rate costs</th><th>Tax on electricity</th><th>TOTAL COSTS</th></tr>
<tr><td>SEOM</td><td>2 140</td><td colspan="2">Power tariff[a]
10 580</td><td>15 660</td><td>12 040</td><td>40 420 SEK/yr</td></tr>
<tr><td>Vattenfall Distribution</td><td>3 360</td><td>Power tariff
11 060</td><td>Energy fee
11 470</td><td>15 660</td><td>12 040</td><td>53 590 SEK/yr</td></tr>
</table>

[a] Time-differentiated

Economic Savings with System

The total savings were calculated by adding the saved costs relating to grid fees, the income from selling excess generation, tax reduction and grid services, from reduction in electricity rate costs and reduction of corresponding tax and VAT. The total savings with SEOM's tariff systems are calculated to be **11 600** SEK per year. With Vattenfall Distribution's applied grid fees the total savings with the system would be **15 830** SEK per year. This is presented in Table 14.

Table 14 Economic savings per year, with battery + PV system with SEOM and Vattenfall Distribution's grid fees respectively, for Case Future. Prices in [SEK/year].

<table>
<tr><th></th><th colspan="2">Peak shaving savings of grid fee</th><th>Selling of excess electricity generation</th><th>Tax reduction and grid services</th><th>Reduction in electricity rate costs</th><th>Reduction of tax on electricity</th><th>TOTAL SAVINGS</th></tr>
<tr><td>SEOM</td><td colspan="2">Power tariff[a]
2 460</td><td>1 430</td><td>1 080</td><td>3 750</td><td>2 880</td><td>11 600 SEK/yr</td></tr>
<tr><td>Vattenfall Distribution</td><td>Power tariff
3 950</td><td>Energy fee
2 740</td><td>1 430</td><td>1 080</td><td>3 750</td><td>2 880</td><td>15 830 SEK/yr</td></tr>
</table>

[a] Time-differentiated

Discounted Payback Periods

With an estimated battery price of 2 500 SEK/kWh the investment cost for a battery of 6 kWh equates to 15 000 SEK. Since it is assumed that there is no longer any battery subsidy, there will only be a discounted payback period for the estimated battery price in 2030 and not for any case with subsidy. The discounted payback period is calculated the same way as for Case Present, thus with a discount rate of 5 % and respective savings by using either SEOM or Vattenfall Distribution's grid fees. Table 15 shows estimated discounted payback periods for Case Future.

Table 15 Discounted payback periods for Case Future.

Discounted payback periods Case Future	***SEOM [years]***	***Vattenfall Distribution [years]***
Battery + PV costs	11.4	7.7
Battery + no PV costs	1.4	1.0

For Case Future, the discounted payback periods have decreased compared to Case Present. Here the discounted payback period is calculated to **11.4** years for SEOM and **7.7** years for Vattenfall Distribution, including PV costs. When PV cost is disregarded the discounted payback period is very short for both cases, with a result of **1.4** years for SEOM and **1.0** years for Vattenfall Distribution.

9.6 *Sensitivity Analysis*

In the sensitivity analysis a number of input parameters used in Case Present are varied in order to determine respective parameter's impact on discounted payback period. This is achieved using SEOM and Vattenfall Distribution's grid fees. The parameters that are varied are:

- Total investment of battery + PV system
- Grid fee

- Electricity prices[50]
- Energy tax on electricity
- Discount rate

The variation of the parameters is set to both increase and decrease with the same percentage. The percentual variation is based on both a plausible change. For the grid fee, also a greater adjustment is varied in order to further investigate its influence on the discounted payback period. Table 16 shows the sensitivity analysis with a base scenario where both battery and PV costs are accounted for as well as their respective subsidy.

Table 16 Sensitivity analysis for Case Present with cost for battery + PV system. Full subsidy applied.

Case	***Scenario description***	***Data input [%]***	***Discounted payback period, SEOM [years]***	***Discounted payback period, Vattenfall Distribution [years]***
Base Case	Case Present with battery + PV system costs	-	19.6	13.3
Case 1	Increase of total investment[a]	+10	23.1	15.3
Case 2	Decrease of total investment	-10	16.5	11.5
Case 3.a	Small increase of total grid fee	+10	19.0	12.7
Case 3.b	Large increase of total grid fee	+50	17.2	10.7
Case 4.a	Small decrease of total grid fee	-10	20.1	14.0
Case 4.b	Large decrease of total grid fee	-50	22.7	17.8
Case 5	Increase of electricity prices	+10	18.0	12.6
Case 6	Decrease of electricity prices	-10	21.4	14.1
Case 7	Increase of energy tax on electricity	+10	18.8	13.0
Case 8	Decrease of energy tax on electricity	-10	20.3	13.7
Case 9	Increase of discount rate	+50[b]	35.3	17.5
Case 10	Decrease of discount rate	-50[c]	14.9	11.1

[a] Total investment in the sensitivity analysis equals the price for battery with subsidy and PV system with subsidy, thus a total investment cost of 32 600 SEK + 98 000 SEK, which amounts to 130 600 SEK

[b] An increase of 50 % of the original discount rate correlates to a new discount rate of 7.5 %.

[c] A decrease of 50 % of the original discount rate correlates to a new discount rate of 2.5 %.

[50] Both Nord Pool's spot prices (for sell) and Vattenfall's electricity rates (for purchase) included

Table 16 shows that variation of total investment and of discount rate have the largest effect on the discounted payback period. It is also important to note that all payback periods longer than 15 years are not reasonable considering that the lifetime of the battery storage is set to 15 years. It is thus impossible for the system to continuously create monetary value, i.e. savings, after it has stopped functioning. However, a changed battery storage lifetime can also be reflected upon in the sensitivity analysis, since it is fairly uncertain due to lack of real time experiences. Due to that a changed lifetime of the battery storage does not affect the discounted payback period, it is not considered in the sensitivity analysis.

10 Analysis

This part triangulates results from the literature, interview and technoeconomic case study in in order to answer the proposed research questions. The analysis is divided into segments discussing legal parameters, additional system services that residential batteries can provide on a local scale, as well as economic viability.

10.1 *Legal Parameters*

The legal framework regarding the Swedish electricity market is old-fashioned and in need of modernization. New market players have evolved such as prosumers and smart energy services and the rapid development of technology such as battery storage demands updated regulation. This is necessary in order for these new market players to be allowed to provide flexibility to the power system. As found in the literature study, SOU 2018:76 proposes several changes necessary to adapt the Swedish Law of Electricity to the future electricity system.

10.1.1 Regulatory Changes

Even though a battery connected to a concessional grid in itself does not produce or use electricity, the owner is required to pay energy tax on electricity stored in the storage as well as in the electricity later fed back to the grid. In SOU 2018:76, it is proposed to exclude owners of battery storage from the demand of dual taxation. This would improve the profitability of battery storage. It should be noted that this aspect has not been taken into considerations for the technoeconomic case study. Another factor allowing for uncertainties within this field is the fact that the Swedish Law of Electricity includes no clear definition of electrical energy storage is. The need for clarification in this area might seem like a minor detail, but would likely increase the clarity regarding how electrical energy storage can be utilized and under what conditions, and thus open up for new market usages and business cases. If the proposition regarding regulations of who can apply for energy storage subsidy come through[51], that means that a larger group of potential beneficiaries could receive funds for installing decentralized battery storage. With an increased maximum subsidy of 150 000 SEK, a potential increased amount of municipalities, companies and Brf:s, who already have or plan to install solar PV, would consider investing in battery storage to enable increased usage of self-produced electricity and thus lower their demand charges. The requirement for micro-production among applicants of the current energy storage subsidy is proposed to be removed. This would allow consumers without self-production to receive the energy storage subsidy and thus open up for new business cases. However, since it does not seem to yet be profitable utilizing only a battery, this would likely not have a larger effect on the battery storage market today. With lower battery prices and increased power tariffs this might change. Moreover, customers with high sensitivity to blackouts and similar might consider installing battery storage instead of using for example a diesel motor as back-up. With increased number of grid failures per year, customers in sensitive parts of the grid could consider the incentive to invest in battery storage larger due to safety reasons.

All of these proposed changes could all have a positive impact for increased implementation of residential battery storage. It should however be stated that according to the literature and interview study, the current energy storage subsidy has not been significantly utilized. With estimated decreasing battery prices, the future of the energy storage subsidy on a longer time frame is unknown.

[51] Decision expected 2019

10.1.2 Tariffs

As mentioned in Chapter 4.4, Ei today requires that grid fees shall be non-discriminating, meaning that the network operators must offer the same type of tariff options to all customers. Results from the interview study point to that several interviewees consider this to restrain several measures of available flexibility options. Many interviewees argue that a more dynamic tariff allowance would let grid operators offer a larger variation of tariffs. The idea behind a more dynamic tariff structure is that different consumers strain the grids in various ways, and as a result of this would be obliged to pay differently. This could potentially result in tariffs based on whether the customer owns an EV, battery storage, solar PV or would be willing to accept a certain number of blackouts per year among others. No certain tariff design is recommended, but instead it is suggested that a more dynamic tariff design would increase the possibilities for enhanced flexibility in the system. Results from the literature and interview study further highlight the need for enabling grid operators to experiment through so called experimental sandboxes or similar. This is considered an important measure towards providing flexibility.

The interview study highlights that several of the interviewed grid operators find Ei's regulation of power tariffs slightly unclear. It further points to the need for grid operators to clearly explain to their customers how the power tariff is applied and in what ways consumers may benefit from it. Given that consumers today have a generally low interest in issues relating to the grid, the need for information and clarification regarding the power tariff grows increasingly important with the larger introduction.

Another factor related to how tariff design could affect the grids, are whether or not they are time-differentiated. According to the literature study, time-differentiated power tariffs could potentially incentivize consumers to consume power during low peak load hours, something that Ei advocates. Non time-differentiated power tariffs would to a higher degree incentivize power peak reductions. With SEOM's time-differentiation of their power tariff, the case study shows that several of the highest monthly power peaks in the studied cases occur outside of the time frame[52]. That could mean that consumers do not find the economic incentive significant enough to actively affect their consumption. This conclusion is validated by Johan Fält, SEOM. According to the preliminary data obtained from Vattenfall Distribution regarding their planned future grid fee structure, the power tariff will be constant over the course of the day for their small customer segment. Thus, this power tariff is likely to enhance power leveling effects rather than power shifting. However, a constant power tariff would mean that customers would need to be aware of their power outtake throughout the whole day, if no aggregating or energy service is applied. It should be mentioned that these results only regard the one studied household.

10.2 *Flexibility Measures*

As mentioned earlier in the report, residential battery storage can provide several system benefits to local grids. By lowering power load peaks and allowing households to consume more self-produced PV electricity, flexibility can be provided on a local scale. The literature study points to that with increased intermittent electricity production and decreased battery prices, batteries could potentially be one part of solving the issue with surplus production as well as problems regarding capacity shortage and bottlenecks within the local grids. An increased introduction of power tariffs among Swedish grid operators is seen as both an

[52] Dimensioned time is 07-19 weekdays for SEOM

incentive towards increasing demand flexibility and for more residential battery storage among end consumers.

The interview study concludes that several of the interviewed grid operators are neutral or positive towards residential battery storage among their customers. The reason for this is the possible lowered power peaks for consumers, which could allow network operators to plan their local distribution better, as well as possibly lessen their needs to invest in new cables or need to decrease, or not increase, the subscription to overhead grid. However, other interviewed grid operators do not have a direct interest in residential battery storage but instead are positive to utilizing larger batteries within the grids. Several of the interviewees further highlight the need for aggregators to provide sufficient flexibility of capacity. Both the literature and interview study point to that demand flexibility could be of importance in the future system, but that consumers today lack knowledge and do not consider the economic incentive sufficient in order to actively change their load patterns. Therefore, the future role of aggregators is intriguing, since this would remove the idea of customers having to engage actively in their consumption. Aggregating capacity with residential battery storage has high potential of helping with flexibility issues in a larger scale than just in the local grids.

As resulting from the three applied methods of the report, different tariff designs are aimed at incentivizing different behaviors among consumers. One problematic factor regarding a time-differentiated power tariffs is the possibility of customers choosing to shift their largest power outtakes to times just outside of the set time-frame, causing high power peaks during early and late hours of the day. This way, the high power peaks still occur but outside of the dimensioned time of the tariff, when the strain on the grid is high. This can possibly result in alternate power peaks, causing strains on the grid just before and after the tariff is applied during the day. Vattenfall Distribution's power tariff that is constant over the course of the day, could to a higher regard than SEOM's tariff allow for a more levelized power outtake. Given the non-varying times Vattenfall Distribution´s applied tariff, it could potentially be too large of an infringement on comfort of customers. It is therefore rather difficult to determine which of the considered tariff designs are the most efficient from a flexibility perspective.

It is further concluded that measuring several of the highest power peaks among consumers over the course of one month, could potentially incentivize customers to lower their power peaks in a higher regard, compared to if only the single highest value was measured and charged for. This could be due to that if a customer causes a high power peak initially during the month, the customer might not see any means to generally lower peaks that month since the demand charge then already is set.

As mentioned in the in the literature study and by several of the interviewees in Chapter 8, the future role of aggregators on the Swedish electricity market is highly interesting in the aspect of providing flexibility and avoiding capacity shortage in local grids. Both the literature and interview study show that providing demand flexibility for end customers could be positive in regards to proposed issues. However, the idea of customers engaging actively by shifting or levelling out load is unlikely, due to the limited current economic incentives and a generally low interest among the general consumer. By allowing aggregators to engage on the market, consumers would not have to actively think or act themselves about their consumption. This solution would allow for grid operators to plan their distribution more evenly and potentially postpone future grid investments. Moreover, in order to be part of the regulating power market to contribute with flexibility to the Swedish grid quite large size of the bids are necessary, as described in Chapter 4.4. By getting access to and aggregating flexibility through residential customers, aggregators would then have the possibility to be a part of the Regulating Power Market, which would not be possible for the individual residential customer.

10.3 *Economic Analysis*

In this part of the analysis, economic barriers are discussed for increased implementation of residential battery storage, as well as what effects an increased introduction of power tariffs could have on the total electricity cost for a household, as well as what savings that can be obtained through installation of battery + PV system. The payback periods for battery + PV system combined with power tariffs is discussed, and what monetary savings can be allocated to the battery. An analysis of Case Future is also presented as well as a sensitivity analysis discussion of Case Present.

10.3.1 Barriers

One of the largest economic barriers today inhibiting increased implementation of residential battery storage is the price, according to both the literature and interview study. If battery prices do not fall, there will be no profitability of installing a residential battery system unless the customer is highly active regarding its electricity usage, according to almost all interviewees.

The still rather low electricity price in Sweden, compared to many other countries, is another barrier for higher implementation of residential battery storages. Due to the comparably low electricity price, there is not sufficient incentives for customers to decrease or shift their use of power, and thus not profitable to invest in battery storage.

A third economic barrier for increased implementation of residential battery storage is that the battery technology could be difficult to understand for both retailers and end customers. Since residential battery storage is still a fairly young technology, long-time tests in real settings are not yet common. Combined with low knowledge about battery technology, that could make an investment in residential battery storage seem uncertain or risky for the common customer. Since the retailers many times also lack knowledge, it is hard for them to answer questions from the customers accurately. There is currently too little awareness of batteries among the public for this technology to be of significant interest.

10.3.2 Economic Impact of Tariffs

A general increased introduction of changed grid fees, including power tariffs, in Sweden could affect the total electricity cost of consumers. In Table 9 the total electricity costs with SEOM and Vattenfall Distribution's grid fees are presented. The total cost amounts to 35 400 SEK per year with SEOM's grid fee and 44 800 SEK per year with Vattenfall Distribution's grid fee, for on the analysed household. Both these total electricity costs are higher than the average total electricity cost of approximately 26 000 SEK/year (2017) and 29 000 SEK/year (2018) for a customer with a consumption of 20 000 kWh per year. It is important to note that the analysed household has a slightly higher electricity consumption of approximately 24 000 kWh per year, but that the difference in total costs of electricity are greater than what can be ascribed to the differing consumption. When Vattenfall Distribution's grid fee including a power tariff is introduced, some customers could see a distinct increase in cost compared to an average household without power tariffs. However, customers with generally lower power peaks could expect lower grid fees, due to that the revenue cap is regulated by Ei. This conclusion coincides with results from the interview study, which signifies that customers who have an interest for, and consider the incentive sufficient, can actually actively affect their total grid costs.

The demand charges accounts to 21 % and 17 % respectively of the total cost of electricity, with Vattenfall Distribution and SEOM's grid fees. With regard to the total grid fee[53], the grid fee accounts to approximately 25 % of the total cost when SEOM's grid fee is applied and approximately 40 % of the total costs, when Vattenfall Distribution's grid fee is applied for the analysed household. In Figure 8, Chapter 4.5, it can be seen that a customer with a usage of 20 000 kWh per year has a grid fee that accounts to approximately 25 % of the total electricity cost 2017. It is thus clear that Vattenfall Distribution's proposed grid fee is very large compared to the norm, and will have an extensive effect on the total electricity cost based on the results from the analysed household. Alike Figure 8, SEOM's grid fee accounts to the same percentage of the total electricity cost as for the compared average costumer. It is thus hard to tell whether or not a larger implementation of power tariffs will increase the total electricity cost. It seems that it will differ depending on structure of grid fee, what network operator is considered as well as the load profile.

The technoeconomic case study shows that the total electricity cost can be lowered by installing a battery + PV system for the analysed household. This is possible due to both decreased power peaks and increased use of surplus generation. Thus, monetary savings can be achieved through both decreased demand charges, due to the power peak reductions, and through less need for purchasing electricity, given micro-production. According to the results in the case study for Case Present, savings amounts to 10 610 SEK per year with SEOM's time-differentiated grid fee. With Vattenfall's grid fee, the total savings with the system amounts to 13 640 SEK per year.

The relatively high savings when applying Vattenfall Distribution's grid fee and battery + PV system, are based on both a high original cost and that the system is optimised to cut the highest power peaks. However, the total electricity cost with Vattenfall Distribution's grid fee and when using the battery + PV system is still higher than that of SEOM's grid fee, even though the yearly savings are less for SEOM's grid fee. Since SEOM's power tariff is time-differentiated, the power peak reduction for the studied household will be lower than for the case with Vattenfall Distribution's grid fee, as seen in Table 8. This results in lower savings appropriated to the power tariff, since the studied household had many of its highest power peaks outside of the time span where SEOM's power tariffs are applicable. If the time-differentiation is not accounted for, the savings by power peak reduction with SEOM's power tariff would increase and thus so would the total savings. However, it is important to remember that this only is valid for the studied household. Another household could have a different number of power peaks within the time frame of SEOM's power tariff, and thus the savings from power peak reduction would be corresponding to the savings applied with Vattenfall Distribution's grid fee.

Another aspect important to recognise regarding the power peak shaving for the two different grid fees, is that the system in SAM is optimized to cut the power peaks as much as possible compared to the highest peak every month, and not compared to the highest peak within the time frame of SEOM's power tariff. This could also impact the results to favour the demand

[53] Total grid fee consists of fixed grid fee, power tariff and energy fee where it is applicable.

charge savings when using the grid fee from Vattenfall Distribution, that is not time-differentiated, and thus full peak shaving optimization can be applied.

The grid fee savings assigned to peak shaving are much lower when applying SEOM's grid fee compared to Vattenfall Distribution's. When only considering the power tariff (and energy fee for Vattenfall Distribution) of the grid fee, the savings from peak reduction amounts to approximately 15-20 % of the total savings. This implies that savings from the other four sections that are accounted for have a great impact on the total savings and that the power tariff only is one part of the explanation of the savings when implementing the battery + PV system.

As can be seen in Table 10, the economic incentives for installing a residential battery storage + PV system with the goal to cut power peaks, is not insignificant. The savings that could be made with the installed battery + PV system in Case Present, allow for discounted payback periods of 19.6 years and 13.3 years for SEOM and Vattenfall Distribution respectively, when considering costs for both PV and battery with full subsidies. The payback period of 19.6 years is not possible to actually achieve, since the lifetime of the battery is set to 15 years, and thus shorter than the payback period. The calculated payback periods achieved with Vattenfall Distribution's grid fee considering costs for both battery and PV are more viable. For a private person, an investment that pays off within that time frame is possible, as long as the investment costs can be covered. According to the calculations performed in the technoeconomic case study, the investment will pay off the last couple of years with Vattenfall Distribution's grid fee, and thus be profitable. When no consideration is taken to PV costs, but including the battery cost with full subsidy, the payback periods are significantly lower for both SEOM and Vattenfall Distribution.

Given the significant installation costs of solar PV compared to the battery storage investment costs, it could be of interest to analyse payback periods considering only battery costs. The calculated discounted payback periods, considering only battery costs, including the battery subsidy, can be seen as very short. Considering that many believe that batteries are still too expensive, this result shows the opposite. However, the calculated discounted payback periods can be argued as reasonable from an economic standpoint due to the optimized peak shaving modelling, that no O&M-costs are considered as well as no degradation of the system is accounted for, that the battery subsidy is applied and that all revenues are allocated to the battery, even though they might derive from the PV system. This way of allocating costs and savings could be considered misleading. Including above mentioned factors into the technoeconomic calculations could potentially have allowed for more reliable and authentic conclusions.

Assumptions

Several assumptions were applied in order to make the simulations and calculations necessary for the technoeconomic case study. These affect the economic outcome of the case study and therefore needs to be reviewed and analysed.

Firstly, load data is used for a household situated in SE1, but all price data is taken for SE3. Households in SE1 might have a slightly higher electricity consumption and power peaks due to the colder weather and longer winter. Simultaneously, the price on electricity is sometimes cheaper in SE1 than in SE3. The electricity consumption of the household is considered normal in all Swedish pricing regions, therefore all other used data regards to SE3 where the chosen network operators are active. This is due to that this factor is assumed to have a larger impact on the result than the normal electricity consumption. These differences are however assumed to be minor and thus do not have any larger effect on the economic calculations and results of the technoeconomic case study.

Secondly, only the highest monthly power peak is accounted for when calculating demand charge. Vattenfall Distribution and SEOM identify 5 and 3 of the customers' highest power peaks[54] every month respectively to get a mean power peak. Thus, the actual power peak used for calculating the demand charge will be lower than what is assumed in the technoeconomic case study. However, the peak shaving would also be smaller, due to lower peak reduction. As a result of this, demand charge savings would also decrease. This indicates that the payback period would not change significantly, since it is based on the savings as well as the total costs. If both are lower, the proportion between them do not change significantly, and thus the payback periods would be more or less the same.

Thirdly, the technoeconomic simulations and calculations are applied assuming optimal conditions. The load data is known in advance and thus the battery can be optimized for peak shaving in regard to that exact load data. No O&M costs are accounted for, nor degradation of the system. This is not how it looks like in real life applications, and thus the peak shaving capabilities along with electricity production will be lower than in the simulated case. Moreover, total costs for the system would be higher if O&M costs were considered, generating lower continuous revenues and savings and thus increased payback periods. However, it is assumed that these are still reasonable assumptions in order to perform any simulations and calculations. The degradation rate of the system is usually not that high, i.e. approximately 0.5 % per year or less, the O&M costs can be seen as negligible compared to the total investment costs of the battery + PV system, and the result from the optimization of the battery's peak shaving capabilities is also considered reasonable. This is due to that the load curve will differ slightly between different households and years, and thus the peak shaving capabilities will differ from year to year and household to household and are therefore not more exact than the assumed peak shaving capabilities of the battery. Moreover, in the future it can be assumed that the peak shaving optimization of the battery + PV system probably will adapt and become better, based on more available data, such as improved electricity and power usage predictions, weather data, electricity price predictions and more. These improved predictions will lead to a potentially improved optimization for residential battery + PV system and thus increase the profitability of the system.

Allocating Costs and Savings

When simulating a combined system of both battery storage and PV-production, it can be difficult to allocate exact numbers regarding how much the battery contributes to the total savings, since the peak reduction is a combination of both using self-produced electricity with the PV system and shifting or decreasing power peaks by using the battery. However, in order to understand for example how the battery can influence peak shaving, and reduction of the demand charge, as well as total cost savings of electricity, allocating certain costs and savings is important.

Firstly, it is important to remember that a battery only can shift load and the time of electricity purchase. It is not possible to buy or use less electricity simply with a battery. To decrease the amount of purchased electricity, it is therefore necessary to have some sort of self-production of electricity. Thus, the large part of the savings that correlates to buying less

[54] Within the time frame of 7 – 19 weekdays for SEOM

electricity is coupled with micro-production and it can thus be concluded that a system with only a battery is less profitable than a system with both battery and PV. This is validated by the results seen in Table 10 in Chapter 9.5.2, where it is clear that the economic savings from reduction of purchased electricity is a significant part of the total savings from a battery + PV system. This means that the incentive for installing a battery without micro-production is lower than for a combination of battery storage and micro-production.

It is difficult to allocate exact numbers regarding how much the battery contributes to the total savings, since the peak reduction is a combination of both using self-produced electricity with the PV system and shifting or decreasing power peaks by using the battery. For the discounted payback periods when cost of PV system is not included, it can be seen as all savings are allocated to the battery. Thus, these results are somewhat misleading and show a very short payback period, since some of the savings should be allocated to the PV system and its cost. However, these payback periods are still of interest, since the PV installation cost is significantly higher than the battery investment cost. Therefore, to get a better understanding of the impact of the battery cost among total cost of the system, payback periods simply for battery storage are considered.

10.3.3 Case Future

Considering economic savings with battery + PV system for Case Future, savings with grid operator SEOM are still less than for Vattenfall Distribution. Moreover, only a slight increase in economic savings with both grid operators compared to Case Present. A potential reason why economic savings have not increased more by 2030 is likely due to that the estimated electricity price used in the calculations for 2030 actually is lower compared to the rates used for 2018. As mentioned earlier, this is probably a result of unusually high rates 2018, that partially is caused by a dry summer. The small decrease in electricity price means that the change of purchased electricity as well as selling of excess generation are slightly lower 2030 than 2018, but do not differ significantly between 2018 and 2030. However, this is considered unlikely since predictions obtained in the literature study as well as from the interviews, foresee increased electricity prices. A larger difference in electricity price between the two considered cases would significantly improve the potential savings that could be applied with an installed battery + PV system.

What is clear from the results is that total costs for the studied household with grid operator Vattenfall Distribution is undoubtedly higher than with SEOM for 2018, and increasingly so in 2030. This could mean that Vattenfall Distribution’s introduction of power tariffs could have serious impact on total electricity costs for households that do not take into consideration how and when they use power. It should be stated that this conclusion only regards the studied household and is not intended to give an indication that Vattenfall Distribution’s introduction of power tariffs potentially can mean increased grid fee costs for household with considered load pattern and dimension.

The calculated payback periods 2030 are significantly lower than 2018. For Case Future it is assumed that currently subsidies are no longer applied, with regards to lower future investment costs of PV and battery storage. This assumption is based on that the current solar subsidy was reduced from 30 % to 20 % in 2019 and that PV and battery costs are estimated to decrease significantly. The estimated Case Future provides unquestionably shorter discounted payback periods than Case Present for battery storage, both with and without PV costs included. The payback periods for Vattenfall Distribution are shorter than for SEOM in Case Future which reflects the results in Case Present. It is concluded that parameters impacting payback periods the most when comparing Case Present with Case Future are investment costs of battery + PV system and increased grid fees.

There are several uncertain factors to estimate relating to Case Future. Future electricity prices cannot be predicted and depend on several factors, as earlier discussed. Electricity prices used for Case Future were obtained from SEA:s *Four futures*. This estimated price was used for both purchasing and selling electricity, since the estimations were considered uncertain regarding the considered time span. Usage of a more authentic electricity price both for selling and purchasing electricity for a micro-producer would have made the calculations more factual. However, with several other uncertain parameters, this was considered an adequate assumption. The estimated future energy tax on electricity used is based on historic values, see Figure 29. This is considered slightly low based on data in figure but was assumed to have very little effect on total cost and economic savings. Tax reduction on micro-produced electricity and compensation for grid services 2030 are assumed constant. It is possible that these may not be applied in 2030 due to a likely increase of micro-producers in Sweden with for example decreased prices of solar PV. However, applied values for tax reduction and grid services did not result in significant impact on economic savings.

10.3.4 Sensitivity Analysis

The sensitivity analysis shows, among other things, the impact that a changed grid fee has on the discounted payback period, both with a small change and a larger variation. Based on these results it can be seen that the change in grid cost does not affect the discounted payback period significantly in SEOM's case, not even if the increase is 50 % of the original grid fee. For the case of Vattenfall Distribution however, with a large change of total grid fee, the payback period changes drastically. It can thus be concluded that the grid fee does not have a substantial impact on the discounted payback period if the variation of grid fee is small (±10 %), and thus probably not either on the profitability of the system. Nevertheless, if the variation of the grid fee is large (±50 %), it is possible that the effect will make it much more profitable to invest in a battery + PV system. However, this only seems to be the case if the grid fee already is very high and accounts for a large part of the total electricity cost from the beginning, as it is for the analysed household with Vattenfall Distribution's applied grid fee.

The parameters that affect the payback period the most, considering both SEOM and Vattenfall Distribution's grid fees, are the total investment and the discount rate. It might be hard to tell exactly what parameter that has the greatest effect on the discounted payback period, since different percentual changes have been assumed. However, a large percental increase and decrease of the discount rate amounts to a rather small change of the percentage point. With a percentual change of 50 % the discount rate is set to either 7.5 % (50 % increase) or 2.5 % (50 % decrease), both reasonable discount rates to assume. The change in payback period when increasing or decreasing the discount rate is especially clear in the case of SEOM's grid fee. It is thus clear that the result will differ significantly depending on what discount rate is assumed for the calculations of the discounted payback period.

A change in investment cost also affected the discounted payback period considerably. Since the costs of PV and battery storage are changing fast and differ between installations, this shows that it is hard to predict and calculate a discounted payback period that is applicable on a general scale and not only for this scenario.

Nevertheless, it is possible to get an understanding of what interval the discounted payback period might be in on a general scale by looking at the range of discounted payback periods displayed in the sensitivity analysis. In Table 16 the discounted payback periods for the sensitivity analysis are presented, based on a case with battery + PV, where the price of both battery and PV are included with subsidies. There it is possible to see that the discounted payback period ranges from approximately 15 to 35 years with consideration to SEOM's grid fee and 11 to 18 years considering Vattenfall Distribution's grid fee. This is quite a large time span, especially for the case with SEOM's grid fee, and thus it might be possible to claim that it is difficult to obtain a general sense of what range the discounted payback period might be in depending on ingoing parameters.

11 Discussion on Methods

This chapter includes a short discussion on the different applied methods and which factors regarding these that have impacted the outcome of the report.

11.1 *Literature Study*

By mainly utilizing recent sources, the authors secured that the gathered information retrieved was up to date. This has been of utmost importance due to the rapid changes of the residential battery storage market and the urgency of implemented flexibility measures in the Swedish power grid. By using material from governmental agencies as well as scientific papers among others, the reliability of the consulted literature is considered high.

11.2 *Interview Study*

Since all interviewees have read and agreed to the publication of their answers, these are assumed truthful. All interviewees are considered knowledgeable within their respective areas. However, assuring total objectivity of the answers could be difficult given that all interviewed grid operators have their own agenda. All interviewees except Anna Wolf, Power Circle, have answered the questions as representatives of their companies or organizations.

In order to enhance reliability of the interview study, an additional number of interviewees could have been asked to participate. Due to time restrictions, no other interviewees were asked to take part in the interview study. An increased number of grid operators applying power tariffs today could have been approached with questions, in order to collect more information and data regarding if introduction of power tariffs have given effects on demand flexibility or increased investments in residential battery storage. An additional interest organizations and governmental organizations. It would further have been of interest to perform a survey on how grid customers consider power tariffs today, whether or not they consider them an incentive towards load shifting or levelling, and if they consider power tariffs an inventive to invest in battery storage. By gathering information regarding the perspective of the consumer, a more in-depth account of the effect of power tariffs on battery storage and demand flexibility could have been obtained.

11.3 *Technoeconomic Case Study*

One major aspect to highlight regarding the case study is that only one household has been simulated. Therefore, it is not necessarily possible to draw any general conclusions of battery profitability with power tariffs from the results of the case study. Instead, it aims to present one example of how power peaks can be lowered and which parameters have the most impact on payback periods and battery profitability.

The grid prices that are simulated for the system of battery and solar PV are acquired through respective grid operator and are assumed to be accurate and updated. It should be noted again that grid prices from Vattenfall Distribution are preliminary. Significant amount of time was spent understanding how SAM operates and thereby how the simulated battery operates. By performing all economic calculations in Excel, a larger understanding of how certain economic parameters impact the result more than others was obtained.

One important factor to take into consideration is that the two studied tariff designs differ. SEOM’s power tariff is a larger component of the total grid fee compared to Vattenfall Distribution’s. This provided a possibility to determine the impact that the different tariffs have on the total cost of electricity.

Applying an increased amount of grid fees from different grid operators could potentially have stronger confirmed the results of the technoeconomic case study. As mentioned in Chapter 4.5.2, the tariffs studied vary with regards to which time of day as well as month of year that they are applied. This was accounted for economically in the case study by, in the case of SEOM's time-differentiated power tariff, calculating demand charge for each month based on the highest power peak within the time frame. Having studied tariff portfolios within a similar time frame could have provided results that are easier to compare. However, as the authors of the thesis learned throughout the work of the report, there are many different applied tariff structures aimed to provide different types of incentives.

Another important aspect is that the two studied grid operators differ significantly in size, geographical location and number of customers. Including an additional amount of grid operators in the case study could have provided a larger weight to the conclusions of the considered case. The strain on the grids differ in northern and southern Sweden, as well as the type and number of customers connected to the grid, thus the geographical location can be considered an important factor that affects the grid fees.

A thorough analysis of how the assumptions made regarding the case study may have impacted the result can be found in Chapter 10.3.

12 Conclusions

Current regulation of the Swedish power grids needs to be modernized due to age, rapid development of smart technology and the introduction of new market players. To mitigate power and capacity shortage in the grids, network operators should be given the possibility to experiment regulatory with tariff options and designs in order to promote resource-efficiency and flexibility measures. The report further concludes that a dynamic tariff structure is preferable, in order to better correlate usage and strain of grids with what the customer pays.

Residential battery storage installations are today subsidized by a maximum of 50 000 SEK. Proposed legal changes regarding battery storage are removal of dual taxation on storage, a clearer definition of electrical energy storage in the Swedish Law of Electricity, an increased maximum battery storage subsidy with more possible applicants and removal of the demand for micro-production, according to SOU 2018:76. If these propositions are adopted new business possibilities for various battery storage customers will emerge, as well as a possible enhancement of a battery investment.

Increasing demand flexibility by incentivizing consumers to become more active regarding their electricity consumption is one way of promoting flexibility on a local scale. Today however the economic incentive for a customer to shift and level out load is low. The report concludes that residential batteries could promote increased demand flexibility among electricity consumers by increasing the economic incentive to become an active consumer. It is further concluded that aggregators are needed, and could play an important part of the future electricity system by accessing flexibility through accumulated capacity.

A larger implementation of power tariffs among Swedish grid operators could provide an incentive for electricity consumers to invest in residential battery storage in order to reduce demand charges. The literature and interview study, as well as the technoeconomic case study show that residential batteries in combination with micro-production can be a profitable investment as a means to decrease total electricity costs. However, the profitability partly depends on how the grid fee is structured and thus differ from case to case. Moreover, it is difficult to distinguish what exact effect residential battery storage has on lowering the demand charge, and what savings should instead be allocated to the PV system.

Economic barriers regarding residential battery storage are mainly high investment as well as the rapid development of battery technology that contributes to uncertainties regarding battery storage investments.

The report further concludes that for the specific household in the technoeconomic calculations, Vattenfall Distribution's introduction of power tariffs means a significantly larger increase of grid fees than for SEOM. It further highlights the importance for the customer to be aware of how they utilize power in order to avoid high demand charges. For the studied household, an investment in battery + PV system could significantly lower the demand charge and provide savings. However, the considered investment costs for battery + PV system in year 2018 still result in significant payback periods. With estimated decreasing prices of solar PV and battery storage, as well as estimated future economic parameters, the case set in 2030 means significantly shorter payback periods. Disregarding solar PV investment costs result in short discounted payback periods for both a case set in 2018 as well as 2030 for the analysed system. Thus, these cases are profitable given that all savings are allocated to the battery storage.

The sensitivity analysis shows that the payback period differs considerably depending on the total investment and discount rate. These parameters are uncertain and differ from installation to installation. It is thereby difficult to determine general payback periods for battery + PV systems in combination with power tariffs. For the case regarding Vattenfall Distribution, where the grid fee contributes to a large part of the total electricity cost, a significant increase of grid fee clearly results in shorter payback periods for the studied system. This concludes that the grid fee has a large impact on profitability of the studied battery + PV system, given these circumstances.

12.1 *Recommendations*

The authors recommend that the following propositions are implemented in the future electricity system in order to facilitate battery storage as a measure of providing flexibility.

- Proposed regulatory measures relating to residential battery storage highlighted in this report are recommended to be adopted.
- Allow for aggregators to participate in flexibility measures in Sweden through clearer definitions of market structure and regulation.
- Allow network operators to experiment regulatory with tariff structures and design, through for example experimental sandboxes.
- It is recommended that network operators include a larger variable part of the grid fee in order to incentivise end customers to shift and level out load.

12.2 *Future Work*

To move forward on these issues, the authors see a need for future work in the following areas:

- Further investigate the future role of battery storage in front of the meter and how regulatory obstacles can be overcome in order to increase flexibility in the electricity system.
- Investigate the impact of profitability, and flexibility measures, of residential and commercial battery storage of larger capacity, given increased battery storage subsidy and more available applicants.
- A larger interview study consulting all grid operators in Sweden with power tariffs, examining what effects they have seen relating to demand flexibility, and the incentive to invest in residential battery storage among their customers.
- A survey aimed at grid customers with power tariffs in order to investigate how they have been economically affected or changed their power consumption accordingly.
- An increasingly detailed economic case study of a system with battery and PV, including more reality-based data such as an increased number of load profiles, other parameters such as degradation rate of system and additional costs, as well as an increased number of considered grid operators with various grid fees in different locations in Sweden.
- More thorough and detailed economic calculations for combined systems with battery and PV, in order to determine the monetary contribution that can be allocated to the battery and PV production respectively.

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14 Appendix

A. Interview Questions

Battery Storage

Do you see a need for residential battery storage today?

If you do not see a need for residential battery storage today, do you think you will in the future? Which parameters would need to change in order for you to be interested?

Would an increased usage of residential battery storage favor you as an actor on the electricity market? If yes, how?

What barriers do you see for increased implementation of residential battery storage in Sweden?

What possibilities do you see for increased implementation of residential battery storage in Sweden?

How do you estimate that the economic profitability of residential battery storage will develop within the coming years and are you interested in the price development?

Are you as network operator interested in residential battery storage? If yes, how?

Which are the major barriers regarding laws and regulation of battery storage in Sweden?

Which system services do you consider with residential battery storage from your perspective?

Demand Flexibility

Do you work to increase demand flexibility among your customers?

What are important measures in order to increase demand flexibility in Sweden?

How do you consider the possibility for customers to affect their electricity consumption by investing in residential battery storage?

Are there other systems than batteries that you consider potential for local energy storage?

Power Tariffs

Vattenfall Distribution will introduce power tariffs in 2020 and also Ellevio considers this tariff structure, which some smaller network operators have had for years. Do you think that this will have an impact on how electricity customers/your customers can increase demand flexibility? If yes, does it affect you economically?

What are the reasons for you to introduce/want to introduce power tariffs now?/What are the reasons that certain network operators want to introduce power tariffs now?

What arguments for and against do you consider regarding implementing power tariffs?

Which time slots will be applied for the tariffs? What is your thought behind this?

What will happen to the fuse subscription when or if power tariffs are introduced?

Which do you consider the largest challenges with implementation of power tariffs?

Ei has been given the task of designing guidelines for the power tariffs. How do you consider the guidelines from Ei?

Do you consider that a larger implementation of power tariffs in Sweden could have an impact on the profitability for residential battery storage? If yes, how?

Have you noticed any difference regarding how customers utilize power, before and after the introduction of power tariffs?

Have you noticed any difference regarding interest for residential battery storage among end customers after the implementation of power tariffs?

When and how did you introduce power tariffs? What incentives or demands were there to do so?

How large part of the grid fee does the power tariff generally account to? How large is the incentive for the average customer to shift or level out load?

How was the change regarding implementation of power tariffs received by your customers?

Have you seen any effects of increased dedication among customers regarding load shifting or load levelling?

Have you noticed any interest among customers regarding the implementation of power tariffs?

What factors are necessary in order to achieve a successful implementation of the tariffs?

How do time-differentiated power tariffs coincide with intermittent electricity production?

Battery Storage Subsidy

In Sweden, customers have the possibility to apply for a battery storage subsidy that today covers 60 % of the investment cost with a maximum sum of 50 000 SEK. SOU 2018:76 proposes an extension of the subsidy as well as a possibility for more applicants to apply. Does the subsidy affect your approach to residential battery storage?

Today’s battery storage subsidy applies only to batteries in combination with self-production. How do you consider a subsidy without a demand for self-production of electricity?

Which policy measures do you believe would have the largest effect regarding an increased implementation of residential battery storage?

How much of what is proposed as measures in SOU 2018:76 regarding battery storage do you think will be implemented?

The battery storage subsidy is proposed to be prolonged until 2022, why not longer?

How many applicants have applied for the battery storage subsidy and how many have been granted?

B. Price Data

Applied Grid Fees

This section provides price data for the small customer segment regarding grid fees for grid operators SEOM and Vattenfall Distribution. This information is utilized in Excel in order to calculate demand charge reductions for a customer with battery + PV system, as well as a grid subscription including a power component. Presented grid fees in Table 17 include VAT.

Table 17 Grid fees of grid operators SEOM (SEOM 2019b) and Vattenfall Distribution (Vattenfall Distribution 2019a). All values are given with VAT.

	Vattenfall Distribution	***SEOM***
Fixed fee [SEK/month]	200	127.5
Power tariff [SEK/kW, month]	68	53.13[a] 106.25[b]
Energy fee [SEK/kWh]	0.34[c]	-

[a] Low peak load months are April – October.

[b] High peak load months are November – March.

[c] Energy fee Enkeltariff which is not time-differentiated.

SEOM's power tariff is applied 07-19 on weekdays (days that are not weekends, Midsummer, Christmas Eve or New Year's Eve) and is doubled during peak load periods. In addition to the power tariff, customers with a main fuse of 16 – 25 A pay a fixed fee of 127.5 SEK/month.

Vattenfall Distribution's preliminary price structure for their small customer segment is not yet presented but the authors were given the following information which has been used for the calculations. The presented values are applicable for a household with a power fuse of 20 A[55]. Grid customers of Vattenfall Distribution have the opportunity to choose between Enkeltariff and Tidstariff regarding the energy fee. Price for Enkeltariff of 0.34 SEK/kWh has been used in the calculations since very few customers subscribe to Tidstariff[56] (Nilsson et al. 2019). The power tariff is constant at 68 SEK/kW per month and a fixed fee of 200 SEK/month is used. It should be stated that this data is preliminary.

Applied Electricity Prices

Price data for Vattenfall's variable electricity rate 2018, monthly electricity metering for SE3, is used for calculating the costs and savings relating to the electricity rate with and without battery + PV system in the technoeconomic case study. Data shown in Figure 28 in Appendix D.

[55] Fixed price for 16 A is 180 SEK/mo. Fixed price for 25 A is 220 SEK/mo.

[56] Tidstariff applied November – March, Monday – Friday 06 – 22.

C. Simulation Model

The simulation program used is **System Advisor Model (SAM)**, a free modelling tool for technoeconomic computer models for renewable energy projects. It is developed and distributed by National Renewable Energy Laboratory (NREL) of the U.S. Department of Energy. The programme is used by policy makers, equipment manufacturers, researchers and project developers. The modelling options are vast and the performance of e.g. wind, geothermal, PV and biomass power systems can be simulated. However, it is only possible to model battery systems with the PV-option. The simulations link technical performance with financial models for renewable energy systems. It is possible to simulate both commercial and residential models depending on the objective (Blair et al. 2018).

In the simulations performed, the battery is optimized to be used for cutting power peaks. How the storage dispatch of the battery is modelled and functioning in SAM is described below. The dispatch schedule of the battery will work the same irrespectively of if a PV system is connected or not.

Battery Dispatch Model in SAM

A demand power target for the specific battery is determined and set to the maximum power level that should be bought from the grid and should thus be as low as possible whilst the limitations regarding the capacity and power usage profile of the specific battery is accounted for. The battery will then charge during the time over the day when the electric load is less than the power target from the grid and will discharge when the electric load is higher than the grid target. An example of this can be seen in Figure 26. The Power Grid Target (P_{target}) has in this case been set to 7 kW, which means that the system has a maximum purchasing limit of 7 kW from the grid. If the power needed exceeds 7 kW, the battery will start to discharge ($E_{discharge}$) and if the battery is not yet fully loaded it will charge when the power need is less than the Power Grid Target (E_{charge}) (DiOrio 2017).

This type of modelling does not consider any cost information by itself, but rather assumes that the peak cost is concurrent with the highest peak demand for a month, no matter the hour and day (DiOrio 2017). This might not be the true case, since the demand charges often are specified for certain high demand hours over the day and week, as well as sometimes for different seasons as well. The type of algorithm that is used in SAM with peak shaving will not consider these other demand charge factors for the demand charge reduction modelling.

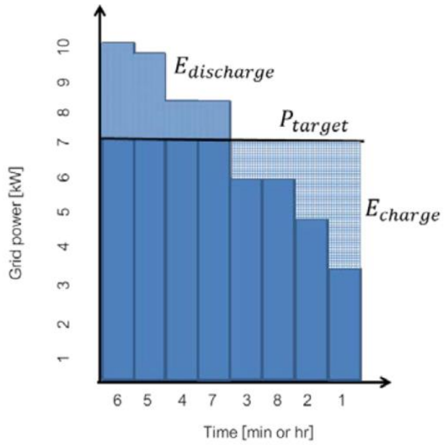

Figure 26 Charge and discharge strategy with a power grid target of 7 kW (DiOrio 2017).

Iteration of Power Peaks
Power peaks without system are retrieved from existing load data for the considered household. Power peaks with system are obtained through iterating and optimizing peak shaving abilities in SAM. This is performed manually in order to get maximum possible peak shaving. For every month a value of power peak with system is estimated, based on which power peak it is without the system for the same month (a first guess is approximately 15 % peak reduction). The estimated value is printed into the simulation tool and run, where it is possible to see if the guessed value can be obtained with the chosen battery + PV system setting or not. If the guessed power peak value can be obtained, a lower value is tried until the battery + PV system setting cannot shave the peak to the guessed value any longer. Thus, the maximum peak shaving ability the system can perform are found through this iterative process for every month.

Additional Battery and PV Input Data for Simulations in SAM
Input data for simulations in SAM are presented in Chapter 9.2. Here additional data used in the simulations in SAM regarding the battery and PV system are displayed in Table 18 and Table 19.

Table 18 System settings in SAM.

PV-type/size	***Tilt- and azimuth angle***	***Modules per string***	***Strings in parallel***	***Total module area***
Poly-crystalline, 6 kW	20° and 180° (south facing)	7	2	44.8 m^2

Table 19 Battery parameters simulated in SAM.

Battery-type/size	***Battery efficiency***	***Min/max SoC***	***Cell Capacity***
Li-ion, 6 kWh	89 %[a]	15 % / 95 %	5 Ah

[a] Including converter and ancillary services such as losses regarding pumps, heaters and other equipment required by the battery system.

D. Economic Parameters and Calculations

Figure 27 presents Nord Pool's spot prices for SE3 for 2017 (in the grey area) and 2018 (both green line and grey area).

Figure 27 Weekly spot prices of electricity in SE3 for 2017 and 2018 [SEK/MWh] (Nord Pool 2017).

Figure 28 shows Vattenfall's variable electricity rates for years 2016, 2017 and 2018. Prices include VAT.

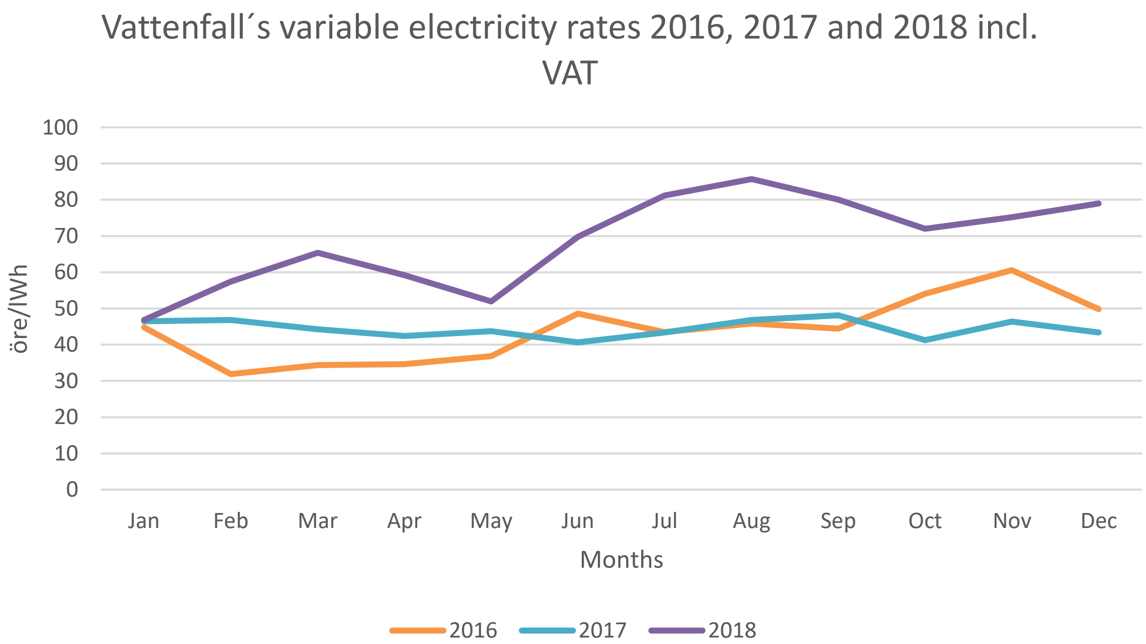

Figure 28 Variable electricity rates for 2016, 2017 and 2018 including VAT for Vattenfall. Price in [öre/kWh].

Figure 29 shows historic development of energy tax on electricity in Sweden since 1977.

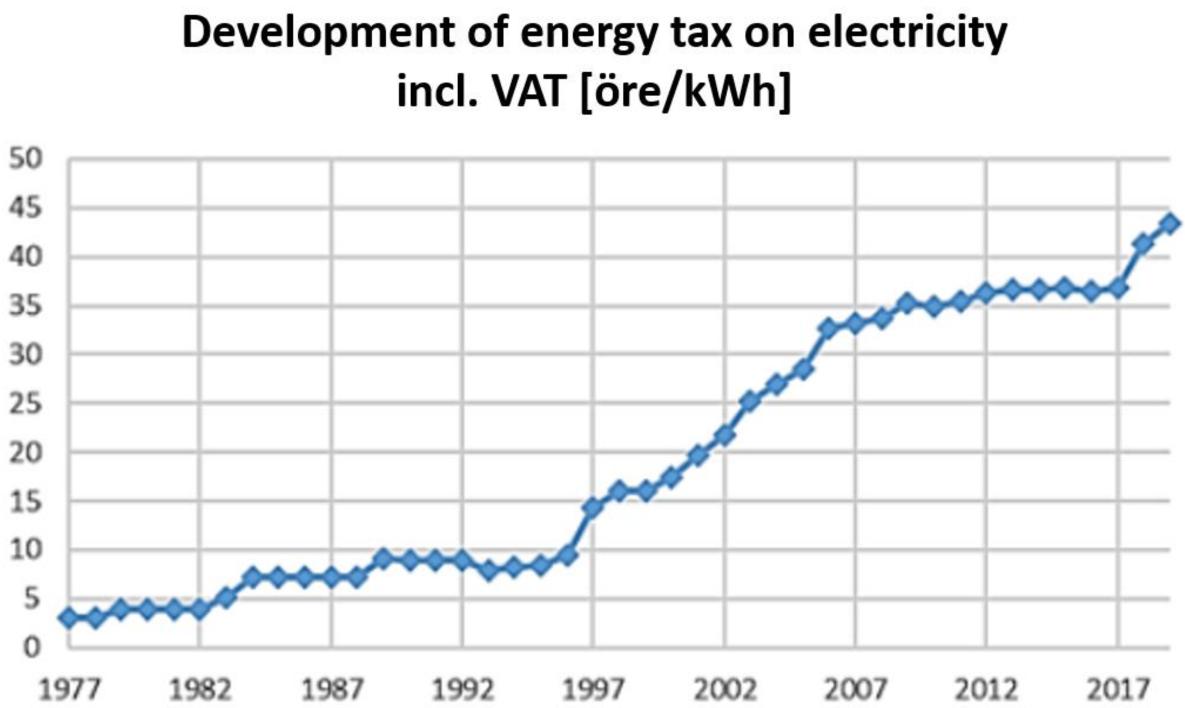

Figure 29 Energy tax on electricity as nominal prices: historic development from 1977. Translated from Swedish to English (Konsumenternas Energimarknadsbyrå 2019b).

Calculations Grid Fees

The grid fee is assumed to increase at approximately the same rate as the last 10 years. The increase is assumed to be divided evenly over respectively part of the grid fee. Thus, evenly distributed over the energy component, the power component and the fixed component of Vattenfall Distribution's grid charge and over the power and fixed component of SEOM's grid charge.

The estimated grid fee increase in 2030 is based on calculations of four different cases. The first grid fee increase is based on Figure 9 in Chapter 4.5, which shows the general increase of grid fee between 2009 and 2018. A yearly mean increase of 1.8 % is used combined with a starting value of 0.34 SEK/kWh for 2018. This calculation result in an approximate grid fee of **0.42 SEK/kWh** 2030 (excluding VAT) and thus a total increase of **23.9 %** between 2018 and 2030.

The second case is divided into two different scenarios[57]. The first scenario sees a mean yearly increase of 2.6 % and a total increase of **40.693 %** between 2017 and 2030. The second scenario sees a yearly increase of 2.97 % and a total increase of **38 %** between 2019 and 2030. The yearly increase varies for the two alternatives, as can be seen in Figure 30, where the orange line represent the first case and the blue line the second case.

[57] Data obtained from Karin Tvingsjö, Ei, via e-mail 2019-05-07.

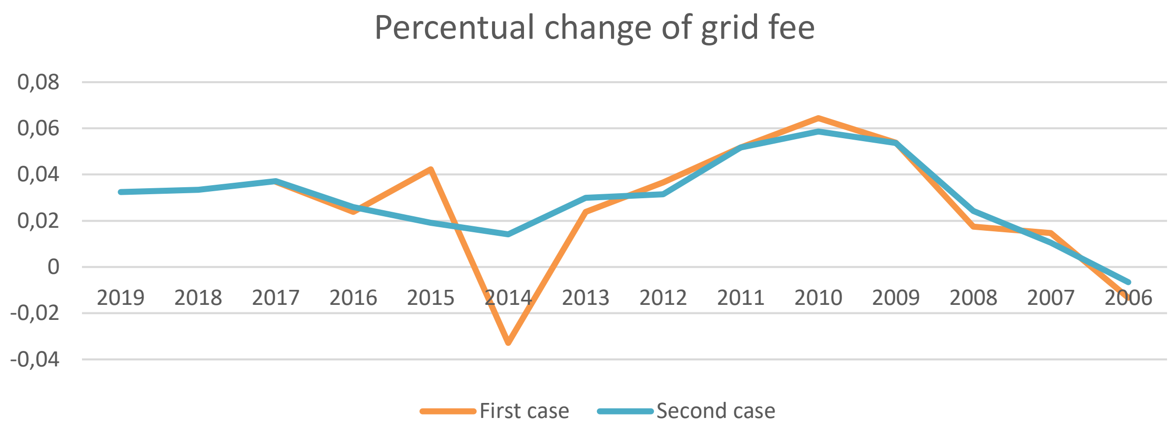

Figure 30 Yearly percentual change of grid fee.

A third alternative uses data regarding the total grid fee for several different network operators for a 25 A house with an electricity use of 20 000 kWh/year between 2015 to 2019. The total grid fee is used to calculate a mean value of the increase of grid fee per year (Konsumenternas Energimarknadsbyrå 2019f). This mean value is then used to calculate the increase until 2030. The total future grid fee based on the mean value of the grid fee for 2019 and its yearly increased mean, are calculated to **11 530 SEK** in 2030, a total increase of **44.5 %** between 2018 and 2030.

To conclude, the estimated increase of grid fee used in the calculations for Case Future is set to **40 %**, and is based on a weighted assessment of the results above for the different estimated grid fee cases.

Calculations Discounted Payback Periods

The discounted payback period that is calculated is based on the cumulative annual savings from using the battery + PV system and the cumulative annual costs, as well as discount rate. When the cumulative annual savings equal the cumulative annual costs the payback period is attained. Since no O&M costs or replacement costs are considered, the only cost will be the investment cost of battery + PV system.

The discounted payback period includes a discount rate of 5 % and uses the same annual savings for every year. No degradation of the system is considered. The discounted payback period is calculated by using following equation:

$$DPP = -\frac{\ln\left(1 - \frac{I}{a} \cdot r\right)}{\ln(1 + r)}$$

DPP = Discounted payback period
I = Initial investment
a = annual savings
r = discount rate