CHALMERS
UNIVERSITY OF TECHNOLOGY

Solar PV coupled with electricity storage in Sweden

The factors aiding the transition

Master's thesis in Sustainable Energy Systems

DAVID SANDAHL

Department of Space, Earth and Environment
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2019

Master's thesis 2019

Solar PV coupled with electricity storage in Sweden

The factors aiding the transition

DAVID SANDAHL

CHALMERS
UNIVERSITY OF TECHNOLOGY

Department of Space, Earth and Environment
Chalmers University of Technology
Gothenburg, Sweden 2019

Solar PV coupled with electricity storage in Sweden
The factors aiding the transition
DAVID SANDAHL

Supervisor: Sujeetha Selvakkumaran, Department of Space, Earth and Environment
Examiner: Erik Ahlgren, Department of Space, Earth and Environment

Master's Thesis 2019
Department of Space, Earth and Environment
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: Picture of solar panels, retrieved from pixabay.com.

Typeset in LaTeX
Printed by Chalmers Reproservice
Gothenburg, Sweden 2019

Solar PV coupled with electricity storage in Sweden
The factors aiding the transition
DAVID SANDAHL
Department of Space, Earth and Environment
Chalmers University of Technology

Abstract

With growing amounts of the worlds electricity supply coming from renewable sources, the intermittent nature of these sources demand an increase of energy storage. In addition to the need for energy storage on grid level, storage also provides possibilities for individual households to use larger amounts of their own produced electricity.

The aim of this study was to examine what barriers the households that install battery storage systems in Sweden encounter, and to investigate how they use the storage systems. The objective was achieved by collecting and analyzing interview data from households with solar PV coupled with battery systems, as well as survey data from households with only solar PV installed.

The findings further highlight barriers that have been previously identified for early adopters of solar PV in Sweden, with the relative value of producing electricity not reaching a level where the significant investment cost is justified. In the case of the battery system, the gap in value between using the produced electricity from the solar panels through the battery compared to selling it to the grid is not substantial enough to make the investment worthwhile. A major factor creating this situation is the tax reduction of 60 öre/kWh received for selling produced electricity to the grid.

Information retrieval was not perceived as a major barrier for owners of solar PV and battery systems since this group of people possess a relatively high level of technical know-how. Improvements regarding available information on back-up power usage of batteries as well as a way of easily comparing offers from companies was requested by study participants.

The batteries are usually charged with electricity from the solar panels that is not directly consumed. By charging the battery from the grid at times of low electricity prices the financial situation of an investment in a battery system could be somewhat improved, with some battery owners requesting this usage to be automatic in the future.

Simplified and long-term legislative frameworks would further encourage adoption. Development of business models that could handle administrative work and guarantee revenue streams would also be of benefit.

Keywords: Domestic battery storage, Domestic photovoltaics, Battery economics, Diffusion of Innovations

Acknowledgements

I would first like to extend my thanks to my supervisor Sujeetha Selvakkumaran and my examiner Erik Ahlgren. Secondly, thanks to Länsstyrelsen in Skåne for quickly providing contact information to potential participants in this study. Also, a big thanks to the interviewees and survey participants for taking time and sharing their experiences to help provide this thesis with content. Thanks to my opponents Johanna and Tove for their work in helping to improve this thesis. I am also grateful for the valuable support from my friends and family.

David Sandahl, Gothenburg, June 2019

Abbreviations & Nomenclature

LCOE	Levelized Cost Of Energy
TPO	Third-Party Ownership
TGC	Tradable Green Certificates
VAT	Value-Added Tax
ROT	Renovation, Reconstruction, Extension
GHG	Green House Gases
EU	European Union
PV	PhotoVoltaics
PPA	Power Purchase Agreement

Contents

List of Figures

List of Tables

1
Introduction

1.1 Background

In a future power sector where renewables have a much bigger role than today, energy storage will be needed to even out the intermittent nature of some renewable energy sources. When and where wind or solar power can be produced is most of the time hard to predict and there is a limit to how much of these technologies you can have in an electricity system before it becomes too unbalanced. A solution to this would be to increase the amount of energy storage in the system. Solar power for example is at its maximum capacity during midday which does not coincide with the peak demand for electricity. The role of energy storage is in this case to store some of the energy produced during the peak hours of solar power to be used later when the demand for electricity is at its highest. This has the effect of evening out the demand curve on a daily basis. The phenomenon of solar power having an effect on the daily demand curve has been studied in California, United States, and has been given the name the ”duck curve”. The name comes from the fact that when extensive solar power is used in households during the peak solar hours, it lowers the demand during that time and gives the demand curve the look of a duck. The difference between peak demand, often during the evening, and the comparably low demand during midday presents a problem because the power produced in the grid needs to be rapidly ramped up during the afternoon to meet the demand during the evening. These changes in demand is difficult for the system to handle and the base load power producers, such as nuclear or coal, are not economical if they have to shut down during a period of the day and then be restarted in the evening. This is one of the big challenges of implementing renewable energy sources in the electricity system. [1] [2]

During the last century, the main technology for storing electricity used in the world has been pumped hydro. It is an economically and technically proven technology that still makes up the vast majority of the worlds usage of energy storage with its 99% market share. Batteries on the other hand are relatively new on the market. But the sector is changing. The efforts to transition to a renewable electricity sector, and the policy changes that comes with it, results in advances in many areas, one of them being battery storage. Batteries can be placed both at the point of demand and at grid level which gives it more flexibility than for example pumped hydro. An increase of battery storage in the electricity system

would allow larger amounts of renewable energy to be introduced into the system and at the same time increase the level of system reliability. [2]
Within the energy system, storage can provide flexibility since it:

- Injects and absorbs electricity fast and with high accuracy
- Smoothens short-term variability
- Eliminates production and local peaks
- Makes solar fully dispatchable

Solar coupled with storage can also give economic advantages since storing solar electricity when prices are high and using it at times when prices are low does not only provide economic benefits for the producer but also provides stabilisation of energy prices which leads to reduced grid upgrades and expansion costs [3].

1.2 Solar PV and storage in the EU

Europe had a total installed solar PV capacity of 114 GW in 2017, which represents a share of 28% of the total global installed capacity. This ranks them second in the world behind China in regard to solar power capacity. The significant rise in yearly installed solar PV that Europe produced during the early 2010s has somewhat stagnated in recent years but there was still an increase in total installed solar PV in 2017 compared to the year before. The market leaders of earlier years, Germany and Italy, have now taken a smaller role among the biggest installers of plants while Turkey has emerged as one of the leaders with an increase of 2.6 GW worth of solar power installations in 2017. Were it not for Turkey, the European PV market would have seen no growth at all. The European solar PV market is expected to see an increase in growth in the next few years though, with countries trying to reach the goals of the 2020 agreement and with emerging markets, such as Russia and Belarus, and re-emerging markets, such as Spain, turning to low-cost solar power. [3]

The European Union is currently working under a set of policies that are called ”The Clean Energy for all Europeans Package”. This includes targets for GHG emission reductions, energy efficiency improvements, share of electricity from renewables and electric interconnectivity. These targets for the years 2020, 2030 and 2050 are part of the EU’s efforts to deliver on their commitments stemming from the Paris agreement. The targets were agreed upon by EU leaders in 2007 and put into legislation by 2009. [4]

The first set of targets are for the year 2020 and are known as the 20/20/20, they are commonly summarised in the following three points.

- 20% cut in greenhouse gas emissions (from 1990 levels)
- 20% of EU energy from renewables
- 20% improvement in energy efficiency

Part of the agreement is also that each country takes on a binding target for the share of energy from renewables in their national energy consumption. These targets vary from country to country according to the level the nation started at when the legislation was decided and its capability to increase it further. For example the nation of Malta has a target of increasing the share of renewables to 10% of total consumption while Sweden has a target of 49%. [4]

The next set of targets are for the year 2030 and are summarised in the following points.

- 32.5% improvement in energy efficiency
- 32% of energy from renewables
- 15% electricity interconnection target

The targets are expected to deliver a 45% reduction in GHG.
The target for the year 2050 is more broad and less detailed, and includes a 80-95% reduction in GHGs by decarbonising the entire energy system.
The different possible routes to achieve this target, through e.g. energy efficiency, nuclear energy renewable energy and carbon capture and storage, are evaluated in the document "The 2050 Energy Roadmap". [5] [6]

Solar power covers around 5% of the total electricity demand of the European Union today, but that share could easily increase to 15% by 2030. For that to be realised, there would need to be a yearly installed capacity of 20 GW, which is not that much considering the previously mentioned installed capacity of 114 GW in 2017. There is currently a trend in Europe where the deployment of solar PV is linked with battery storage. In the UK for example, where the first large scale solar PV and storage installations are being developed free of subsidy support. Or in Germany, where around half of all residential solar installations in 2016/2017 were coupled with battery storage [3].

A successful subsidy program for solar storage has been run in Germany for a few years, serving as a good comparable. In May 2013, Germany introduced a market incentive program for battery storage systems [7]. Financial support for the investment cost of storage systems coupled with solar panels is offered for systems installed after January 1st 2013. The amount of support depends on the capacity of the solar power system, up to 660 Euros per kilowatt of peak solar capacity. This rule is applied until the maximum cap of 3000 euros is reached. The German Solar Association that offers this subsidy states that the direct consumption of solar power can more than double through the usage of storage systems. Along with low-interest loans provided for solar storage systems, this makes Germany one of the world leaders in annual installed storage capacity. Worldwide in 2017, Germany trailed only Australia in annual residential installed power capacity and had nearly 80'000 behind-the-meter installations in total by the end of the year [8]. Compared to for example Sweden, it is more economically viable to produce your own electricity in Germany since the electricity prices are around 50% higher there than in Sweden [9].

1.3 Solar PV and storage in Sweden

The Swedish solar PV market consisted almost exclusively of small off-grid systems until the early 2000s. The application of the systems were usually in holiday cottages, marine applications and caravans. The annual installed grid-connected capacity surpassed the annual installed off-grid equivalent in 2007 which has led to Sweden having fifteen times more grid-connected capacity than off-grid in 2016. Almost all of the installations are made up of roof-mounted systems installed by either individual households or companies, with around 32% of the systems being installed on small houses and and 62% on company, agriculture or public buildings. Only a small part, around 6%, of the installed capacity is made up of ground-mounted centralised parks. [10]

The political discussions on Sweden's broader energy policies ended up in the creation of the Swedish Energy Commission in March 2015. The commission's purpose was to produce a general political consensus on the future of the Swedish electricity system beyond the year of 2025. The result of these discussions was an agreement between five political parties that Sweden will have an electricity generating system that is 100% renewable by the year 2040. In the long term, this political agreement may lead to the phasing out of ageing nuclear reactors and continue to promote renewable energies. The decision to extend the green electricity certificate system in Sweden from 2020 to 2030 will likely be something that has an influence on the political legislation changes in the coming years. The green electricity certificate system and the fact that the agreement states that small scale electricity production will be made easier, are things that are potentially positive for the solar PV market. [10]

The purpose of the green electricity certificate system is to make it more profitable for electricity producers that use renewable sources to produce their electricity. The basic principle of the system is that certificates are traded between electricity producers and consumers depending on if the consumers reach a determined share of used electricity coming from renewable sources. A producer of renewable electricity receives a certificate from the government for each MWh produced. This certificate can then be sold to an electricity consumer that does not reach the minimum required share of electricity that comes from renewable sources. The quota level was 24.7% of total electricity produced in 2017. The producers that are buyers in this system are obligated to acquire enough certificates so that they reach the minimum share of renewables. [10]

The majority of the approved plants within the certificate system has in recent years been photovoltaic systems. But the total installed power and the number of produced certificates are still rather low for PV systems compared to the other technologies. Many of the PV plants are small in capacity, for example those that are installed mainly for use in individual households. Since the meter registering the produced solar electricity is usually fitted between the household and the grid, it only measures the electricity that the household does not use for itself, the excess electricity production. If the household was to install a meter inside the house it could get certificates for all the solar produced electricity. The additional cost of this new meter, the annual metering fee and the added administrative work for the owner tends to make the producer decide against applying for certificates. [10]

Since 2016, households in Sweden have the possibility to apply for a subsidy that would pay the equivalent of 60% of the total investment cost for a battery system, up to a limit of 50 000 SEK. The subsidy is aimed at households wanting to store their electricity produced from a plant producing renewable energy, thereby using a larger amount of the produced electricity rather than selling it to the grid. The goal of the policy is to increase the amount of renewable energy used. The subsidy cannot be combined with other investment reductions, such as the ROT-deduction. [11]

There are certain taxation rules for households that sell their produced renewable electricity to the grid. For every kWh of electricity that is sold to the grid, the income tax of the owner is reduced by 0.6 SEK. The scheme was introduced in 2015 and is valid for as many kWh of produced electricity as the household buys from the grid during the year, or a maximum of 30 000 kWh. [12]

2
Aim, research questions and scope

The following section defines the general aim of the study. The aim is first expressed in broader terms to then be defined through a set of research questions. What will be included and excluded in the study is specified in the scope section.

2.1 Aim

The objective of this thesis was to find out what the factors are that are aiding or preventing households in the adoption of battery storage systems in Sweden, with specific focus on Skåne. It was also of interest to investigate how the households are using the battery storage. The current financial situation of an investment in a battery system and what the impact of the subsidy scheme for energy storage has had, are topics that will be discussed as well.

2.2 Research questions

These are the questions with which the objective of the thesis can be summarised as well as being the starting point of the research work.

- Does the subsidy scheme for battery storage systems encourage households to invest?
- What is the households reasoning behind investing in a battery system?
- How are the households using the battery system?
- Is it economically viable for the households?

2.3 Scope

The subject of the study was solar PV coupled with battery storage and because these technologies are closely related in this setting the topic of solar PV will inevitably be touched upon, but the main focus will be on the battery system. The study focused on the county of Skåne and did therefore not involve the rest of Sweden. The main focus was on solar PV coupled with battery systems installed in households. Similar systems installed outside of households, for example in industrial or commercial buildings, was not be included in the thesis.

3
Barriers and drivers from literature

At the time of this study being performed, there was no literature available on the subject of barriers and drivers to adoption of solar PV coupled with battery storage. The literature presented and discussed in this chapter will instead focus on the barriers and drivers encountered for adoption of solar PV, which is deemed applicable on the subject of this thesis as well. The literature discussed focuses on cases in both Sweden and other parts of the world. The first two sections discuss literature regarding solar PV adoption and the information search connected to it in Sweden while the third section focuses on solar PV adoption internationally and the approach conducted in successful markets.

3.1 Barriers and drivers for solar PV in Sweden

Jenny Palm and Maria Tengvard [14] explore the motivations behind households in Sweden installing solar PV. The objective of this article excludes the battery storage system, but the main drivers for the decisions are considered applicable to the objective of this thesis as well. From a number of interviews performed with households, six partially interrelated motives were cited.

- ***Concern for the environment and lifestyle harmonisation:*** The decision to install solar PV for this group is mainly driven by the will to implement a sustainable lifestyle on as many aspects of everyday life as possible. To actually be able to convert the ”green” thinking into something physical and real, which results you can see, is something that appeals to this group.
- ***Own production as a way to act and set an example for others:*** Households with this way of thinking sees the investment as a social act and puts emphasis on its symbolism. The main driver is not that the investment will be beneficial for the individual household in isolation but that the presence of visible solar PV in the neighbourhood will encourage other households in the same area to also invest in similar systems and that way instigate a greater change.
- ***As a way to protest against energy companies or the ”big***

brother" society: This group is of the opinion that the big companies in charge of the electricity production does not act for the good of the people but only to make money, and according to one household are acting in an unfair, monopolistic and counterproductive way. The decision to produce ones own electricity is then seen as a way to "score points" off the big energy companies and decrease their power over customers. Some even go as far as to say that it is a statement against the whole social system.

- ***Own production as a way to become independent:*** The households taking part in the interview process that were situated in rural areas cited a general will to live near nature and also live off the surrounding resources, like growing their own vegetables and producing their own electricity. The electricity production is part of an effort to become more self-sufficient. A general consensus among the households was also the idea that own production of electricity also made them less vulnerable to power failure and longer periods of blackout.

- ***Financial reasons:*** Most of the interviewed households stated that they had no intention of making money off the energy production. Only one interviewee stated a hope of having a payback period of 10 years through selling the overproduction during summer time back to the grid. The investment is instead seen by most households as a luxury purchase that replaces another purchase of for example a swimming pool or an expensive car.

- ***Technological reasons:*** This factor appeals to the satisfaction the own production of electricity gives the home owner. An interest in the technology behind the energy production results in some households to consider it a fun concept to produce its own electricity.

Even though the financial reasons still might not be the biggest driver when it comes to investing in solar PV, it is quite a lot more economically viable to purchase these systems today compared to when the interviews were performed in 2011. The falling prices on solar panels and the changes in regulations making it easier and less expensive to sell electricity back to the grid are factors that strengthens the economic factor in the case of a purchase. In most of the cases in this article though, the reason for purchasing solar PV is more a statement and as a part of a green lifestyle rather than economic. At the point in time where these interviews were performed, the households deciding to invest in these systems were home owners with above average salary, above average education and environmentally conscious people with an interest in the technology used. Even though it has made progress since this article, the goal of the solar PV market must still be to expand its target group to people outside of this rather niche group, to the "general public". To further expand the market it is important to make it economically viable and the trend is certainly pointing that way.

3.2 Solar PV information search in Sweden

Jenny Palm and Elina Eriksson [15] investigate how households in Sweden search for information before a possible investment in solar panels for their house. Once again, the focus of the article is on solar PV excluding energy storage but it is considered applicable in this study as well. The households are divided into four groups. Non-adopters, the environmentally engaged, the professionally skilled and the accidental adopters.

- ***Non-adopters:*** The non-adopters have limited previous knowledge about the technology and the solar panel market which makes the information barrier overwhelming for them. They have a tendency to emphasise the problems instead of seeing the possibilities. The task ahead of searching for information and making the decision becomes too much for them. To be able to reach the non-adopters, there needs to be easily accessible, simple and standardised information available. Compared to the more technically interested households, these people do not want any deeper knowledge about the technical aspects of the solar panels but rather as little information as possible to be able to make a decision.

- ***Environmentally engaged:*** The environmentally engaged group does not need any convincing when it comes to making the investment. The will to make the investment is already there. The obstacle instead becomes to find information from a third party instead of from the different retailers. This group also requires comparable standardised quotes as well as information without too many technical descriptions which is easily accessible.

- ***Professional:*** The professional group are people that work within the energy sector and are therefore not scared away by technical descriptions and does not have any difficulties finding information. This group could also benefit from standardised quotes though. They are cited to have experienced troubles with the installation process and would therefore be in favour of perhaps a website where customers rate their experience with the companies performing the installations and possibly also a mandatory certification for the installation firms.

- ***Accidental:*** This group is characterised by the fact that the reason for their investment in solar panels is influenced by what they see and hear and not by a conscious decision to search for information themselves. This group is the one that would be the most affected by the ”peer effect” when solar panels on houses become more common. The thought of investing in their own solar panels might not arise until they see them on a house in their surroundings.

In general there seems to be a shortage of easily accessible and understandable information about solar PV available. The visibility of solar panels also needs to increase to reach the people that do not already have plans on investing in solar

PV. Both by households buying solar panels, making them visible to their neighbours, and also by advertising. There needs to be different stages of information that each suits the different groups, both those that are not familiar with the technology at all and those that have a bit more previous knowledge. Easily accessible and understandable information about the technology and administrative proceedings, along with standardised information about retailers and installation firms that make comparisons possible would be a good start. Several households expressed a wish to have some kind of certification for installers of renewable energy and at this date there is a service available through the website of *Energimyndigheten* to find certified installers [16].

3.3 Barriers and drivers for solar PV from an international perspective

The work of Alvar Palm [17] focuses on the barriers and drivers to the deployment of residential PV systems and the mechanisms in play are deemed to be applicable to the case of residential solar coupled with batteries. The research studies the deployment of a mature technology in a catching-up market using a set of different frameworks regarding business models and innovations. The Swedish situation is compared with countries where implementation of residential solar has been successful, such as the United States, Germany and Japan. According to Palm [17], the Swedish sociotechnical system for PV deployment has been immature and infested by institutional barriers. Even though there have been subsidy payments available for households investing in solar PV, the deployment of these has been complex and discontinuous. The long queues to receive the subsidy has been quoted as one of the factors decreasing the will to invest in solar PV systems. There has also been an uncertainty around how the institutional set-up will develop in the future. On the local level, the importance of the influence of local electric utilities and private individuals has been shown. The electric utilities can influence people through providing information and the private individuals can provide social influence to people around them through peer effects. The key is the visibility of the option of residential solar PV. Some of the barriers encountered in Sweden for solar PV are listed below.

- Small commercial market for PV deployment, small companies with local focus. Little implementation within construction companies and almost no options of third-party ownership.
- Poor economic profitability, because of expensive PV systems, relatively low solar influx levels and low electricity prices.
- Problems with subsidies, waiting times and funding reaching cap.
- Complicated and expensive TGC scheme. Hassle and expensive metering equipment.

3.3.1 Approaches in successful markets

In a global perspective, three of the biggest solar cell markets have gained success through different approaches to the implementation of residential solar PV. The barriers to implementation of solar PV are not the same in all countries. Every area of the world represents a different set of barriers which needs to be handled in different ways. How these situations has been handled in the bigger solar markets of the USA, Japan and Germany is evaluated below.

3.3.1.1 USA

The biggest barriers for households in the US has been the relatively low savings rate of homeowners, the tendency of people to move quite frequently and the fact that the transaction costs have been high in the US. The way that these factors have been overcome is by using business models based on third-party ownership (TPO), with TPOs accounting for 70-90% of installations of residential solar PV in important states regarding solar PV, such as California, Arizona and Colorado. In these business models, the homeowner is not the owner of the PV system. It is instead the selling firm that provides a service which covers all areas of ownership, including planning, installation and maintenance. The financing is covered through an arrangement where firms put several projects into a package which are then sold to investors. The way that the TPO models are run is usually through one of two options, power purchase agreement (PPA) or a lease. With the PPA option, the homeowner buys the electricity produced from the solar PV system and after a period of around 15 to 20 years, the homeowner can purchase the PV system off the providing firm, have it removed by the PPA provider or just renew the agreement. PPA is not allowed in all states though, and in these states, a leasing option is often used instead. In this case, the homeowner instead pays a time-based fee for using the system and gets to use the produced electricity at no extra cost. The only point of contact for the customer in a business model like this is with the firm providing the TPO model. From then on, the firm handles contact with installation firms and maintenance firms, banks, insurers and government agencies. The firm also takes care of the administrative tasks regarding subsidies, permits and grid-connection. Lastly, the fact that transaction costs are relatively high in the US and that they are shifted to the TPO firm instead of the homeowner also weighs into the decision. So on top of providing a way for the adopter to avoid paying the large upfront investment cost, the TPO business model also shifts alot of the risks and hassle involved in investing in a PV system from the adopter to the firm.

3.3.1.2 Germany

The relatively high savings rate of the average German household and the lower transaction costs has made the TPO business model somewhat redundant. PV systems have in Germany been mostly financed and owned by the homeowners themselves. The focus of business models in Germany that have had success has instead been centered around proposing PV adoption as a low-risk investment with guaranteed stable revenues for around 20 years through feed-in tariffs. The legal-administrative process in connection to solar PV implementation is considered to be one of the least complicated in Europe which has contributed to the success of the German solar PV market. In those cases where the households cannot afford the full up-front cost associated with the PV system, a government-owned bank has been providing low-interest loans especially dedicated to PV installations. Unlike Sweden, German firms have been providing a number of different services to reduce the amount of uncertainty surrounding an investment. When the commitment is as long as it is with a PV investment, insurance packages, long-term warranties and certifications of PV systems components and installers are all part of convincing the customer that the investment is worthwhile.

3.3.1.3 Japan

Japan is different from the other countries mentioned before since one of the reasons of the success of solar PV has been its integration with prefabricated homes. The prefabricated homes sector has held a substantial part of the industry of new homes and solar PV systems built onto prefabricated homes makes up around 10-15% of the residential PV market. The cost of the system has commonly been integrated into the home mortgage which has kept the transaction costs and interest rates down. Several factors have contributed to the success of this business model in Japan. It benefitted from the fact that the Japanese prefabrication sector of homes was already highly industrialised. The reason for this industrialisation has been a culture of scrapping old buildings and building new ones, resulting in very high percentage of sold houses being newly built, thus increasing the level of newly built homes that can be fitted with solar PV. Assurances from the national government that the subsidies would be present for a long time has also had a part in the success of solar PV.

4
Theoretical framework

The purpose of the theoretical framework is to explain, predict and understand phenomena, to provide a deeper understanding of technological adoption in the case of the individual homeowner [19]. Three different frameworks has been chosen for this thesis.

The theory of *Diffusion of innovations* provides a broader explanation of how technological adoption spreads in a social system through communication and over time.

The *Technological innovation systems* framework focuses more on specific technologies, often new ones, from a sociotechnical systems perspective. It has become one of the dominant analytic tools to understand different drivers and barriers to sustainable technology transitions [20].

Business models have been proven to play an important role when it comes to overcoming barriers of technology diffusion in general and especially when barriers change depending on geographical context [17].

4.1 Diffusion of innovations

The theory called *Diffusion of innovations* was introduced by Everett M. Rogers in the book with the same name that was first released in 1962, and that is now in its fifth edition [21]. The theory aims to explain the spreading of new ideas and technology. How, why and at what rate it happens is of focus. Diffusion is defined in the literature as ”*the process by which an innovation is communicated through certain channels over time among the members of a social system*” [21, p.35]. The social system includes different personality types and the framework seeks to explain how these groups relate to the adoption of an innovation and how different attributes of innovations affect their adoption rates.

Rogers argues that the adoption of an innovation can be described by a curve that takes the shape of an S. At first, only a few individuals make the decision to adopt the innovation. The curve then gradually gets steeper as the innovation is communicated between individuals over time and thereby, more individuals adopt. As time goes by, fewer individuals who are yet to adopt remain. The curve therefore levels out and eventually reaches its asymptote. The diffusion process is finished and the social system is saturated. The diffusion curve is shown in Figure 4.1.

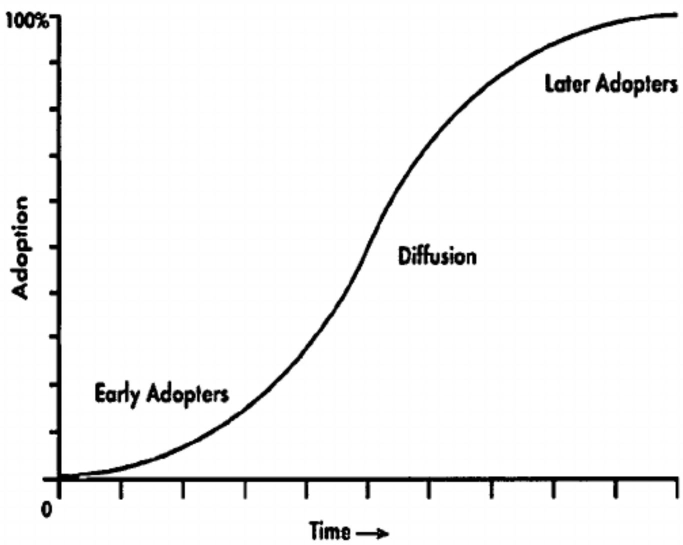

Figure 4.1: Adoption curve according to Rogers' theory [21]

Rogers divides the potential adopters into five groups according to when in the process they are likely to adopt. The adopter groups are described in the literature as *ideal types* and it is conceded that exceptions exists. But Rogers also argues that "*if no exceptions or deviations existed, ideal types would not be necessary*" [21, p.282]. The groups are named and defined as follows:

- ***Innovators*** tend to adopt new technologies mainly because they are new. There is usually a high degree of uncertainty surrounding an innovation at the time of this groups adoption, demanding the group to be able to cope with this. This uncertainty means that there is a significant risk of the investment being unprofitable. Thus, the individuals in this group needs to have control of significant financial resources. There is also a need for these individuals to have the ability to understand and apply complex technology.
- ***Early adopters*** are conceived as the leaders in most social systems. One of the main differences between this group and the innovators is that they are a more integrated part of the local system. Individuals that are part of the local system looks to this group for advice and information about an innovation. They serve as a role model for other members of a social system as they "*are not too far ahead of the average individual in innovativeness*" [21, p.283]. The early adopter is respected by the others in the local system and their adoption of the innovation works as a trigger for others to follow their lead.
- The ***early majority*** adopts an innovation slightly before the average individual in a social system. They work as a link in the diffusion process between the individuals adopting innovations earlier and later than average.

The early majority make up one third of all members in a system and they frequently interact with their peers. These two things make them a very important group to reach for anyone interested in launching an innovation. Once parts of this group has been persuaded, the adoption rate can be increased significantly.

- The ***late majority*** adopts an innovation after the average individual. Like the early majority, this group is also numerous, making up a third of the total individuals in a system. They are not risk takers. Most of the doubt and potential risk surrounding an innovation must be removed before the late majority considers adopting it. As adoption of an innovation increases, the peer pressure on this group to do the same intensifies. Their lack of substantial financial resources makes it necessary for the innovation to be economically sound. At least one of these factors, or perhaps both, need to be fulfilled for this group to be persuaded to adopt.
- ***Laggards*** are the last to adopt an innovation in a social system. They tend to be isolated from the rest of the social system and interact mainly with others that also hold traditional views. The fact that their resources are limited and that they are usually suspicious of innovations results in an innovation-decision process that tends to be lengthy. They need to be certain that an innovation will not fail before they can adopt.

Figure 4.2 shows the frequency of adoption at different times during the diffusion process. The average time of adoption ($\bar{X}$) and the standard deviation (sd) are used to categorise the different adopters. Like the S-shaped adoption curve, the frequency distribution closely approach normality. The percentages shown in the figure represents the share of the total number of individuals that each category makes up. How many individuals that is included in each category depends on what the total number of potential adopters is considered to be. Adopters of solar PV coupled with battery storage would most certainly be categorised as *innovators* since the number of adopters in Sweden is low. The number of smaller houses in Sweden is around 1.9 million [22] and the number of solar PV installations under 20 kW (a system for an average house is usually smaller than that value) in Sweden were around 13 000 in 2017 [23]. Even if only half of the houses were suitable for solar PV and all of the solar PV systems were coupled with battery systems the share that those 13 000 potential battery systems would still represent only 1.4%.

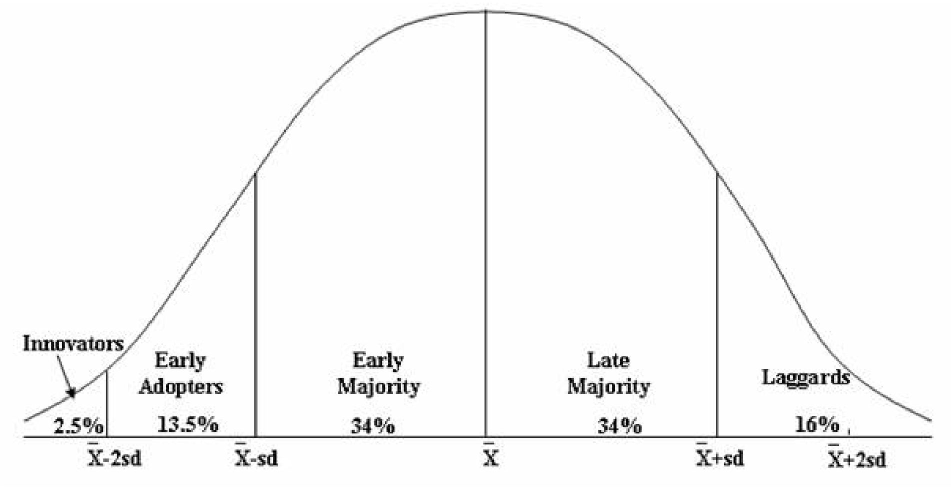

Figure 4.2: Adopters categorised depending on time of adoption during [24]

.

The adoption rate of different innovations varies. The variation is explained by Rogers through different attributes that the innovations have that are generalised into five categories:

- ***Relative advantage*** is to which degree the innovation is perceived to be better than its alternatives. The alternative to solar PV with battery storage could then be solar PV on its own, buying electricity from the grid or even another financial investment altogether.
- ***Compatibility*** with, for example, the needs, past experiences and values of the potential adopter. Naming and adapting the innovation to align with these factors would therefore be important.
- ***Complexity*** in the eyes of the potential adopter. A highly complex technology will influence the adoption rate negatively.
- ***Trialability*** is the possibility for potential adopters to test the innovation before adopting it.
- ***Observability*** is the possibility of the potential adopter to observe the technology in its surroundings and the results of the innovation.

One could argue that most of these attributes are working against the adoption of solar PV with storage. Alternatives such as buying electricity have an economic relative advantage compared to this technology. The compatibility of the technology depends a lot on the values of the adopter, for example regarding climate change. Even though much of the installation process is taken care of by the retailer, the complexity of this process and the actual usage of the technology might influence the potential adopter negatively. The trialability of solar PV with storage is practically non-existent. Solar PV in itself is very visible when adopted but the low degree of adoption and the fact that potential storage isn't visible influences the adoption rate negatively.

4.2 Technological innovation systems

Similarly to the theory of *diffusion of innovations*, *technological innovation systems* (TIS) can be defined as a concept within the field of innovation studies which goal is to explain the nature and rate of technological change [25]. Carlsson and Stankiewicz state that *"a technological system may be defined as a network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion, and utilisation of technology. Technological systems are defined in terms of knowledge/competence flows rather than flows of ordinary goods and services"* [26, p.111]. The TIS literature is a branch within the broader approach of literature dealing with innovation systems. Other innovation systems are classified depending on the choice of boundaries of the system, including national, regional and sectoral boundaries. While these approaches depend on their geographical scope, the TIS is focused around specific technologies [27] [17]. Since this thesis is focused around the adoption of a specific technology, it is deemed an appropriate starting point. The structure of a TIS is usually thought of to be made up of three system components [26] [28] [17]:

- ***Actors:*** Organisations and individuals that in some way are relevant to the development or deployment of the technology in question. These include actors that influence the process directly, such as developers and adopters, or indirectly, like policy makers for example. How the TIS develops depends largely on the interrelations of these actors. For example, if a subsidy scheme is introduced by a government, the potential adopters are more inclined to invest.
- ***Networks:*** The interconnections between actors form a network. Through the linkages within the network, information is exchanged. The communication taking place between potential adopters that is stated to be of great importance in Rogers diffusion theory is an example of an informal network. Networks of more formal nature could be for example associations for installers and suppliers.
- ***Institutions:*** Societal rules that shape human interaction. Formal institutions are those that are created and enforced by authorities while informal institutions can be described as social norms, values and collective mind frames that have been created through interaction between actors. Formal institutions such as technology standards and informal institutions like popular perception are often important regarding adoption of new technologies. Institutions can work in both ways when it comes to innovation adoption. Sometimes they facilitate deployment while other times they prohibit and complicate the process.

These components contribute to the development, diffusion and utilisation of new products and processes [29]. There is a view that components of a system needs to contribute to the overall *goal* of the system, otherwise it would not be considered a part of the system [27]. This happens either consciously or not. The contribution of each component towards the goal is what is often called *functions*. The number of functions and their definition varies between literature but can be defined accordingly [30] [31]:

- ***Knowledge development and diffusion:*** In order to increase the chances of success when it comes to diffusion of a technology, key actors need to have the necessary knowledge. These actors, such as firms, policy makers and potential adopters, need an understanding of how to install, market, regulate, support and use the technology [17].
- ***Guidance of the search:*** To "*influence the direction in which actors deploy their resources*" [27]. Guidance in terms of choice of technology, business areas or markets.
- ***Entrepreneurial experimentation:*** Firms that use innovative and various ways of deploying a technology. Business models and different applications are used creatively to suite the specific technology and the market.
- ***Market formation:*** All activities that increase demand of a product. Markets do not necessarily form on their own. Facilitation of information exchange and the transfer of knowledge can help to create or stimulate existing markets.
- ***Legitimation:*** Changes regarding the social acceptance of a technology. This does not change by itself though, Bergek argues that legitimacy is not given "*...but is formed through conscious actions by various organisations and individuals...*" [30, p.20]. It is especially important to overcome this barrier for new technologies, which is the case for many renewable energy technologies. The outcome of a diffusion process is greatly influenced by how good or desirable the specific technology is perceived to be.
- ***Resource mobilisation:*** For a TIS to perform well, the availability of competence and financial capital is important. The necessary resources needs to be mobilised. In the case of renewable energy technologies, one such resource could be financial capital for subsidy schemes [17].

Identification and strengthening of functions that are currently performing poorly would improve the overall performance of a TIS [17]. This could be achieved by strengthening or adding drivers, or by weakening or removing barriers [30].

4.3 Business models

The functions of *market formation* and *entrepreneurial experimentation* from the previous section plays a part in the structure of business models. The definition of a business model has been expressed as "*how an organisation creates, delivers and captures value*" [32, p.14]. In order for a technological transition to take place, the technical innovation in itself may not be enough. Innovation within the field of organisation might be needed as well. Boons and Lüdeke-Freund [33] describes a generic business model that include the following four elements:

- ***Value proposition:*** The value that the product or service contains that the firm offers to its customers.
- ***Supply chain:*** The structure and management of the upstream relationships with suppliers.
- ***Customer interface:*** The structure and management of the downstream relationships with customers.
- ***Financial model:*** The relationship between the costs and benefits of the previous elements and their distribution across the stakeholders of the business model.

Business models can be utilised to help overcome incompatibilities with existing institutions and regulations, but also the uncertainties of the customer. Uncertainties comes with new technology and an investment in the technology is usually associated with a perceived risk. The role of the business model could in this case be to shift the risk and transaction cost from the customer to the company, as well as neutralising the institutional barriers in question [17]. Additionally, the barriers of diffusion and the solutions to these are not the same in geographical context. Companies need to adapt their approach depending on the deployment related problems that are present in their area of influence.

5
Methodology

The simplified methodology that was set from the start to try to answer the questions raised for this thesis consists of the following parts:

- A review of literature that evaluates the factors that enable or disable the transition to households investing in battery systems coupled with solar PV.
- Identification of households which have already invested in battery storage systems and to interview them about the reasoning behind the investment and how the battery storage system is useful for them.
- Collection of quantitative and qualitative data, regarding the battery storage systems and the investment decision, and analysis of the collected data would then be the final task. Data will also be collected from households which have invested in solar PV without battery storage.

The following sections explains the research type and design that has been used during this thesis work.

5.1 Literature review

The purpose of the literature review, presented in Chapter 3, was to gather an understanding of previously identified barriers and drivers to adoption of solar battery storage. The literature studied has ranged from reports on the current situation of PV and energy storage adoption in the rest of Europe to previous studies on PV adoption at a more local level in Sweden. The available literature focuses mainly only on solar PV adoption but the factors affecting the decision making were deemed to be similar to solar battery storage adoption.

5.2 Research type

One of the main decisions was to conduct bottom-up research, i.e. contacting adopters of solar PV as well as adopters of solar PV coupled with battery storage. The other option would be to conduct top-down research, i.e. contacting experts and retailers. But since the main purpose of this thesis was to investigate the reasoning of individual households when it comes to investing in solar battery storage as well as how the technology is used, it was deemed preferable to use the bottom-up approach.

The research conducted has been a mixture of qualitative and quantitative research. Since the data gathered from the owners of solar PV coupled with battery systems was retrieved through interviews, it would be classified as qualitative research. The information retrieved was in this case mainly in the form of words and thoughts and "*information is considered qualitative in nature if it cannot be analysed by means of mathematical techniques*" [34, p.13].

Quantitative research "*describes, infers and resolves problems using numbers*" [34, p.15]. While some parts in the interviews handled numerical data regarding the solar PV system and would be deemed as quantitative, the main focus was for the gathered data to be qualitative. In comparison, the self-completion survey was mainly quantitative with some smaller elements of qualitative questions. The survey implemented the use of the Likert-scale [35] where the participant chooses a ranking according to the level of which they agree with the question. This method was used in order to achieve easily quantifiable data as well as making the answering process easier and inviting to participation.

5.3 Research design

Both primary data, in the form of interviews and survey, and secondary data, through literature review and internet searches, were collected and used in this thesis. As stated in the previous section, quantitative research was performed as well but the main research type used was qualitative.

The research of this thesis has been performed mainly in the form of a case study. A case study has been described as "*the preferred strategy when "how" or "why" questions are being posed, when the investigator has little control over events, and when the focus is on contemporary phenomenon within some real-life context.*" [36, p.1]. Since the main questions of this thesis very much falls into the category of "how" and "why", case study is an appropriate way of describing the research.

5.3.1 Data collection

The households from which the information would be retrieved were split into two groups, those with solar PV coupled with battery storage and those that only had installed solar PV. While the households with battery storage could offer helpful insight into their reasoning behind the investment and the usefulness of it, it was also regarded as important to examine the reasons for which some owners of solar PV did not make the investment.

For the questions regarding what the reasoning behind an investment in solar PV coupled with battery storage was for the owners and also, how they used the system, it was most reasonable to talk to the owners themselves. With the help of information received from researchers at Lund university, contact was made with a few households in the region of Skåne that had made the investment in solar PV and battery storage. These introductions resulted in three interviews of 30-40 minutes. The aim was for the interviews to be semi-structured [37], i.e. the questions were to be phrased in such a way that the answer would give the wanted information but at the same give some flexibility to the interviewee. The information received from the interviews was fairly homogeneous and it was therefore not deemed necessary to perform further interviews in order to complete the analysis.

The number of questions that were needed to be asked to the owners of only solar PV were fewer than for the battery group and it was therefore deemed sufficient to use a self-completion survey for this group, shown in Appendix A. Households were identified by contacting *Länsstyrelsen Skåne* for contact information to the households that had applied for and received subsidy payments for investments in solar PV. The information received was in the form of a list of recipients of the subsidy, including payment amount and postal address. A self-completion survey was then sent out by postal service to 50 different households from the list. The survey was constructed in a way that would invite participation, with a low amount of questions and a financial incentive in the way of a possible gift voucher. The participant had the option of either sending their response via postal service or completing an online survey with the same questions. The result was a total response rate of 74%, or 37 respondents, which is to be regarded as high. 31 of the responses were received via postal service while 6 were received via the online survey. Five of these responses arrived too late to be included in the analysis.

5.4 Financial calculations

Some financial calculations were performed to present the current economic situation of a battery storage investment as well as how this situation changes in different usage and legislative scenarios. Calculations of produced electricity value and payback periods are presented below.

5.4.1 Value of produced electricity

Calculations were performed to highlight the differences in value of the produced electricity for the owner depending on if it is sold or used, as well as the electricity contract and the existence of tax reduction. The value of the electricity for the owner was calculated for four scenarios listed below.

- **Own use, fixed electricity price:** Produced electricity from solar panels is used within the household. Electricity contract based on fixed price.
- **Own use, power tariff:** Produced electricity from solar panels is used within the household. Electricity contract based on power usage.

- **Sold electricity with tax reduction:** Produced electricity from solar panels is sold to the grid. Value for owner includes tax reduction.
- **Sold electricity without tax reduction:** Produced electricity from solar panels is sold to the grid. Value for owner excludes tax reduction.

The parts that make up the value of the produced electricity are added up for the different scenarios and are then presented in a chart.

5.4.2 Calculation of payback period

There are several ways to calculate the profitability of an investment, e.g. cash flow analysis and LCOE. But traditionally for solar PV, it has been popular to use payback-time since it gives the adopter a clear idea of how long it will take for the investment to ”break-even”. Therefore it was deemed a relevant method for the investment of a battery system as well. The formula that was used for calculating the payback period is shown in Equation 5.1.

$$Payback\,period = \frac{Initial\,investment}{Net\,cash\,flow\,per\,period} \tag{5.1}$$

where the ”Initial investment” is the total investment cost including installation costs. The ”Net cash flow per period” is defined in Equation 5.2.

$$Net\,cash\,flow\,per\,period = Battery\,capacity \cdot 365 \cdot Usage \cdot Savings \tag{5.2}$$

where ”Battery capacity” is the usable capacity of the battery, ”365” is the number of days per year, ”Usage” is the fraction of the total capacity of the battery that is used during a year and ”Savings” is the possible savings relative to selling the produced electricity in the different scenarios.

Payback periods for investments in battery storage were then calculated for three different scenarios that are defined in Section 6.4.2. The differences between the scenarios include how much of the battery’s maximum capacity that is used over time and the existence of the tax reduction on sold electricity since these two factors have a major impact on the profitability of a battery storage investment.

6

Results

The resulting answers on the questions asked from the respondents are presented in this chapter. The respondents are split into two groups, the ”solar PV group” and the ”battery group”. The solar PV group consists of the 32 respondents included from the survey participant group while the battery group consists of the three households that were interviewed. All the households from both groups are situated in the region of Skåne.

The results are presented and structured using the set of research questions established in Chapter 2. The questions are answered one by one using the qualitative and quantitative data retrieved from the interviews and surveys. Data from the interviews is presented using quotes from the interviewees while the data from the survey participants is presented quantitatively.

6.1 Does the subsidy scheme for battery storage systems encourage households to invest?

6.1.1 Solar PV group

For the subsidy scheme to be successful and encourage households to invest, the potential adopters first and foremost need to know that it exists. The question whether the participants knew about the subsidy was asked to the group with solar PV without a battery system, with all 32 included participants leaving complete answers. The result is presented as Question 1 in Table 6.1.

Table 6.1: Response share for survey questions.

Question	**Yes**	**No**
1: Do you know about the subsidy scheme for batteries?	53%	47%
2: Have you ever considered investing in a battery system?	68%	32%
3: Do you possess a battery system coupled with the solar panels?	13%	87%
4: Have you been in contact with someone that owns a battery system?	9%	91%

The households that answered that they possess a battery system were excluded for the questions that were aimed at households without battery systems.

6.1.2 Battery group

The interviewees were asked if the possibility of subsidy payments played a part in their decision to invest or if they would have made the investment anyway. All of the three households with battery systems that were interviewed stated that they would not have made the investment at this point in time were it not for the subsidy. One of the households had the following line of thought:

> *Then it would probably have taken longer before I installed the battery. The economic calculation is not obvious. So it is because of other reasons that you decide to install the battery. The current situation is that the electricity I produce myself is cheaper than the electricity I buy from the grid. But then again, you get fairly well paid for the electricity you sell but the more of what I produce that I use myself, the cheaper it is and it also gives a better feeling. Those who buy batteries today are those that bought solar cells first, where the economic part is not the brightest shining light.*

Another household reasoned along the same lines:

> *It helped a lot. The solar panels I probably would have installed anyways but the battery, that I could get so much back. I got half of the investment cost of the battery back, and I think that was incredibly generous. It helped to make that decision.*

6.1.2.1 Subsidy application and information search

The general experience among the interviewees was that the application and processing of the subsidy payments went smoothly. Though there were differences in the amount of time it took to receive the payment between the solar PV and battery subsidies:

> *The subsidy payment for the solar panels took almost two years. While for the battery it only took a few weeks. There's not alot of people applying for that.*

The time it took to receive the payments for the solar panels varied among the interviewees. One household received the payments four months after the application, another after almost two years, while the third one did not provide such data. An increase in the percentage of the investment cost being paid for by the subsidy led to a surge in the number of applicants, leading to longer processing times. This is probably the cause of the difference in time it took to receive the payments.

The general technological interest that is present among the households investing in battery storage means that the information search prior to the investment is not considered a major hurdle. Though one of the households found it difficult to compare offers:

> *The information wasn't hard to find if you just look. The information was available from all the companies, you just had to visit their websites and dig a little deeper. Find some general information on the internet and then look at the ones you think are good. What took me the longest was to get offers that were comparable. I think I had seven different offers that I tried to compare but it was really difficult since there are differences between the companies with what's included. What do I have to do myself? What do they help me with? So the comparison wasn't easy.*

6.2 What is the households reasoning behind investing in a battery system?

6.2.1 Solar PV group

While it's important to consult the battery owners of why they made the investment it is also of interest to ask the question to the solar PV group why they did not. There might be an inclination from both groups to argue strongly for their own decision and therefore the non-investors are seen as an important part of the study to get a more nuanced picture of what the thoughts involving the investment or non-investment are.

First and foremost, the participants were asked if they had ever considered investing in a battery system, with all 32 included participants leaving complete answers. The result is presented as Question 2 in Table 6.1. Of these there were four households that possessed a battery system connected to the solar panels. The share of these households compared to all 32 included participants is presented as Question 3 in Table 6.1. Only one of these households left a complete answer as to what the reasons for the investment were. This was seen as insufficient to present as results and since asking battery owners about their investment was not the primary objective of the survey, the interviews with the battery owners was seen as sufficient for answering that question.

The next natural step was to ask the survey participants what the factors were that influenced their decision to not invest in a battery system. This was done by asking the participants to rate a few reasons from 1 to 5, 1 for ”not important” and 5 for "very important", as well as being offered a chance to add their own reasons. Of 32 respondents, 18 left complete answers to the question. Of the other 16, some left no answer at all while most just rated one of the reasons, which in this case was seen as insufficient. The result can be seen in Figure 6.1.

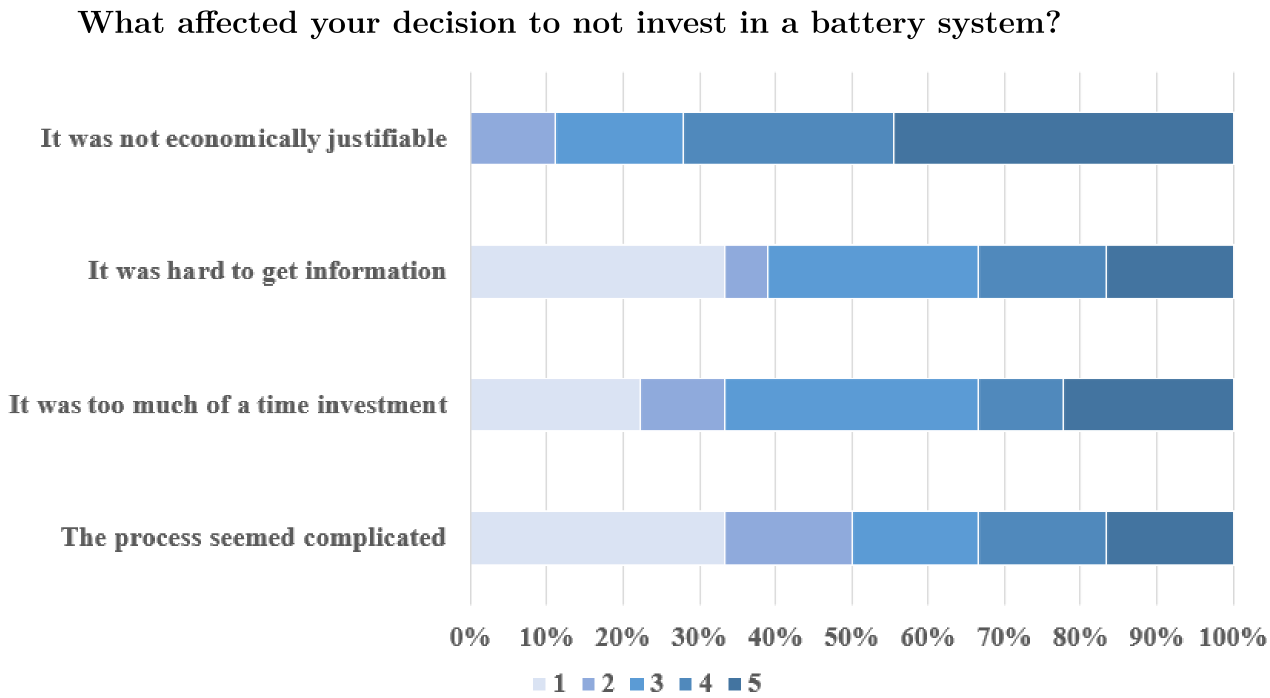

Figure 6.1: Rating of the respondents' reasons to not invest in a battery system, where 1 represents the reason being "not important" and 5 "very important"

The possibility to visually be exposed to the invention or product in question has been cited to be of importance within innovation diffusion [17]. An individual is much more likely to be at least visually exposed to solar panels mounted on the roofs of houses than to battery systems since they are usually installed in the interior of the houses. So, the factor of being affected by peers in the individuals surroundings is probably not one of the major influences when it comes to reasons for the battery owners investment. The potential adopter can also be affected in this case by battery owners through "word of mouth" or direct contact with the battery owner but since the overall adoption of battery storage in Sweden is rather low, those contacts were thought to be few. This is strengthened by the answers received when the question was asked to the solar PV group, with all 32 included participants leaving complete answers. The result is presented as Question 4 in Table 6.1.

6.2.2 Battery group

Regarding why the households made the investment they all state that it was because of a general technological interest and concern for the environment, while one household also quotes financial benefits. Regarding the main reasons of the investment, one of the households stated:

> *I have a technological interest. I am interested in wasting less of the resources of our world. So environment wise, it has affected both the investment in the battery as well as the solar panels.*

Another reason that was mentioned was the good the battery storage could do for the grid system. One of the households reasons:

> *Then also, I feel that as a battery owner you can be of use for the grid as well. Like today, for example, the high spot prices has an influence as well, when there is less electricity available I can use my battery instead. In that way I can do my part and not wear on the grid at those times. You can do some good for society as well as a battery owner.*

Two of the households stated that they needed something to spend their money on and saw the investment in solar PV as a better way to use their money than just save it in a bank account. This reasoning leaves out the battery storage since the households are aware that they probably won't get their money back on the battery storage investment. But for the investment in solar panels, one household says:

> *If I'm going to invest some money I might as well do it this way and get some kind of interest back. It pays off immediately since I have a lower electricity consumption now. Last year I bought 5000 kWh less electricity, and that's almost 5000 SEK. If you're counting only the investment in the solar panels of 200 000 SEK and then 5000 SEK in savings, then you start to get a decent interest. And then I have maximum subsidy payment on them, so it costs 150 000 SEK instead of 200 000 SEK. And then I've also sold electricity for 5000 SEK, so the balance calculations becomes even better right now.*

The ”right now” refers to that the payment received on sold electricity is in some cases a bit higher during the first year after the installment of solar panels since some of the companies that buy the produced electricity give up to an extra 1 SEK per kWh of electricity during the first year [38].

6.3 How are the households using the battery system?

6.3.1 General usage

The usage of the battery system determines how much of a benefit it is for the grid and how much the owner can save financially. The most common usage is to simply charge the battery with the electricity produced from the solar panels that is not consumed:

> *It's not like everything that is being produced goes into the battery, it takes a part of the production and the rest goes into the house so to speak.*

The times at which the battery is charged can also be controlled, and the battery can be charged even when the solar panels are not producing:

> *First when I got the battery, I installed it in November I think, and then I tried to charge it at night as well to use at other hours of the day. So I think that is another advantage with the battery, that you can adjust when you buy and use electricity. So there might be an economic advantage to have an hour-based price. So yes, in the beginning I charged a little from the grid because basically nothing was produced from the solar panels because the sun wasn't shining. Now lately the days have become longer so from around mid-January I have charged the batteries just from the sun. The last week the weather has been very good so there has been several days where the charged battery has lasted from one day to another, so that it hasn't been completely empty when the sun started shining again.*

One of the households wished for possibilities of controlling more precisely when to buy and sell electricity:

> *I would like to choose at what hours you charge the battery. I would like to see that the battery could be connected to Nord Pool spot for example. So that during the winter when the production from the solar panels is low, I could charge it with electricity from the grid and in that way lower my electricity costs. But I miss that control.*

6.3.2 Back-up power

To utilise the battery as back-up power at times of power outages is a possible usage of the storage system. But usage of this sort requires installation of an additional device. In the case of a power outage, the household must be able to disconnect from the grid since potential reparation works might be dangerous otherwise. The hope of one of the battery owners was originally to be able to use the storage in these circumstances:

> *Originally, my reason for buying a battery was that I wanted power supply in case of a power outage. But you can't do that in Sweden without a special device.*

Another household expressed a wish that the information about this usage of the battery system was made more easily accessible as well as reasoning that the need for back-up power is declining:

The information about back-up power could be a bit clearer. But it's not a major problem with power outages now if you live fairly close to a city or in a city because it has become a lot better the last 10 or 20 years. The grid has become more stable. So from that point of view, it's not that important with back-up power.

6.3.3 Electricity data for interviewed household

One of the households provided detailed usage data regarding the solar panels and battery, as well as overall electricity data of the house. The data from this particular household is used since it was the only one out of the three that could provide detailed data from both overall electricity usage, and the usage of the solar panels and battery over a longer period of time. The household kept track of the data through monthly reports on electricity consumption, produced electricity from the solar panels, sold electricity from solar panels and amount of bought electricity from the grid. Usage of the battery could in this case be observed either through a mobile phone application or through an internet portal. The data was provided in the form of an Excel file. General data about the house, electricity usage, solar panels and the battery are summarised in Table 6.2.

Table 6.2: Electricity data of household

Parameter	Value
Size of house [m^2]	230
Overall electricity consumption [kWh/year]	14500
Total electricity produced from solar PV [kWh/year]	10538
Electricity consumption for utilities [kWh/year]	1000 - 2000
Electricity consumption for heat [kWh/year]	10 000 - 11 000
Power capacity of solar panels [W]	10 300
Energy capacity of battery [kWh]	8
Power capacity of battery [W]	3300

Figure 6.2 shows how the production from the solar panels changes over the course of a day in March. The production is quite heavily centered around noon and the effect of cloudy weather can also be seen, where the production can be close to zero even during midday.

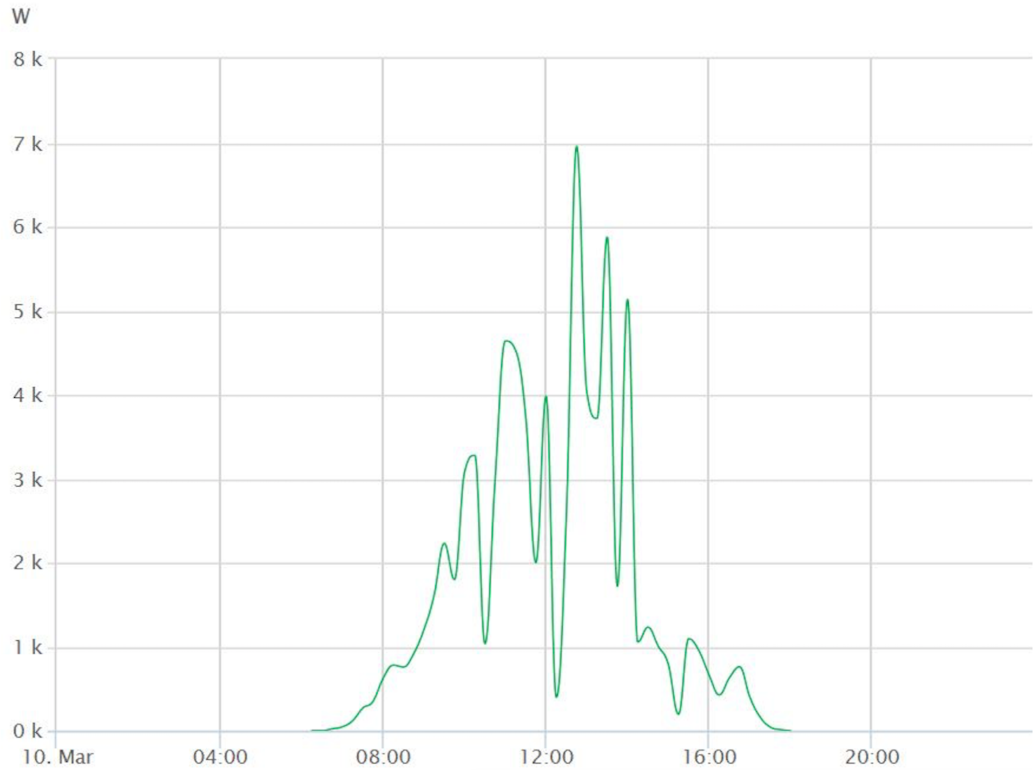

Figure 6.2: Solar PV production during a day in March, obtained from a household

The following figures instead show the energy data on a monthly basis for a full year, in this case between March 2018 and February 2019. In Figure 6.3, the ways in which the household handles the production and consumption of electricity during the year is visualised. In Figure 6.4, the same data is used as in Figure 6.3. This figure instead shows only electricity data that is directly connected to the solar panels and battery system, to make this part of the data collection more easily readable.

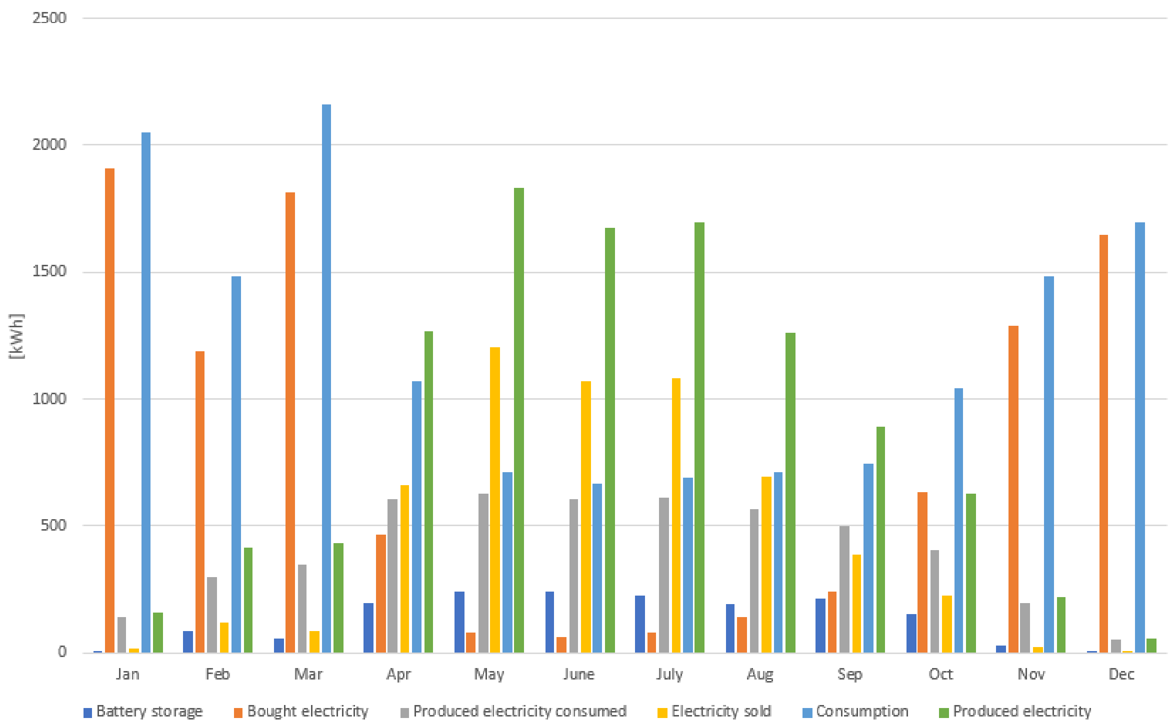

Figure 6.3: Electricity data for each month, obtained from an interviewed household

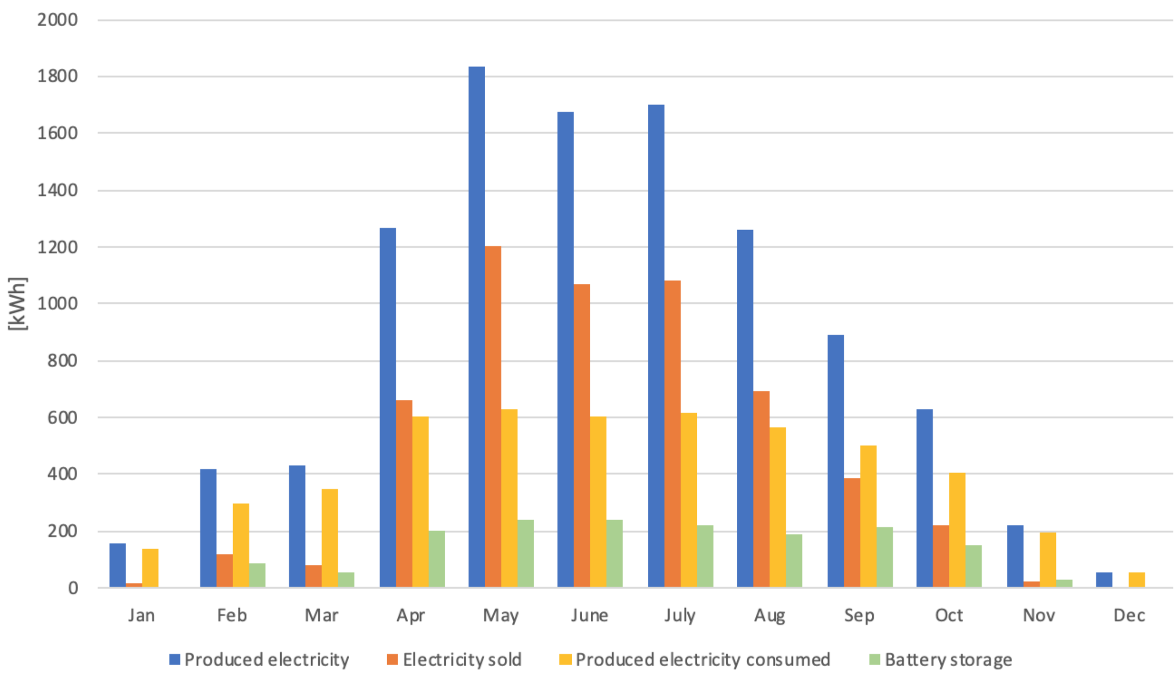

Figure 6.4: Comparison of data regarding solar cells and battery usage, data obtained from an interviewed household

6.4 Is it economically viable for the households?

The largest barrier to adoption of battery storage is the substantial investment cost. Even though the current adopters do not expect the investment to be economically viable, the economic factor needs to be in favor of the investment for the diffusion to increase. For the investment to be worthwhile from an economic point of view, the money spent needs to induce a net positive cash flow to the extent that the money is regained during the lifetime of the batteries. The following section will explain the current economic situation of an investment in a battery system connected to solar panels and the different costs and revenues involved.

6.4.1 Value of produced electricity

Table 6.3 is a summary of the different parameters used in the comparison.

Table 6.3: Parameters used for financial calculations

Parameter	Value and unit	Sources
Tax reduction	60 [öre/kWh]	Skatteverket [12]
Guarantee of origin	1 [öre/kWh]	Svensk solenergi [39]
Green certificate	16 [öre/kWh]	SKM [40]
Nord Pool spot SE4	39 [öre/kWh]	Vattenfall [41]
Energy compensation	4.7 [öre/kWh]	Vattenfall [42]
Value-added tax	25 [%]	Skatteverket [43]
Green certificate charge	5.8 [öre/kWh]	Öresundskraft [44]
Energy tax	34.7 [öre/kWh]	Vattenfall [45]
Transmission cost	27.2 [öre/kWh]	Vattenfall [46]
Electricity price	58.89 [öre/kWh]	Kundkraft [47]

Figure 6.5 shows what value the different costs and revenues gives the owner per kWh of electricity in four different scenarios, as described in Section 5.4.1. It shows how big of an impact the tax reduction on sold electricity has on the economic calculations. The difference in value between using the produced electricity and selling it becomes modest.

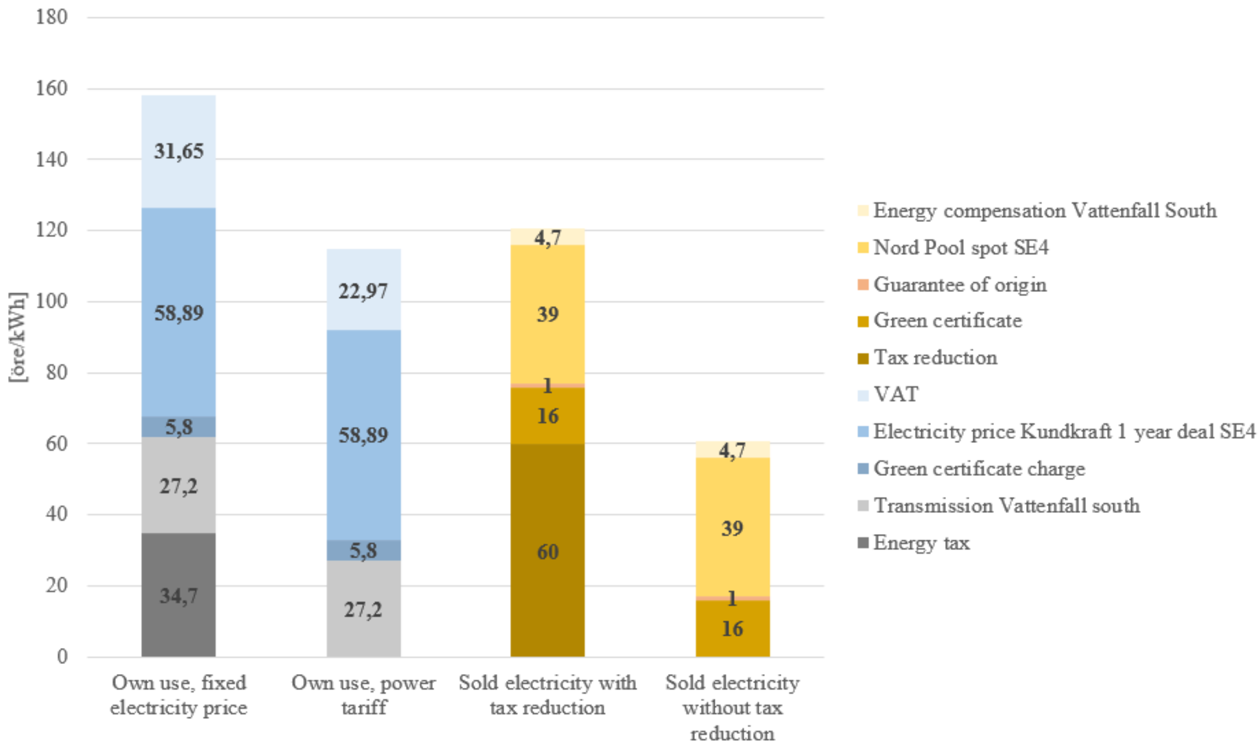

Figure 6.5: Value comparison of used and sold electricity [48, authors calculations]

6.4.2 Calculation of payback period

Since the alternative to storing the produced electricity is to sell it to the grid, the economic performance of the battery needs to be compared to that. The efficiency of a battery system is in this case around 94% [49], so the value of using the produced electricity from the solar panels through the battery needs to be at least 6% higher than the value of selling it for it to be net positive. Once net positivity is reached, the focus switches to the payback period of the investment. To explain the current situation of a battery investment, an example will be presented involving one of the cheaper alternatives available on the Swedish market. The parameters regarding the battery needed for the calculations as well as the possible savings established in Section 6.4.1 are presented in Table 6.4.

Table 6.4: Investment parameters used in calculations of payback periods

Parameter	Value
Investment cost of battery system [SEK]	55 858 [49]
Investment cost after subsidy payment [SEK]	22 343 [49]
Energy capacity of battery [kWh]	3.6 [49]
Savings of using battery system with tax reduction [öre/kWh]	37.5
Savings of using battery system without tax reduction [öre/kWh]	97.5
Warranty [years]	5
Expected lifetime [years]	20

If the battery is charged and discharged with its full capacity every day during a year, the maximum possible energy used from the battery in the household is 1314 kWh. This is, though, a high assumption. The calculated usage of the battery's capacity during a full year for the battery data in Section 6.3 was around 56.2%. This will be used as a more realistic usage of the battery's capacity compared to the battery being fully charged and discharged every day during the year. The payback period will be calculated using a few different scenarios ranging from realistic to optimistic.

- ***Scenario 1:*** Payback period with current tax reduction on sold electricity and a usage of 56.2% of the maximum capacity of the battery system.
- ***Scenario 2:*** Payback period with current tax reduction on sold electricity and a usage of a 100% of the maximum capacity of the battery system.
- ***Scenario 3:*** Payback period without current tax reduction on sold electricity and a usage of a 100% of the maximum capacity of the battery system.

The payback period of each scenario is presented in Figure 6.6

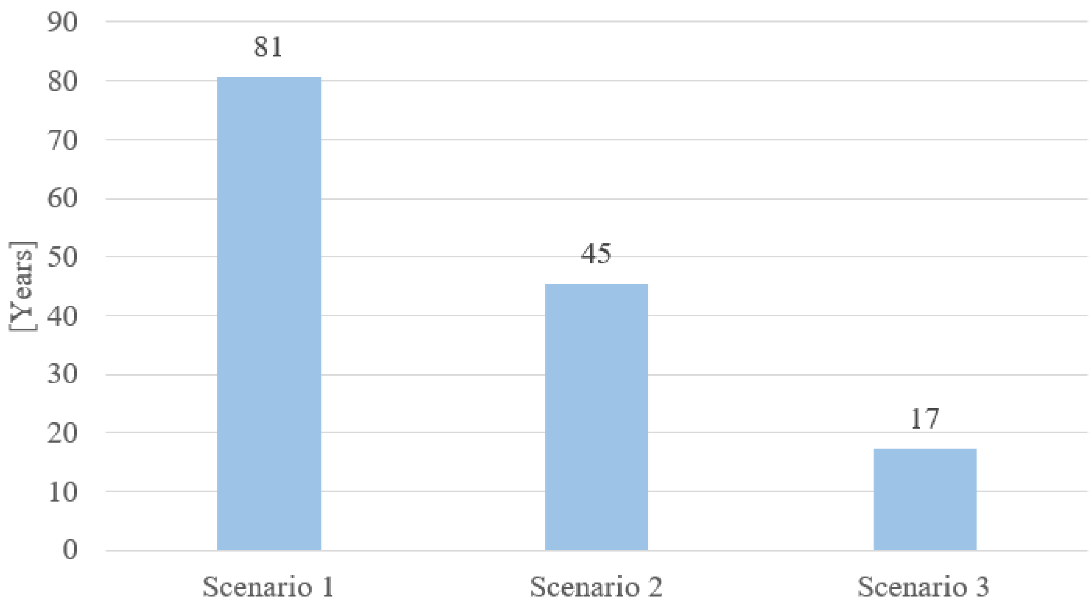

Figure 6.6: Payback period for an investment in battery storage using values from Table 6.4 for each scenario

7
Discussion

This section comments on some of the methodological choices and evaluates the theoretical framework. The results for each research question are discussed which naturally leads the discussion into the present and future of policy and economic prospects.

7.1 Theoretical framework

7.1.1 Diffusion of innovations

As explained in Section 4.1, the adopters of battery storage in Sweden are still firmly categorised as *innovators* and the number of adopters need to increase many times over for that to change. The battery owners of today are in the same situation as the owners of solar PV were in a few years ago. The reason for adoption cited among the interviewees corresponds with the expected one according to the theory, with the reason for adopting the technology being "*mainly because it is new*". The risk of the investment being unprofitable is of lesser concern since these households were in control of enough financial resources and were mainly looking for a way to spend their money. From the theory, these individuals are categorised as wanting to understand and apply complex technology, which is also something that has been observed from the contact with these households.

The rate of adoption depends according to theory on five attributes. A substantial decrease of the investment cost of battery storage is the primary way of changing the *relative advantage* of battery storage compared to alternatives. The perceived *compatibility* and *complexity* of the technology could be altered with improved presentation and advertisement of the product.

7.1.2 Technological innovation systems

The essence of the TIS, that is presented in Section 4.2, is knowledge and competence exchange between *actors* in the system. Knowledge and information spread to the actors in need of it could help solve specific issues raised in the study such as installation problems, providing clear information regarding back-up power usage and to help individuals in their search for information as well as in their applications for subsidies. These are all issues that connect to the factors *knowledge development* and *guidance of search* that are defined within the TIS. The need within this specific TIS to work towards changing the perception of the technology, by interaction between *actors*, has been raised in this study. The importance of altering the so called *institutions*, the collective mind frames, is key in diffusion of a new technology where the goal is to reach *legitimation.* The design and operation of the subsidy scheme and tax reduction are examples of *resource mobilisation.* These schemes individually are performing well, but in the specific case of solar PV coupled with battery storage, they are somewhat working against each other. Business models use *entrepreneurial experimentation* in order to increase demand of the product, or alter the *market formation.* The application on this specific technology is studied in the following section.

7.1.3 Business models

In Section 3.3.1, examples are given of how business models have been used in different markets around the world to increase diffusion of solar PV.

The interviewees experienced some problems with the installation process, with delays occurring because of installation mistakes that had to be resolved later on. These problems are possibly stemming from the relative newness of the battery systems on the market with inexperience of the installers playing a role. These problems would of course be decreased with an increasing number of installations but conscious efforts of structural improvements to the *supply chain* could also be needed.

The overall adoption of battery systems could be increased with it's integration with other products. A similar approach could be utilised as the one used in Japan where newly built homes come with solar PV. Homes could be sold with solar PV coupled with storage or solar PV and storage could be arranged in package deals to be installed in already built homes.

Solar PV adoption has been increased in the US with the help of third-party ownership. This overcomes the problem of the high up-front cost for both solar PV and battery storage. But since households in Sweden have a higher level of savings, the barrier for investing in battery storage is instead that the investment is not profitable during the lifetime of the product. Thus not solving the problem with third-party ownership.

The barriers existing in Sweden for both solar PV and battery storage are comparable to those of Germany. Lowering the risk of the investment with guaranteed revenues over the lifetime of the products as well as making the legal-administrative process less complicated are measures that would encourage Swedish households to invest, as it has done in Germany. The two latter potential efforts would work towards adding value for the customer. Increasing the *value proposition* by adjusting the *financial model.*

7.2 Methodology

The chosen research type and design served its purpose of providing tools for achieving the objective of answering the research questions. The majority of the analysis was performed qualitatively and provided results that are nuanced and descriptive.

It could be argued that the number of interviews performed with battery owners should have been increased. But the decision was made that it was sufficient since the analysis for this group was qualitative and therefore not dependent on the answers being numerous, as well as the answers received from the interviewees being fairly homogeneous. From experience during this project, owners of solar PV as well as solar PV coupled with batteries are generally compliant when it comes to sharing their experiences. With that said, there were also some difficulties regarding recruitment of participants for the study.

The method used for retrieving information from the solar PV group was proven successful given the number of respondents. Owners of both solar PV and solar PV coupled with battery storage have a will to share their experiences from, and reasons for, the investment. This along with the economic incentive might be the reasons for the high level of participation.

7.3 Research questions

7.3.1 Does the subsidy scheme for battery storage systems encourage households to invest?

53% of the survey participants stated that they knew about the subsidy scheme. Though considering that these are owners of solar PV systems and therefore probably keep themselves fairly updated on this particular technological area, the result could still be considered as rather low. A quite conservative estimation would be that the corresponding number for the average Swedish household would be significantly lower.

Among the interviewees there was consensus regarding that the subsidy was essential in their decision to invest in a battery system. The prospect of receiving such large payments as the subsidy provides, is tempting for the potential adopters. During the early stages of a technology's adoption process, according to Rogers' diffusion theory [21] [24], innovators and early adopters are needed to legitimise the technology in the eyes of other potential adopters. Even if an investment in a battery system isn't economically viable even with the subsidy and that this discourages most potential investors, the fact that it encourages early adopters to take that step means that its existence is important. Guarantees for long term existence of subsidy programs would be of benefit, which has not been the case so far in Sweden.

7.3.1.1 Subsidy application and information search

As concluded in the literature discussed in Section 3.3, problems with subsidies have provided barriers for solar PV adoption, with long waiting times being one of the most significant ones. Interviewees in this study have confirmed the notion that the long waiting times for solar PV subsidies that have existed in Sweden discourages potential adopters. The lower number of applicants for the battery subsidy results in a much faster process. Apart from possible problems with fairly complicated technical details during the application, the process of receiving battery subsidy payments does not provide any major barriers.

Among the interviewed battery owners, one of the participants would be classified as *professional* according to the information search categories defined in Section 3.2. The other two have some kind of educational background within engineering which might help them in interpreting and understanding technical descriptions encountered in the information search. Even though they technically cannot be categorised as *professionals*, their ability to search for and understand the information fits well with the definition of this category.

Figure 6.1 shows that the participants from the solar PV group rated the information retrieval in connection to a battery investment on average as a 2.78 on the scale from 1 to 5. Though still not an alarmingly high value, it stands in contrast to the battery group who were cited to have practically no issues with the information search. Categorisation of this group according to Section 3.2 becomes difficult since they have invested in solar PV but in the context of battery systems, they would be categorised as non-adopters and share some characteristics with the definition of this category.

7.3.2 What is the households reasoning behind investing in a battery system?

7.3.2.1 Solar PV group

It is evident from the results shown in Figure 6.1 that the economic factor is by far the biggest influence on the decision of not investing, with around 45% of the respondents rating it as 5 on the scale. The information search and the complexity of the investment process were rated similarly and was not seen as major hindrances to the potential investment. A reason for this is probably the experience this group has from their earlier investment in solar PV and that they have gone through the process of finding the information needed before. That would make the process of purchasing a battery system seem less complicated.

7.3.2.2 Battery group

The reasons for the battery investment presented in Section 6.2.2 are similar to those that has previously been cited for investments in solar PV excluding the battery system. These are defined and explained in Section 3.1.

For one of the households, an environmental concern was stated as the primary reason for the investment. This concern was apparent in other parts of their lifestyle, with a conscious decision of traveling less being given as an example of this. As described in Section 3.1, for this group, the investments becomes a way of expressing the ”green” thinking into something physical and real, and that appeals to the household. For the other interviewees, the environmental aspect was mentioned as a secondary reason for the investment. These two household instead link more strongly to the *technological* category cited in Section 3.1, with a technological interest being the primary reasons for investing.

As stated by one household in Section 6.2.2, the battery storage can also be seen as a way of reducing the maximum stress on the grid by not using electricity from the grid. With a potentially increased share of renewable energy sources in the electricity grid of the future, it will be increasingly important to reduce the stress on the grid during peak electricity production while using curtailment to a minimum.

7.3.3 How are the households using the battery system?

7.3.3.1 General usage

The interviewees state that the most common way of using the battery system is to simply allow the battery to be charged by the solar panels when this electricity is not directly consumed, but more precise usage is possible. To increase the chance of the battery investment becoming economically viable, charging from the grid and using it at times when the electricity price is higher could be of benefit. Though, the subsidy statement says that a battery investment that is granted a subsidy payment should be used to increase the usage of renewable energy and therefore not be used to charge from the grid. But since there is no way for the Swedish Energy Agency to enforce this rule, it becomes a choice for the battery owner to choose between personal economic benefit or using the battery for what was intended. Even though the battery would be used by also charging from the grid, it would still do some benefit for the grid by reducing peak demand.

On average over a full year, the difference between the highest and lowest electricity price during a day is somewhere around 20 öre/kWh. Even for a bigger battery of around 8 kWh, it would still only give savings of 1.6 SEK/day or 584 SEK/year. It decreases the yearly electricity cost but it does not go a long way in paying back the investment cost of the battery. A combination of storing the produced electricity in the summer and storing electricity from and selling it to the grid in the winter would maximise the energy savings.

7.3.3.2 Electricity data for interviewed household

A Swedish household will experience an increase in electricity consumption during the winter months because of the increased need for heat production. Given the data in Table 6.2, the produced electricity from this particular solar PV system during a year is only around 4000 kWh away from covering the total electricity consumption. The majority of the production though, is taking place in months where the consumption is low, leading to most of it being sold to the grid, even though the battery is used to its full capacity during the summer months.

From Figure 6.4 it is obvious that the energy stored in the battery system is only a fraction of what is produced by the solar panels. The capacity of both the solar panels and the battery system are relatively high in this setup compared to the average household installation, but it is still close to following the general rule of thumb of having one kWh of battery storage for each kW of solar cell capacity. That would imply that these proportions are similar to other systems of solar cells coupled with batteries.

7.3.4 Is it economically viable for the households?

Given the current tax reduction on sold electricity and the relatively high up-front cost of investing in a battery system, it is not possible to reach a payback period that is within the length of the warranty of the battery. The battery's expected lifetime in scenario 3 in Figure 6.6 is longer than the calculated payback period but the capacity of the battery is gradually decreasing over time, with an expected minimum capacity of 68% after 15 years [49], making the probable actual payback period longer than the lifetime of the battery. The values in Figure 6.6 assumes no gradual loss of capacity.

There are possibilities of household battery storage becoming economically viable on its own in the future with decreasing investment costs for batteries. But there might be a need for policy changes in order to encourage households to invest by either using economic incentives to make it more economical to use your produced electricity or making it less favourable to sell it to the grid. As things stand, the tax reduction on sold electricity is a major factor in making an investment in storage for individual households redundant. While at the same time it being a balancing act since the aim is also to encourage households to invest in solar PV. The relatively low electricity prices are also a factor in the current economic situation of a battery investment. Selling electricity instead of storing it results in an increased need for buying electricity from the grid, thus increasing the importance of the price of electricity. With higher electricity prices, the economic gain of storing the produced electricity increases.

The potential economical gain of selling green certificates is relatively low. At 0.16 SEK/kWh it is providing added value for households for selling produced electricity but it is also just a fraction of the 0.6 SEK/kWh provided through the tax reduction. One survey participant expressed complaints over the complexity of both the tax reduction and green certificates system while a couple of the interviewees stated they did not know much about the green certificate system. This lack of will to gain information about the green certificate system indicates that it is not perceived as worthwhile.

8 Conclusion

The current legislative situation in Sweden connected to investments of both solar PV and battery system presents barriers for potential adopters. These adopters need to perform extensive information searches and applications regarding ROT-deduction, tax reduction, VAT registration, certificates of origin, green certificates, and the investment support.

The investment support for solar PV is crippled by long waiting times while the subsidy for battery storage is not, because of the difference in number of applicants. Long term guarantees of subsidy schemes could further encourage investments.

Even including the subsidy payment, the investment cost of the battery storage system is still the largest barrier to adoption. The tax reduction of 60 öre/kWh on sold electricity is a major factor in making the relative value of storing energy much too small to make an investment in battery storage economically viable. Decreasing prices on batteries might make the investment viable in the long term. Legislative changes are needed for financial viability in the short term.

The usage of the batteries usually follows the procedure that they are charged with the produced electricity from the solar panels that is not used directly by the house. The usage characteristics can be controlled more precisely by the owner if needed. Though a wish for even more precise control, with automatic charging from the grid at times of low electricity prices, was expressed. It was originally the hopes of the owners to be able to use the battery system for back-up power at times of power outages, but that capability requires additional equipment.

Business practices are somewhat underdeveloped in some areas. Owners have experienced problems with installations because of the limited experience of the installers. There is little implementation within the construction sector regarding the possibility of installing both solar PV and battery storage in newly built houses. Options of third-party ownership and possibilities of acquiring services that would handle all areas of ownership, including planning, installation, maintenance and legislative applications are slim.

Owners of solar PV and battery systems usually possess a relatively high level of technical know-how and therefore does not encounter major problems regarding information retrieval. Though some areas have room for improvement. The information regarding usage of battery system for back-up power could be more easily available. Potential adopters of solar PV and storage also requested more easily comparable offers from companies. What was included in the purchase from the different companies regarding applications and installations was not always clear, which made comparison difficult.

Bibliography

[1] B. Jones-Albertus, ”Confronting the Duck Curve: How to Address Over-Generation of Solar Energy.” [Online]. Available: https://www.energy.gov/eere/articles/confronting-duck-curve-how-address-over-generation-solar-energy, [Accessed: Jan. 24, 2019]

[2] International Renewable Energy Agency, ”Battery Storage for Renewables: Market Status and Technology Outlook.” [Online]. Available: https://www.irena.org/documentdownloads/publications/irena_battery_storage_report_2015.pdf, Jan, 2015 [Accessed: Jan. 24, 2019]

[3] SolarPower Europe, ”Global Market Outlook 2018-2022.” [Online]. Available: http://www.solarpowereurope.org/wp-content/uploads/2018/09/Global-Market-Outlook-2018-2022.pdf, 2018 [Accessed: Jan. 22, 2019]

[4] European Commission, ”2020 climate & energy package.” [Online]. Available: https://ec.europa.eu/clima/policies/strategies/2020_en#tab-0-0, [Accessed: Jan. 22, 2019].

[5] European Commission, ”Energy roadmap 2050.” [Online]. Available: https://ec.europa.eu/energy/sites/ener/files/documents/2012_energy_roadmap_2050_en_0.pdf, Dec. 15, 2011 [Accessed: Feb. 7, 2019]

[6] European Network of Transmission System Operators for Electricity, ”POWERFACTS EUROPE 2019.” [Online]. Available: https://docstore.entsoe.eu/Documents/Publications/ENTSO-E%20general%20publications/ENTSO-E_PowerFacts_2019.pdf, 2019 [Accessed: Feb. 7, 2019]

[7] BSW-Solar, ”Information on support measures for solar power storage systems.” [Online]. Available: https://www.solarwirtschaft.de/fileadmin/media/pdf/infopaper_energy_storage.pdf, Aug. 30, 2013 [Accessed: Feb. 11, 2019]

[8] gtmresearch, ”Global Energy Storage: 2017 year in review and 2018-2022 outlook.” [Online]. Available: https://www.woodmac.com/our-expertise/focus/Power--Renewables/Global-Energy-Storage/, May. 9, 2018 [Accessed: Feb. 11, 2019]

[9] Eurostat, ”Electricity price statistics.” [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics, Nov, 2018 [Accessed: Feb. 11, 2019]

[10] J. Lindahl, ”National Survey Report of PV Power Applications in Sweden - 2016.” [Online]. http://www.iea-pvps.org/index.php?id=93&tx_damfrontend_pi1=&tx_damfrontend_pi1%5BcatPlus%5D=&tx_damfrontend_pi1%5BcatEquals%5D=&tx_damfrontend_pi1%5BcatMinus%5D=&tx_damfrontend_pi1%5BcatPlus_Rec%5D=57&tx_damfrontend_pi1%5BcatMinus_Rec%5D=&tx_damfrontend_pi1%5BtreeID%5D=201&tx_damfrontend_pi1%5Bid%5D=93, Oct. 10, 2017 [Accessed: Jan. 22, 2019]

[11] Energimyndigheten, ”Subsidy application for energy storage at home is open”, energimyndigheten.se, 2016. [Online]. Available: http://www.energimyndigheten.se/nyhetsarkiv/2016/oppet-att-soka-stod-for-energilagring-i-hemmet/. [Accessed: May. 6, 2019]

[12] Skatteverket, ”Micro production of renewable energy - private home”, skatteverket.se. [Online]. Available: https://skatteverket.se/privat/fastigheterochbostad/mikroproduktionavfornybarelprivatbostad.4.12815e4f14a62bc048f41a7.html. [Accessed: May. 6, 2019]

[13] L. Söder, ”On track toward an electricity supply based solely on renewable energy in Sweden.” [Online]. Available: http://www.diva-portal.org/smash/get/diva2:570566/FULLTEXT02, Nov. 12, 2012 [Accessed: Feb. 6, 2019]

[14] J. Palm & M. Tengvard, ”Motives for and barriers to household adoption of small-scale production of electricity: examples from Sweden.” Sustainability: Science, Practice and Policy, 7:1, 6-15, DOI: 10.1080/15487733.2011.11908061

[15] J. Palm & E. Eriksson, ”Residential solar electricity adoption: how households in Sweden search for and use information”, Energy, Sustainability and Society, vol. 8, no. 1, 2018. Available: 10.1186/s13705-018-0156-1 [Accessed 29 April 2019].

[16] Energimyndigheten, ”Certified installers of renewable energy.” [Online]. Available: https://www.energimyndigheten.se/energieffektivisering/jag-arbetar-med-energieffektivisering/installator/certifierade-installatorer-inom-fornybar-energi/, Jan. 18, 2018 [Accessed: Feb. 11, 2019]

[17] A. Palm, *Residential solar photovoltaics deployment: barriers and drivers in space*, Lund: IIIEE, Lund University, 2017.

[18] C. Robson, *Real world research: a resource for social scientists and practitioner researchers*, 2nd ed., Oxford: Blackwell, 2002.

[19] G. Abend, ”The Meaning of ‘Theory”’, *Sociological Theory*, vol. 26, no. 2, p. 173-199, 2008. Available: 10.1111/j.1467-9558.2008.00324.x.

[20] L. Coenen, P. Benneworth and B. Truffer, ”Toward a spatial perspective on sustainability transitions”, *Research Policy*, vol. 41, no. 6, p. 968-979, 2012. Available: 10.1016/j.respol.2012.02.014 [Accessed 29 March 2019].

[21] E. M. Rogers, *Diffusion of innovations*, 5th ed., New York, NY: Free press, 2003.

[22] SCB, ”Number of households by living situation, living area and year.” [Online]. Available: http://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__HE__HE0111/HushallT27/table/tableViewLayout1/?rxid=26157997-0ba3-4697-a3f3-94f7f8bd9e5e, 2017 [Accessed: March. 19, 2019]

[23] SCB, ”Number of solar plants och installed power (MW), by region. Year 2016 - 2017.” [Online]. Available: http://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__EN__EN0123/InstSolcellNY/table/tableViewLayout1/?rxid=8a2b55a6-ecb1-4fc6-8994-b7bf5740a08b#, 2017 [Accessed: March. 19, 2019]

[24] E. M. Rogers, *Diffusion of innovations*, 4th ed., New York, NY: Free press, 1995.

[25] R. E. H. M. Smits, ”Innovation studies in the 21st century,” *Technological Forecasting and Social Change*, 69 (2002) p. 861-883. [Abstract]. Available: https://www.sciencedirect.com/science/article/pii/S0040162501001810, 2017 [Accessed: March. 20, 2019]

[26] B. Carlsson, R. Stankiewicz, ”On the nature, function and composition of technological systems,” *Journal of Evolutionary Economics*, vol. 1, no. 2, p. 93-118, June 1991. [Abstract]. Available: https://www.sciencedirect.com/science/article/pii/S0040162506000564, 2017 [Accessed: March. 20, 2019]

[27] A. Bergek, ”Shaping and Exploiting Technological Opportunities: The Case of Renewable Energy Technology in Sweden,” Ph.D dissertation, Department of Industrial Dynamics, Chalmers University of Technology, Göteborg, 2002.

[28] R. Suurs, M. Hekkert and R. Smits, ”Understanding the build-up of a technological innovation system around hydrogen and fuel cell technologies”, *International Journal of Hydrogen Energy*, vol. 34, no. 24, p. 9639-9654,2009. Available: 10.1016/j.ijhydene.2009.09.092. [Accessed 22 March 2019]

[29] B. Carlsson and R. Stankiewicz, ”On the Nature, Function and Composition of Technological Systems”, *Technological Systems and Economic Performance: The Case of Factory Automation*, p. 21-56, 1995. Available: 10.1007/978-94-011-0145-5_2 [Accessed 21 March 2019]

[30] A. Bergek, S. Jacobsson, B. Carlsson, S. Lindmark and A. Rickne, ”Analyzing the functional dynamics of technological innovation systems: A scheme of analysis”, *Research Policy*, vol. 37, no. 3, p. 407-429, 2008. Available: `10.1016/j.respol.2007.12.003.`

[31] M. P. Hekkert, R. A. A. Suurs, S. O. Negro, S. Kuhlmann, R. E. H. M. Smits, ”Functions of innovation systems: A new approach for analysing technological change,” *Technological Forecasting and Social Change*, 74 (2007) p. 413-432. [Abstract]. Available: `https://www.sciencedirect.com/science/article/pii/S0040162506000564`, 2017 [Accessed: March. 20, 2019]

[32] A. Osterwalder, Y. Pigneur, *Business Model Generation*, Hoboken, NJ: John Wiley & Sons, Inc., 2010.

[33] F. Boons and F. Lüdeke-Freund, ”Business models for sustainable innovation: state-of-the-art and steps towards a research agenda”, *Journal of Cleaner Production*, vol. 45, p. 9-19, 2013. Available: `10.1016/j.jclepro.2012.07.007.`

[34] D. Coldwell and F. Herbst, *Business research*, Cape Town: Juta Academic, 2004.

[35] R. Likert, “A Technique for the Measurement of Attitudes,” *Archives of Psychology*, vol. 22, no. 140, p. 1-55, 1932.

[36] R. K. Yin, *Case study research: design and methods*, 2nd ed., Thousand Oaks, Calif.: Sage publications, 2003.

[37] A. Bryman, E. Bell, *Business Research Methods*, Oxford: Oxford University Press, 2003.

[38] Vattenfall, ”Micro production - sell your excess electricity - Vattenfall.”, Vattenfall.se, 2019. [Online]. Available: `https://www.vattenfall.se/solceller/salj-din-overskottsel/`. [Accessed: May. 12, 2019].

[39] Svensk solenergi, ”Greatly increased trade of guarantees of origin for solar electricity.”, Svensksolenergi.se, 2019. [Online]. Available: `https://www.svensksolenergi.se/nyheter/nyheter-2018/kraftigt-oekad-handel-med-ursprungsgarantier-foer-solel`. [Accessed: May. 11, 2019].

[40] SKM - Svensk Kraftmäkling, ”SKM Elcertificate price history.”, Skm.se, 2019. [Online]. Available: `http://www.skm.se/priceinfo/history/2018/`. [Accessed: May. 11, 2019].

[41] Vattenfall, ”Hourly rate on the power exchange Nord Pool Spot - Vattenfall.”, Vattenfall.se, 2019. [Online]. Available: `https://www.vattenfall.se/elavtal/elpriser/rorligt-elpris/timpris-pa-elborsen/`. [Accessed: May. 11, 2019].

[42] Vattenfall, ”Compensation and fees for electricity production - Vattenfall electricity distribution.”, Vattenfalleldistribution.se, 2019. [Online]. Available: https://www.vattenfalleldistribution.se/foretag/producera-el/ersattning-och-avgifter/. [Accessed: May. 11, 2019].

[43] Skatteverket, ”Amount and percentages income year 2019 - private | Skatteverket.”, Skatteverket.se, 2019. [Online]. Available: https://www.skatteverket.se/privat/skatter/beloppochprocent/2019.4.309a41aa1672ad0c837788f.html#h-Momsskattesatser. [Accessed: May. 11, 2019].

[44] Öresundskraft, ”The law of green certificates.”, oresundskraft.se, 2019. [Online]. Available: https://www.oresundskraft.se/villa/el/elcertifikat/?openAsOverlay. [Accessed: May. 11, 2019].

[45] Vattenfall, ”Energy tax on electricity 2019 - Vattenfall.”, Vattenfall.se, 2019. [Online]. Available: https://www.vattenfall.se/foretag/elavtal/energiskatter/. [Accessed: May. 11, 2019].

[46] Vattenfall, ”Invoice explanation - Vattenfall.”, Vattenfall.se, 2019. [Online]. Available: https://www.vattenfall.se/kundservice/amne/faktura-och-betalning/fakturaforklaring/. [Accessed: May. 11, 2019].

[47] Kundkraft, ”Current electricity prices - All you need to know at Kundkraft.se.”, Kundkraft.se, 2019. [Online]. Available: https://www.kundkraft.se/elpriser. [Accessed: May. 11, 2019].

[48] Bengt Stridh, ”Value of own used and sold electricity - update”, Bengts nya villablogg, 2019. [Online]. Available: http://bengtsvillablogg.info/2016/10/15/varde-av-egenanvand-och-sald-solel-uppdatering/. [Accessed: May. 21, 2019].

[49] E.on, ”Solar cell batteries | Use more solar electricity with a storage battery - E.ON.”, Eon.se, 2019. [Online]. Available: https://www.eon.se/privat/for-hemmet/solceller/solcellsbatteri.html. [Accessed: May. 12, 2019].

A

Appendix 1

Appendix 1 shows the survey that was sent out to 50 selected owners of solar PV in the region of Skåne.

Hej!

Hjälp till att öka kunskaperna om hur övergången till förnybar energi kan stödjas!

Jag utför för tillfället mitt examensarbete vid Chalmers tekniska högskola som handlar om vad som hindrar och driver hushåll till att investera i solceller och batterisystem i Sverige, med specifikt fokus på Skåne. Jag kontaktar dig då du, enligt data jag erhållit från Länsstyrelsen Skåne, har en solcellsanläggning.

Jag är tacksam om du vill fylla i enkäten nedan. Det går fort, och genom din medverkan deltar du i utlottningen av ett presentkort värt 1000 kr på Beijer Byggmaterial. Alla svar kommer att behandlas konfidentiellt. Jag är mycket tacksam för din medverkan.

Du kan svara genom att använda bifogat svarskuvert. Portot är givetvis betalt.

Du kan även svara genom att besvara samma frågor via ett frågeformulär som du kan besöka på nedanstående webbadress:

https://goo.gl/forms/QWXiPVi6DpnhtXsz2

Med vänlig hälsning,

David Sandahl

Institutionen för rymd-, geo- och miljövetenskap, Chalmers tekniska högskola

076–1864645

davsanda@student.chalmers.se

Instruktioner:

- Om du är osäker, svara det du tror är mest riktigt
- Om någon annan person än du i ditt hushåll varit den drivande i att skaffa solceller, be gärna denna person fylla i enkäten istället
- Om någon fråga inte är relevant för dig kan den lämnas tom

Namn: ____

Frågor:

1. Innehar du ett solcellssystem?

☐ Ja

☐ Nej

Ev. övrig info: ____

2. Hur är detta solcellssystem placerat?

☐ På/vid mitt hem

☐ På/vid mitt fritidshus

☐ Annat: ____

3. Vilket år beställde du installation av systemet (när skrevs kontraktet)?

Svar: År____

4. Vad påverkade ditt beslut att investera i solceller? (Ringa in en siffra)

	Ej viktigt				*Mycket viktigt*
Jag ville minska min miljöpåverkan	**1**	**2**	**3**	**4**	**5**
Jag ville bli mer energimässigt självständig	**1**	**2**	**3**	**4**	**5**
Jag är intresserad av tekniken	**1**	**2**	**3**	**4**	**5**
Jag ville sänka mina energikostnader	**1**	**2**	**3**	**4**	**5**
Annat: ____					

5. Innehar du ett batterisystem kopplat till solpanelerna?

☐ Ja

☐ Nej

Ev. övrig info: ____

5.1. Vad påverkade ditt beslut att investera i batterisystemet? (Ringa in en siffra)

	Ej viktigt				*Mycket viktigt*
Jag ville minska min miljöpåverkan	**1**	**2**	**3**	**4**	**5**
Jag ville bli mer energimässigt självständig	**1**	**2**	**3**	**4**	**5**
Jag är intresserad av tekniken	**1**	**2**	**3**	**4**	**5**
Jag ville sänka mina energikostnader	**1**	**2**	**3**	**4**	**5**
Annat: ____					

6. Har du någon gång funderat på att investera i ett batterisystem kopplat till solpanelerna?

☐ Ja

☐ Nej

Ev. övrig info: ____

6.1. Vad påverkade ditt beslut att <u>inte</u> investera i ett batterisystem? (Ringa in en siffra)

	Ej viktigt				*Mycket viktigt*
Det var inte ekonomiskt försvarbart	**1**	**2**	**3**	**4**	**5**
Det var svårt att få tag på information	**1**	**2**	**3**	**4**	**5**
Det var en för stor tidsinvestering	**1**	**2**	**3**	**4**	**5**
Processen verkade krånglig	**1**	**2**	**3**	**4**	**5**
Annat: ____					

7. Känner du till att det finns bidrag att få vid köp av batterisystem?

☐ Ja

☐ Nej

Ev. övrig info: ____

8. Har du haft kontakt med någon som äger solpaneler med batterisystem?

☐ Ja

☐ Nej

Ev. övrig info: ____

8.1. Har denna kontakt gjort dig mer eller mindre benägen att investera i ett batterisystem?

☐ Mer

☐ Mindre

Varför?: ____

____

9. Har du något mer att tillägga?

____

____

____

____

____

Eventuellt kommer jag att vilja kontakta dig för att ställa någon följdfråga. Kan du tänka dig att bli kontaktad?

Lämna i så fall ditt telefonnummer här: ______________________

Tack för din medverkan! Lägg enkäten i det bifogade svarskuvertet och glöm inte att posta ☺.