CHALMERS
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Aiding households to invest in domestic photovoltaics

An adopter-centric analysis

Master of Science thesis in master degree programme, Sustainable Energy Systems

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover: Photograph of houses in Västerås, Sweden.

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ABSTRACT

The world could be entering an era of carbon neutral, decentralised electricity production, fuelled by plummeting prices of solar photovoltaic systems, and the empowerment of property owners and small-scale investors. The entry of individual homeowners poses however challenges for the further diffusion of photovoltaics, as they are likely to bring new mechanisms onto the power market; whether it be "folk" ways of economic reasoning and risk evaluation, or if it implies higher transaction costs due to small-scale investments and increased difficulties of obtaining and processing information.

The aim of this study is to enter the everyday nitty-gritty of being a prospective small-scale solar electricity producer in Sweden. By collecting interview data from market actors and industry experts, as well as survey data from the municipal energy advisors, a picture of the contemporary landscape for domestic photovoltaic electricity production is drawn.

The findings emphasise notions from innovation system theory; that a range of issues inflict uncertainty on a novel technology, and thereby barriers against its diffusion–most noticeably in this study due to complicated and short-term legislation, perceived technical complexity, difficulties predicting economic performance, as well as troubles finding and selecting suppliers.

To gain *legitimacy* on the Swedish market for domestic PV, a web tool, which intends to aid homeowners prior to an investment with economic and technical calculations, is prototyped and presented. Three checklists are made to guide homeowners step-by-step: to find and select installer, estimate yield, and orientate in the legislation.

Swedish policy makers are advised to simplify and ensure a long-term legislative framework. To reduce the abstraction perceived by homeowners, firms are recommended to develop business models, which could include service of the technical equipment, electricity yield guarantees, and administrative work.

It is ultimately concluded that legitimation of a novel technology, in general, could be strengthened by establishing several functions: *comprehensible* and continuously updated information sources, standard ways of calculating profitability, simplified legislative frameworks, as well as marketplaces or functions to help consumers find and select suppliers. These aspects become increasingly important when the consumer group consists of individuals (rather than firms), and early in a diffusion process when peer effects remain small.

Key concepts: Diffusion of Innovations; Domestic photovoltaics; Legitimacy; Technical Innovation Systems; Transaction cost economics; PV economics

"We call it light; 'electricity' is too sterile a word, and 'power' too stiff, for this Nigerian phenomenon that can buoy spirits and smother dreams"

– Chimamanda Ngozi Adichie (2015)[1]

[1] From the opinion piece "Lights Out in Nigeria". Published in The New York Times, 2015-01-31

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Glossary

Photovoltaics	A technology converting solar light into direct current electricity using semiconducting materials.
Transaction costs	Costs, in terms of time or money, that accrue to the searching and processing of information as well as negotiating and making sure contracts are followed through.
Adopter	A first-time purchaser of a technical artefact–in this thesis often referring to a domestic photovoltaic system.
Energy advisor	A person working for the municipality providing free and commercially neutral advice about energy and its climate effects.
Advice seeker	An individual contacting the municipal energy advisors inquiring about solar photovoltaic technology.
Advisory discussion	A discussion on photovoltaics that takes place between an advice seeker and a municipal energy and climate advisor.
Prosumers	Individuals who both consume and produce electricity.
Micro-producers	Electricity producers with systems smaller than 43.5 kW (as defined by Swedish law), where parts (or all) of the electricity is consumed on the consumer side of the meter.
Fragmented market	A market where consumers are separated into segments that have their own needs and preferences.

Abbreviations

PV	Photovoltaics
TC	Transaction Costs
LCOE	Levelised Cost of Electricity
TIS	Technical Innovation System
SQ	Survey Question
AC & DC	Alternating Current & Direct Current

Table of contents

List of tables

List of figures

1. *The energy system of today*

In this study, I am motivated by the necessity of steering away from a fossil fuel based power system to one that is resilient, carbon neutral, democratic and safe.

The likelihood of humans being the main culprit of altered atmospheric temperatures the last century was elevated to 95% certainty in the latest IPCC[2] report (IPCC 2014), with the main part of anthropogenic greenhouse gas emissions stemming from the combustion of fossil fuels used in our energy system to power industries, heat houses and fuel transports.

A glance at the current state of global power system provides a grim reading; in 2012, 68% of the power was produced from fossil fuels and only 21% came from renewable energy sources (IEA 2014a). Adding up, power generation is worldwide subject to substantial local environmental issues, resource depletion, as well as significant political and social disturbances. In the last twenty years world electricity demand has almost doubled and the rate of increase has been three per cent annually (IEA 2014a). Albeit promising energy efficiency prospects, the global electricity demand is projected to increase the upcoming decades due to population increase, increased global welfare, and a shift to electricity as the energy carrier of preference in more sectors (e.g. mobility, Sandén et al. 2013).

In the last years it has become increasingly clear that directly converted solar energy, namely photovoltaics (PV), has the potential to become one of the absolutely most important power sources; it is carbon neutral, the physical potential is by all means sufficient to power the world (Sandén et al. 2014a), abundant silicon entails few material constraints, and, due to widespread possibilities of micro-production, it is possible for virtually everyone to participate in the generation of PV electricity.

In the end of 2014, the aggregated installed capacity had grown to 177 GW, with an average annual growth of 20% the preceding 10 years (IEA 2015). Although still a

[2] Intergovernmental Panel of Climate Change

relatively small contributor to the global electricity output (around 1%), the prospects bear significant promise. Between 2009 and the end of 2013 solar PV modules costs fell by a factor of five; installation costs fell by a factor of three (IEA 2014b). Although it is likely that the era of *rapid* price reduction of modules is over (IEA 2014b), PV is nevertheless emerging into, a not only viable technological option, but also one of significant commercial potential (e.g. Bronski 2014).

1.1. Meanwhile in Sweden

Unlike other European countries such as Germany, Great Britain, and Italy, Sweden's cumulative PV capacity has remained rather low. At the end of 2014, Sweden had installed 79 MW, amounting to an estimated yearly production of 74 GWh (0.06% of the Swedish electricity mix) (Lindahl 2015). However, Sweden has doubled its PV capacity four consecutive years, albeit from low departing levels. At the beginning of 2015 there were likely between 6 000-8 000 PV systems[3], as compared to more than 1 400 000 in Germany (Wirth 2015).

Traditionally, the Swedish PV market has been comprised of mainly off-grid applications–powering caravans, off-grid cottages and boats. Due to a surge in grid-connected applications since 2008, the balance has shifted towards a system where the large majority of installed capacity is connected to the grid (Lindahl 2015). These systems are almost exclusively mounted on rooftops. The largest share of the installed capacity is over 20 kW and installed by companies–although homeowners own the majority of the PV systems (Lindahl 2015).

It is often misinterpreted that it's the solar resource that severely restricts PV deployment in Northern climates. Sweden, actually, only has marginally lower insolation than regions such as Northern Germany and Great Britain, which have seen a rapid growth of installed PV capacity. (See Norwood et al. 2014, for an illustrative map of PV potential across Europe). As an example, to produce the equivalent of Sweden's complete supply of electricity one would need to cover 0.37%

[3] The total amount of registered systems is not covered by the data (Lindahl 2015). However, by assuming the average domestic PV system to 5 kW it is possible to estimate the amount of systems.

of the area with PV[4] (Šúri et al. 2007). Just by covering suitable[5] building surfaces it is estimated that PV could cover roughly 30% of the annual consumption of electricity (Kjellsson 2000).

1.2. Towards distributed generation?

For a long time power production has almost exclusively taken place in large-scale, centralised power plants. However, PV, along with other small-scale technologies such as micro-CHP (combined heat and power) and wind power, enables widespread possibilities of *distributed generation*–defined by Ackermann et al. (2001, p. 201) as "an electric power source connected directly to the distribution network or on the customer side of the meter". As a consequence, a largely new group has entered the category of potential power producers–most noticeably everyone that owns a rooftop, or a piece of land.

Property owners are particularly well suited for investing in PV, especially since self-generated electricity–that replaces bought electricity–can cut electricity bills due to reduced taxes and grid fees. Grid parity, often regarded as the threshold for when PV will be considered a commercial technology (Branker et al. 2011), occurs when the levelised cost of electricity (LCOE) is lower than the variable portion of the retail price (this includes spot-market electricity costs, variable transmission and distribution costs, utility and grid operator margins, as well as taxes). This induces property owners to invest in their own PV systems, and replace their domestic electricity use. According to IEA (2014b), grid parity has already occurred in several countries and regions. In Sweden, the LCOE from PV is approaching grid parity according to certain assumptions[6] (Stridh et al. 2014). The Swedish spot prices, however, are substantially lower than the LCOE of PV, which renders unsubsidised large non-domestic PV plants unprofitable–despite lower installation costs due to scale effects.

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[4] Not taking storage or balancing of supply into account, which would be integral to any electricity system with a large share of variable electricity production.

[5] Defined as all surfaces that are struck by >70% of the global irradiation. This would amount to 40 TWh annually.

[6] By using a discount rate of 4% and a PV lifetime of 30 years.

1.3. Promoting household PV adoption

The entry of individual homeowners poses, however, challenges for the further diffusion of PV, as they are likely to bring new mechanisms onto the power market; whether it be "folk" ways of economic reasoning and risk evaluation (e.g. Train 1985, Kempton and Layne 1994), or if it implies high *transaction costs* due to small-scale investments and increased difficulties of obtaining and processing information. In order to be able to aid homeowners prior to investment decisions in PV, this study will take a broad theoretical, site-specific and adopter-centric grip regarding the topic of diffusion of domestic PV in Sweden.

Figure 1.1: PV household

2. Aim, research questions and scope

This thesis includes a range of topics: behavioural aspects of domestic PV adopters, the concepts of legitimacy in a technological innovation system as well as a description of the legislative and financial framework of the Swedish PV market. The risks are thus that the analysis of the topic leads in several different directions and fails to answer the main purpose of the study. To avoid these prospects, Robson (2002) recommends the researcher to define research questions and boundaries from the outset.

2.1. Aim of the study

The aim of the study is to enter the everyday nitty-gritty of being a prospective small-scale PV electricity producer in Sweden. The goal is to be able to provide sufficient background knowledge for a web-based service that intends to aid homeowners prior to investments in PV. The study, in general, seeks to contribute to the understanding of how uncertainties surrounding a novel technology can be decreased among potential adopters.

2.2. Research questions

RQ1) What characterises the Swedish retail market for domestic PV of today?

RQ2) Which are the most salient uncertainties perceived by potential adopters of domestic PV?

RQ3) How can the study of the Swedish market of domestic PV contribute to the theoretical understanding of functions required to decrease uncertainty surrounding a novel technology?

RQ4) How can a web interface be designed in order to aid households prior to investments in domestic PV in Sweden?

In answering RQ1, a generic picture of the Swedish retail market for PV is mapped. The legislative framework, technical features, and main actors are identified along with the common business models. Knowledge of the current system is a necessary starting point for understanding uncertainties among homeowners.

RQ2 provides the main input to how homeowners can be aided regarding investment decisions. It sheds light on the spread and scope of the sensed uncertainties as well as qualitative aspects of economic reasoning and energy literacy.

In RQ3, the findings are evaluated through the lenses of the theoretical framework. Generalisable implications are discussed and presented.

Based on the findings of RQ1, RQ2 and RQ3, a web tool, intending to aid homeowners with investment decisions in PV, is prototyped according to several criteria founded in the theoretical framework of the study.

2.3 Scope

While designing a PV system there is a great possibility of selecting and combining components. The thesis has no goal of covering all possible configurations of PV systems. It is restricted to the mainstream options of modules, inverters and mounting structures on the Swedish PV market. The prototyped tool may be useful for other groups, such as property owners and small commercial enterprises such as farms. In this report, however, only the parameters relevant to homeowners are presented and discussed. This thesis doesn't attempt to offer new insights on the theoretical way of calculating profitability, nor designing optimal PV systems, but rather understand how households think of PV investments and popularise the findings of other studies.

This study is by no means the boundaries of a fully developed tool; the plan is to continue both the planning and development once this thesis is handed in. All useful information sources for PV will also have to be continuously updated, as legislation and price information change at a fast pace. The design decisions taken in this study are limited to those of content, whereas aspects regarding interaction design are not considered.

3. Theoretical framework

The purpose of the theoretical framework is to provide a deeper understanding of technological adoption in the case of individual homeowners. It should be seen as the lenses from which the study is conducted and provides background for how households can be aided regarding investment decisions in PV.

One way of looking at the issues homeowners confront prior to purchasing PV is through the concept of transaction costs. When an individual acquires a technology, there are several real costs that don't accrue to the function of the service or product. In first hand, the final product of this study strives to decrease these costs. As plenty research has been carried out regarding transaction costs within the field of energy efficiency (e.g., Decanio 1998, Ostertag 1999), concepts and explanations will be borrowed from there.

Secondly, where transaction costs economics is illuminating and important in regards of allocating a monetary value to market barriers, the theory isn't especially refined when it comes to the dynamical, evolutionary developments of a diffusion process (Nelson and Nelson 2002). The natural complement is therefore the diffusion of innovations literature, as presented by Rogers (2003). It emphasises the role of the individual adopters and their social networks, and provides explanations of how individuals along the diffusion route can be categorised and analysed.

The third theoretical perspective puts the technical artefacts in a wider socio-technical context where innovations co-evolve with their users and with their respective society during the diffusion process (e.g. Bergek et al. 2008a, Bijker 1997, Geels 2005). In this study, the focus is on technical innovation systems (TIS) and specifically the notion of legitimacy. Legitimacy can be understood as the perceptions the actors in a system have regarding the functions of a technology and the surrounding long-term developments (Bergek et al. 2008b). There is both a well-developed theoretical concept of TIS (Bergek et al. 2008a) and a relevant application of the concept within the Swedish PV industry (Sandén et al. 2014b)[7].

It can be pointed out that the combination of theories is not entirely conventional. Nelson and Nelson (2002), with others, have, however, expressed the desire of "marrying" organisational economics (of which transaction cost economics belong) with innovation system theory (e.g. technical innovation systems). Also, the theories are by no means isolated[8], as all are put forward as alternatives to the 'market failure'-explanation of neoclassical economics *vis-à-vis* barriers towards technological innovation and dissemination (e.g., Bergek et al. 2008a, Decanio 1998).

3.1 Transaction cost economics

Transaction cost economics can be traced back to Ronald Coase's (1937) article the Nature of the Firm. There, he proclaimed that hidden costs inhibit all transactions: to identify a partner, to formulate, and negotiate the contract, and control and execute it thereafter. These transaction costs (at the time not mentioned explicitly), as contrary to production costs, involve the costs or time of searching for information, setting up a deal and making sure it's followed through. In reality, these prevent actors from negotiating efficient outcomes.

The theory of transaction costs provides the missing link of why organisations vertically integrate; the *raison d'être* of organising in firms is to minimise transaction costs (Coase 1937). Whereas companies vertically integrate–i.e. they organise themselves by putting necessary experience and professionals like administrators, engineers, and business controllers on the pay roll–individual homeowners seldom have similar, suitable expertise to their disposal.

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[7] The Swedish Energy Agency financed in 2013 a report on technical innovation systems for several technologies in order to analyse and identify weaknesses and strengths of the innovation systems. The report was published in 2014 and one of the studied technologies was PV.

[8] See, e.g., Van De Ven (1993) for parallels between innovation system theory and transaction costs; Ostertag (1999) for a dynamical system perspective on transaction costs; Keirstead (2006) for diffusion of innovations and socio-technical system; Wilson and Dowlatabadi (2007) for an evaluation of all three regarding the empirical effectiveness of describing adoption rates of energy efficiency measures.

Williamson (1981) suggests that there are two behavioural conditions on which transaction costs (TC) relies; (1) individuals are subject to bounded rationality, i.e. unlike the hyperrational "economic man" people in reality are equipped with lesser analytical tools, and (2) some humans are given to opportunism–basically, various economic actors are dishonest, which leads to market asymmetries.

Akerlof (1970), for example, showed in an influential study how information asymmetry, stemming from the notion that the seller on a given market has more knowledge of a product than a buyer, can lead to distorted price mechanisms. 'Lemons' (inferior products) can then drive high quality products out of the market due to the bad reputation they impose on other products. This occurred, for example, during the early stages of heat pump diffusion in Sweden in the 80's, which led to a market collapse (before it boomed again in the mid 90's following a technology procurement programme that aimed to bring more high quality products onto the market) (Neij and Jakob 2012).

One can characterise transaction costs by their determinants: uncertainty, the frequency at which a transaction occurs, and the degree to which transaction-specific investments are incurred (Williamson 1981). The later refers to cases where there is a cost attributed to a specific situation, which renders marketability and standardisation among users more difficult. Ostertag (1999) suggests that "search-costs" may occur only once (or less frequently) for a contingency of qualitatively similar transactions, i.e. TC decrease due to learning effects. In the case of PV, due to the lifetime of a system, one could assume that the *individual*[9] homeowner won't be able to profit considerably from such mechanisms.

3.2. Transaction costs in energy efficiency

Although investments in domestic PV systems don't qualify as energy efficiency measures *per se*[10], much of the reasoning is similar. The investments pay back by

[9] On a societal level, however, it is reasonable to assume that transaction costs reduce in tandem with the diffusion rate. For example, as neighbours invest in a given technology the knowledge would spread in the neighbourhood and transaction costs decrease accordingly.

[10] Keirstead (2006) showed in a study of PV adopters in Britain that investments in domestic PV had led to average energy savings of 6%, coining it the 'double-dividend' of PV.

reducing electricity bills, they are illiquid (i.e. you can't rip out the insolation and sell it on the second-hand market), future energy price developments constitute uncertainties, and they are often taken up on fragmented markets where the knowledge asymmetries between seller and buyer can be vast.

Transaction costs are a presented as a central cause of what has been coined the 'energy efficiency gap'–referring to the notion that seemingly profitable investments in energy efficiency are not taken up (Jaffe and Stavins 1994). While discussing rates of energy efficiency deployment, it's sometimes stated that the profit of an energy efficiency measure is outweighed by the time and thus costs that accrue to the searching, comparing and evaluating of the performance characteristics (e.g. Sanstad and Howarth 1994). TC are not restricted to the technical characteristics, as they also include the interpretation and knowledge gathering required to comply with policies and rules (Michaelowa and Jotzo 2005).

Hein and Blok (1995) show that search costs aren't proportional to the total cost, but rather tend to decrease as the size of investment increase. Also, energy utilities tend to enjoy economies of scale in disseminating and promoting energy efficiency measures, meaning that the communication and guidance might not come small actors and individual homeowners to service (Sioshansi 1991). Both of these conditions seem to imply increased difficulties for potential adopters of domestic PV (as compared to other customer groups).

To compare various technically advanced products prior to an investment poses difficulties for most homeowners as there is a vast empirical evidence suggesting low energy literacy among residential customers (Brounen et al. 2013, Kempton and Layne 1994, Kempton and Montgomery 1982). Kempton and Layne (1994, p. 857) show for example that most American homeowners measure their energy use primarily in dollars rather than the "easy to meter, but irrelevant to the buyer, measure of electron flow (kWh)".

Sometimes it is argued that the barriers do not discourage energy efficiency investments specifically–rather that the postulated efficiency gap can be described by unusually high discount rates (e.g. Sutherland 1991). Uncertain price developments of energy, as well as illiquid investments, mean that energy efficiency measures are inherently risky and require a high discount rate to mitigate the financial risk. It is, however, important to highlight the interdependency of the discount rate and transaction costs. A risk factor is baked into the discount rate, which rises in cases of low knowledge (or asymmetric knowledge between the seller and the buyer). Kurtz et al. (2009, p. 2), for example, pointed explicitly at the necessity of increasing reliability in economic assumptions of PV, since "confident predictions of system performance, availability, and lifetime translate directly into lower interest and insurance costs".

3.3. Diffusion of innovations

The theory of diffusion of innovations has traditionally been understood through Rogers' work Diffusion of Innovations (2003)[11]. The theories are focused around an S-shaped curve (see figure 3.1), depicting how innovations, at first, spread slowly when there are few adopters in each time period. The curve then accelerates until it levels out as there are fewer and fewer potential adopters remaining. Along the reasoning of Rogers, the S-shape is normal, since, just as physical traits such as height and weight are normally distributed, so are behavioural traits; specifically in this case, *innovativeness*. Also, a normally distributed adoption rate is expected because there is an increased cumulative influence upon individuals to adopt an innovation due to the activation of peer networks. Thus, adoption rates increase as the knowledge within the system increases.

Along the diffusion curve, five 'ideal' consumer types are identified and described depending on their degree of innovativeness. The first individuals to adopt an innovation are the *innovators*. They need to be able to understand and apply complex technical knowledge and are able to cope with a high degree of financial uncertainty about an innovation at the time of adoption (p. 282). The innovators are followed by the *early adopters*. They have the highest degree of opinion leadership and important regarding reducing uncertainty by putting their approval mark on new ideas (p. 283). The *early majority* adopts innovations just before the average consumer and the *late*

[11] It was the fifth edition of the book. The first edition was published in 1962 (New York: Free Press). The theories were initially based on studies of how agricultural innovations spread among farms in Iowa.

majority right after. The last category to adopt new innovations–the *laggards*–is conservative and tends to be suspicious of new technologies. One explanation, though, points at typically precarious economic resources, which require a cautious decision-making, grounded on proved ability of the adopted innovation.

If one ought to follow Roger's categorisation strictly, it is, arguably, mainly the innovators (the first 2.5% in a population to embrace a new technology) who currently adopt PV in Sweden. If a saturation of 1 million PV households is assumed, corresponding to little less than the amount of residential heat pumps in Sweden (Energimynidgheten 2015a), the innovators should pave way for the first 25 000 system (there are less than 8000 systems in Sweden).

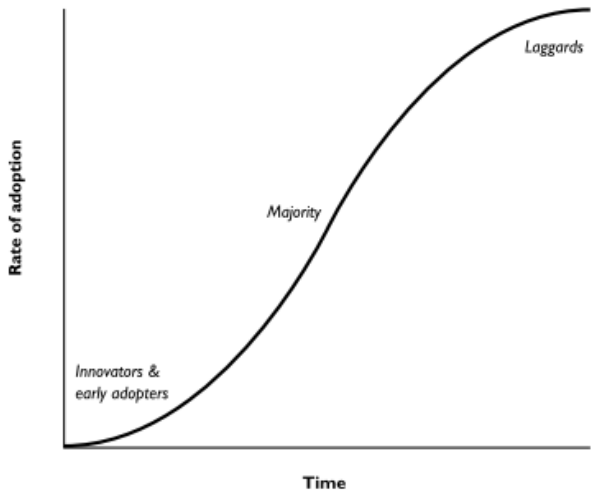

Figure 3.1: Adoption-curve. Source: Rogers 2003

The diffusion of innovation literature lists five technical features, which determines the rate of adoption: complexity, compatibility, observability, trialability and relative advantage (Rogers 2003). It has been pointed out that almost all of these characteristics seem to work against the diffusion of PV (Keirstead 2006). Compared to buying electricity from the grid, PV has poor compatibility and is definitely more complex. Due to modest diffusion in Sweden, and the lack of visible systems, observability and trialability are accordingly low (although more than a million rooftop PV systems is up and running in Germany). The decreasing prices for turnkey systems are, however, providing relative *economic* advantage in some cases already (e.g. Bronski et al. 2014).

Diffusion networks lies at bottom of the diffusion route. The awareness-knowledge of an innovation is often obtained through mass media, or means of communications that are not sought after purposely. As the knowledge gathering becomes more active, or when taking a decision, the role of subjective recommendations from peers become more important. This holds especially true for the adopter categories after innovators and early adopters (Rogers 2003). Instead of purely fact-based evaluations, adopters further down the adoption curve tend to base their decision on *perceived* advantages and disadvantages–or "subjective evaluations of an innovation that is conveyed to them from other individuals like themselves who already have adopted the innovation" (p. 18-19). The role of social peer networks is even more important for advanced technical equipment that poses difficulties in determining the quality of the product (Nelson 1970) or for technologies with high upfront costs (Rogers 2003). Both of these conditions hold true for PV. A couple of studies have showed indications of peer effects in the diffusion of domestic PV[12].

3.4. Technical innovation systems

A shortcoming of the diffusions of innovations theory, pointed out by Keirstead (2007), is that it touches upon technological determinism; the technology will spread merely on its own qualities and it will do so until the technology has spread among the whole population. The critique has pointed at the necessity of including "the broader system in which diffusion process occurs" (Rogers 2003, p. 115).

Studies on technical innovation systems (Bergek 2002) and studies on socio-technical systems (e.g. Bijker 1997) have shown that enablers of diffusion of technological artefacts differ largely from case to case and depending on geographical context. Bijker (1997) has emphasised the techno-cultural context in shaping a technology in its childhood–i.e. the diffusion of for example PV becomes a question how actors in a system interact (individual homeowners, retailers, legislators etc.). Or, as Rip (1995,

[12] Bollinger and Gillingham (2012) found that previous installations had increased the likelihood of further adoption in the same ZIP code area by 0.78 percentage points. Rai and Robinson (2013) observed that a high concentration of residential PV systems in an area shortened the decision periods for prospective adopters by an average of 6.7 months (from an outset of 8.7 months).

p. 25) puts it, embedding a new technology in society "is a process in which all sorts of actors actively try to exert influence, and/or passively shape what happens by not doing something, or doing something else."

A technical innovation system can be defined as a "socio-technical systems focused on the development, diffusion and use of a particular technology (in terms of knowledge, product, or both)" (Bergek et al. 2008a, p. 408). Although actors within a TIS can compete, fundamentally they work towards a common overall function, consciously or not. In a TIS, there are several *functions,* all of which contribute to the goal of the system (i.e. in case of PV, the wider development and adoption). Some of these include knowledge development and diffusion, influence on the direction of search, development of positive external economies, and legitimation. This study, due to the adopter-centric perspective (i.e. what is significant to the adopter in the moment of a decision), is focused around one of the functions–legitimation.

Legitimacy is formed by "expectations and visions as well as regulative alignment, including issues such as market regulations, tax policies or the direction of science and technology policy" (Bergek et al. 2008b, p. 578). In other words, it is a matter of social acceptance where the actors and adopters (the demand) see the technology as desirable and reliable to fill a certain purpose. Legitimacy of a technology is shaped proactively by actors to overcome its 'liability of newness' (Bergek et al. 2008b, Zimmerman and Zeitz 2002). Strategies of legitimation can consist of alignment of practices, conformance, i.e. by following an established product standard, or creation of new institutional frameworks (Bergek et al. 2008b, Rip 1995, Zimmerman and Zeitz 2002).

Legitimation can also be formed by external factors; the climate change debate has for example been essential in fronting PV as a desirable technology for the future (Palmblad et al. 2006). Threats to legitimacy can consist of the lobbying from incumbent, threatened, TIS or perceptions of new technologies as expensive or inferior to the pre-existing alternative. It is for example been pointed out by Sandén et al. (2014b) that the rapid diffusion of PV in Germany (and the fact that they have taken a heavy role in pulling down the employment costs of PV) has led to perceptions of PV as expensive on a societal scale. Also, PV is not seldom framed as being less efficient than centralised electricity production (Bergek et al. 2008b).

4. Methodology

Stemming from the theoretical viewpoint, two areas of focus were identified. It is impossible to understand the uncertainties of homeowners adopting PV without a vast empirical account of the market of domestic PV–comprising technological and economic characteristics of PV, the legislative and financial framework, as well as common business practices. Additionally, a broader understanding of the adopters' profile and needs was deemed necessary. Both areas were answered by doing a literature review and thereafter by conducting mainly qualitative research. Ultimately, a description of how the main design decisions have been made is presented.

The main road crossing in determining the methodology was to conduct top-down data gathering, focusing on actors with deep knowledge of the industry, rather than bottom-up data gathering, i.e. approaching prior or prospective adopters of domestic PV systems. It was, however, judged that by focusing on installers, experts, and energy advisors–with a large experience of customer-acquisition and consultancy contacts with prospective PV installers–the research could be more effective and meanwhile provide enhanced results.

4.1. Research type

The research has been primarily inductive, meaning that theory is the *outcome* of the empirical observations and findings (Bryman and Bell 2003). Thus the study draws general inferences out of observations, rather than deducing a hypothesis. In this study, the data gathering preceded the main analysis of the theory. The theoretical chapters are mainly for structure reasons and to provide a 'frame' for the analytical parts of the study.

Generally, an inductive strategy of data gathering is associated with qualitative research, and so also in this case (Bryman and Bell 2003). According to Cresswell (2003), qualitative research is suitable if the research questions are open-ended and when results are text-based rather than numerical. Since all research questions search for descriptive answers, the research type classification is adequate. Parts of the primary data were gathered through semi-structured interviews. This study is, however, to some extent mixed method research since quantitative survey data was gathered and used to verify some of the findings from the interviews.

Although the main structure of the research was inductive, the study was also *iterative* since the empirical findings from the interviews were tested in the second phase of the data gathering. According to Bryman and Bell (2003) a study is called iterative if further data is collected once the first theoretical reflection on a set of data has been carried out. Also, the primary data was analysed during and in between the interviews. According to Quinn Patton (2002) the researcher conducting qualitative research has two sources for the final analysis; the questions and answers that were generated during the conceptual and design phase, and the insights and interpretations that emerged in tandem.

4.2. Research design

The research has been carried out as a *case study*. In a case study, the case provides interest in its own right and the purpose of the research is to provide an in-depth elucidation (Bryman and Bell 2003). The case of this study is, naturally, the Swedish market for domestic PV system and its actors (retailers, information sources and consumers). Stake (1995) distinguishes between three kinds of case studies–intrinsic, instrumental and multi-studies. The prior are undertaken to gain understanding of the particularities in the specific case, the second is used to gain a broader understanding of a phenomena while looking at a certain case, and the later looks at several cases to explore a generic phenomena. The main goal of this study is to gain understanding of the Swedish market of domestic PV, thus the description of the first case study option lies closest. The lines are, nevertheless, blurry between the types, as this study strives to be useful also when it comes to a broader understanding of diffusion of other technologies within energy efficiency, and micro electricity production and storage, among actors with relatively low capabilities of knowledge gathering.

4.3. Literature review

The literature review was done to get a picture of the technical, economic and legislative aspects affecting the purchase of domestic PV in Sweden. The studied literature has ranged from governmental documents on the legislation in Sweden to articles on technical and economic performance of PV. An important source for mapping out the Swedish PV market was, quite unconventionally, a blog– http://bengtsvillablogg.info/. Bengt Stridh, ABB corporate research and professor at Mälardalen University, is arguably the most important public PV expert in Sweden. Energy advisors and industry actors[13] alike refer to his blog as the most important information source for homeowners in Sweden.

4.4. Semi-structured interviews

The data that couldn't be retrieved by studying the literature was gathered through semi-structured interviews with market actors and PV experts. In semi-structured interviews the researcher has a list of questions to be covered, but the interviewee has some flexibility in how the responses are given (Bryman and Bell 2003). Questions that are not in the interview plan can be asked in order to pursue interesting paths during the interview. The questions should not be leading, nor encourage simplistic yes-or-no answers.

4.4.1. Target groups

In all, ten interviewees were selected by using two criteria equivalent to those of Nässén et al. (2008); the interviewees have a deep knowledge of the Swedish PV market and complementary individual experiences. To some extent the 'snow-ball' method was used, i.e. whilst departing from an industry or technology base the first identified actors were asked to point towards further actors of interest to the topic (Rickne 2001). Finally, three main categories were represented: (1) installers or retailers, (2) independent experts/consultants of PV, and (3) municipal energy and climate advisors (table 4.1 or Appendix A for an exhaustive list).

[13] See table 6.4 (p. 50) for the information sources identified by the energy advisors. Furthermore, almost all interviewees mentioned Bengt Stridh's importance for knowledge diffusion of PV in Sweden.

Table 4.1: Interview categories

Category	Amount of interviews
Installers and retailers	4
Independent experts and consultants	4
Municipal energy and climate advisors	2

Several informal discussions took place with the personnel at the Chalmers departments of Energy System Analysis and Physical Resource Theory. The discussions ranged from practicalities such as pointing out industry experts, to topic-oriented discussions on the future developments of the electricity market, different routes of technology diffusion and communication of PV. Particularly discussions with Jörgen Larsson, researcher at Chalmers and a community organiser of PV projects, has given much input to the economic calculations presented in this thesis. One interview, outside the scope of this report, was conducted with Hans Nilsson, previously the director of Swedish Energy Efficiency Programme and responsible of the technology procurement program that has been identified as a major event in the Swedish success-story of heat pump diffusion (Neij and Jacob 2012). The purpose was to get inspiration and theoretical insights on the diffusion of technology that could aid the progress of this thesis. Ultimately, one study visit was made to Katrineholm and "Kullendagen"–a PV demonstration day organised by the installation company Egen El. There, oral communication with several representatives of Egen El took place.

4.4.2. Implementation

All interviews have ranged between 45 and 90 minutes, and conducted face to face or by telephone. Two group interviews were conducted–with the founder and CEO of PPAM, and two of the municipal energy advisors in Gothenburg. The interview schedule was tailor-made depending on the occupation of the interviewee. The first questions in almost all interviews were asked about the uncertainties among homeowners. Thereafter, the questions became more specific and varied depending on the interviewee. At the category 1 and 2 interviews, many questions revolved around the installation process in order to obtain a deeper understanding of legitimate uncertainties perceived by homeowners. This was necessary in order to prepare material for RQ3. At the category 3 interviews, the later questions revolved around typical inquiries from homeowners.

4.5. Self-completion survey

A self-completion survey was sent out to the Swedish municipal energy and climate advisors. The survey substantially increased the outreach, both in numbers and in geographical scope of the study. According to Bryman and Bell (2003) a self-completion survey is in its nature similar to structured interviewing, and the same rules apply *vis-à-vis* the importance of non-leading and unambiguous questions. As a rule, though, self-completion surveys have clearer instructions, they are shorter due to the prospects of *respondent fatique*, and include fewer open-ended questions.

4.5.1 Target group

In Sweden there are ~250 energy and climate advisors (averaging slightly less than one advisor per municipality)[14]. They work both proactively–by arranging seminars and searching possibilities to inform the public, and passively, by receiving phone calls and face-to-face consultant meetings. They are publicly financed and offer technology neutral and commercially neutral advise to the general public and to companies about energy and its emissions (Energimyndigheten 2015b). All of the energy advisors go through the same education conducted by the Swedish Energy Agency[14].

4.5.2 Survey design

The questionnaire was designed [15] to gain information about the perceived uncertainties among Swedish homeowners with interest in PV. The questions couldn’t be to specific since they largely revolved around experiences that were undocumented, and thus expected to be answered off-the-top-of-the-head of the respondents. The preceding interviews with three municipal energy advisors were important to obtain a job-description and to be able to foresee how questions would be interpreted.

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[14] Tore Carlsson, Swedish Energy Agency.

[15] The survey questions can be found in Appendix B.

The survey had five sections, and main aims, as following:

- Identify the geographical profile of the energy advisors. The first section intends to give background of from which of the 14 geographically distributed energy offices, and of what experience the energy advisor have.

- Estimate the extent of PV interest in the given municipalities, and of the category of people that most commonly contacts the energy advisors. The answers are used to validate to which extent the answers can be used to draw conclusions for the examined target group. Naturally, low general interest, and thereby lower experience of handling PV inquiries, generates less value for the study.

- Categorise the knowledge level of the homeowners and to identify at which stage the energy advisors normally are consulted.

- Map the content of the advisory discussions. This is the most extensive part of the survey and all questions are answered by using a bipolar numerical response format, ranging from 1-5, between the extremes "Very unusual" and "Very common". Here both quantitative and qualitative aspects are sought after. Most questions are used to identify the most frequent question and topics in the advisory discussions. However, some similar questions but with different abstraction levels are posed. The objective is to understand to what extent homeowners are interested in gathering understanding of a PV system and its economics. In this category one can for example distinguish between questions such as "Is it possible to install PV if there is partial shading?" as compared to the more specific and technology oriented question "In my case, is a microinverter or a power optimizer a good idea?" Most questions came with a clarification, mentioning that all questions that have similar qualitative significance should be taken into account. For example: What will the electricity prices be during the lifetime of the system? *Or other versions of the advice seeker wanting you to reason about the future developments of the electricity prices.* Questions that supposedly always come up during advisory discussions[16,17] were left out from the survey. Virtually all energy advisors bring up questions such as, "What is the payback of PV?", "How much electricity will I be able to produce?" and "Is the inclination of my roof okay?"

- Describe price levels of turnkey systems, uncertainties and information sources on the Swedish PV market for homeowners. The last six questions were open-ended and used to receive a more nuanced account of the experiences of the energy advisors. This section can also be seen as direct feedback of the most salient requirements for RQ3.

4.5.3. Implementation

Since a sample from the target group already had been interviewed, it was deemed sufficient to evaluate the survey by sending it to two Challenge Lab participants, the supervisor and one independent in order to examine clarity and scope of the questions. The pilot led to the survey being separated into five parts with power bars, to reduce the perceived length. Some questions were added in section four, and a few questions were clarified.

The survey was sent out as a Google web survey and judged to take between 15 and 20 minutes to complete (also with input from the test persons). The web link was at first posted on the intranet of the energy and climate advisors by coordinators at the Swedish Energy Agency. The survey was presented as the basis of a master thesis, with an added comment that the generated data would also be valuable for the evaluation work of the Energy Agency centrally. At first, the respondent rate was poor (after three days on the web the survey had generated 19 responses), so the survey was sent out in directed emails to the coordinators of the 14 locally distributed energy offices, which in their turn forwarded the survey to their respective energy advisors. The manner of how the survey was forwarded could possibly explain the differences in response rate.

[16] Zandra Wenngren, Municipality of Västerås.

[17] Mats Danielsson and Mikael Eriksson, Municipality of Göteborg.

It is estimated that ~220 energy advisors were targeted with direct information (one mail), of which 88 answered[18]. The final response rate was thus around 40%. The geographical distribution was good, providing at least three responses from all but two regions (survey question (SQ) 1, Appendix C). After sifting through the survey answers it was understood that not all energy advisors had experience of people inquiring about PV. Four of the respondents expressed this explicitly, and 13 respondents in total had received fewer than ten contacts from individuals with an interest of PV.

The non-responses could stem from low interest of PV in the given municipality, short working experience, or from division of labour at the municipal energy office where some advisors are exempted from PV inquiries. This lack of relevance could explain why some of the advisors refrained from answering the survey. It is coarsely estimated that the relevant population (that had received more than 10 contacts in total inquiring about PV) was 200 energy advisors, or fewer.

4.5. Analysis of the survey answers

The semi-structured interviews and the open-ended survey questions survey were analysed by distinguishing common themes and identifying aspects where differentiating views occurred within the industry. The remaining survey answers were analysed in the commercial tool SPSS by doing descriptive statistics (e.g. by presenting frequency tables and standard deviations). The 13 respondents with little experience of PV inquiries (<10 contacts in total) were sorted out prior to the data analysis due to a lack of relevance.

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[18] The number of contacted energy advisors is slightly uncertain since the author didn't control the mailing of the survey. Lower local response rate *could* be explained by unclear or insufficient communication. The energy advisors of the local energy office of Västernorrland did not receive direct communication. In the Stockholm-region only a few energy advisors were contacted directly. In a discussion with the local coordinator of the energy advisors in Stockholm it was decided that only the advisors with relevant job description and education were contacted (due to a different organisational setting there).

Table 4.1: SQ6 How many contacts regarding PV have you received in total?

PV inquiries	Amount
10-50	31
50-100	12
100-200	14
200-500	14
>500	4
Mean: 50-100	**Σ 75**

Although the energy advisors was the targeted group, the main reason of the survey was to better understand the inquiries and uncertainties perceived by households prior to PV investments. Before looking at the answers it is thus important to analyse the characteristics and amount of contacts. Most energy advisors had in their professional role received 10-50 contacts the last six months (SQ5, Appendix C), which was also the case regarding the total amount of contacts (table 4.2). This indicates that the interest in PV is rather novel in Sweden. The by far most common group contacting the advisors for advice on PV is individual homeowners[19], which was vital for the validity of the survey answers in light of this study. Most of the advice seekers contact the energy advisors early on in the process of investing in PV[20], and very few later, when contact with the installer has been taken. This indicates that most advice seekers use the energy advisors as information sources rather than consumer advice (by comparing offers or receipts etc.).

The advice seekers are deemed a heterogeneous group both regarding technical know-how and economic reasoning (table 4.3), i.e. as a whole not succumbing to any of the specific adopter group stereotypes by Rogers (2003). When asked to categorise

[19] 72 out of 75 respondents answered that private persons comprised between 100-60% of the contacts. 40 respondents answered that private persons was 100-80%. The two other categories, commercial entities and housing organisations were on par with each other (SQ4-7, Appendix C). One comment expressed he/she missed the category "non-profit organisations".

[20] 52 respondents answered that most advice seekers contacted them at the most early stage "One has just understood that it's possible to generate one's own PV electricity (SQ10). The advice seeker wants to learn more about the technology and its costs." 18 answered the second option – "a suitable rooftop is identified and the seeker wants to know more specific things about the technology and the support schemes."

the knowledge levels of the advice seekers (SQ14), most (47) energy advisors responded that the advice seekers were ”…technologically interested but with little knowledge of PV”, whereas 25 answered they have ”rudimentary technical skills in general.” Only three answered that the advice seekers were “…tech-savvy with high cognisance of PV”. Thus, with the diffusion of innovations literature in mind, it is probably not the *innovators*–characterised by being able to apply complex technical knowledge–that primarily seek advice with the energy advisors. Regarding suitability for the study it is, however, ideal since the main goal is to understand the adopter categories further down the diffusion route, with lesser technical skills. It should be pointed out that several respondents expressed frustration choosing just one of the options regarding the economic reasoning and knowledge levels of the “typical” advice seeker. Others expressed that the categories of people contacting them had changed recently[21].

Table 4.2: SQ15 Which of the following descriptions fits best for the advice seekers of PV?

Statement	Respondents
The advice seeker is interested in PV for environmental or technological reasons. Whether it pays back is secondary.	17
The advice seeker wants the PV to pay back, but the time scope isn't important. The investment could for example be a mean of retirement savings.	33
The advice seeker wants the investment to pay back in maximum ten years.	25
	Σ 75

4.7. Biases and limitations

Although the survey respondents give a picture of a diverse group of advice seekers, it is important to be aware of the limitations and biases. The advice seekers, providing background of the experiences of the survey respondents, should not be

[21] “The groups inquiring about PV are broader today and therefore there is a broader range of knowledge levels and questions.” and “We will probably see a shift from “idealists” to “economists” with an increasing need of exact calculations and “everything” that is required for a generating system”

understood as the people who *actually* adopt PV as of today. Thus with solely the background of the survey results, it remains impossible to draw conclusions of the groups currently adopting PV. However, it is still plausible that the advice seekers have differentiating values and drivers than the "wider public" in order to ponder an adoption PV at this early stage of diffusion. As pointed out by Keirstead (2006), to an extent, this bias is unavoidable since the nature of this kind of studies explores a small subset of potential early adopters. There might also be a demographic bias underbuilding the experiences of the energy advisors. A couple of the survey respondents mentioned in the open comment part of the survey, that it was mainly older persons who contacted them for advice. Furthermore, one person, during the preparatory interviews[22] of the survey, suggested that the energy advisors could to an extent shape the content of the advisory discussions, especially with advice seekers with little relative knowledge. This could, for example skew the survey answers in section 4 (Appendix B).

The non-response of the survey was around ~60% (as pointed out, though, an important reason of non-response could be a lack of perceived relevance due to little experience of PV inquiries). Since the target group (the energy advisors) was homogenous in education and job description, the response rate was deemed sufficient. It is judged that the survey wasn't particularly vulnerable to non-response bias since the vast majority of the questions revolved around general experiences of PV inquiries rather than own opinions (i.e. little room to express subjective views).

All interviews were conducted with relatively large installers, which could have given an artificial view of common business practices (the three installers represented here are likely also the largest three companies on the market of domestic PV). However, no document readings pointed at important differences in business models among smaller actors, although reports have come out recently regarding a smaller energy utility engaging in 'leasing'. As Nässen et al. (2008) stated, in these kinds of studies there is an unavoidable technology bias since all interviewed actors have own professional interests vested in the success of PV diffusion.

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[22] Mats Danielsson, Municipality of Göteborg.

4.8. Design of a web tool

The conducted research underbuilds several design decisions following three criteria. The bottom line is to provide the conceptualisation of a pedagogical, concentrated, guide and calculation program for potential PV adopters. It attempts to reduce uncertainty and search-costs for the individual adopter, and to support pre-existing initiatives[23] to establish norms and legitimacy on the Swedish market of domestic PV. A technical PV model has been built up in parallel with this thesis and model results of electricity generation at several Swedish locations can be seen on page 32 for illustration purposes.

4.8.1. Criteria 1 – Simplicity

As expressed by one of the survey respondents the risk of "information overload" is evident when it comes to PV; often what is required is to distinguish what is important and give information in portions. As compared to purchases of established technical appliances such as cars or vacuum cleaners, the sheer lifetime of a PV system means that most people will likely only purchase one or maximum two PV systems during a lifetime. It is, thus, reasonable to assume that most people investing in PV are not going to be experts and the information should be framed accordingly, both in language and scope.

4.8.2. Criteria 2 – Legitimacy

For all technologies, the issue of legitimacy is key in the childhood of a diffusion process (Bergek et al. 2008). Kurtz et al. (2009), for example, pointed specifically at the need of increasing reliability of PV in terms of using well-researched assumptions in calculations of technical and economic performance. By providing thorough information, which is aligned with established practices, legitimacy can be furthered among potential PV households in Sweden.

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[23] Bengt Stridh has for example worked to establish a standard method of calculating the profitability of PV investments (e.g. Stridh et al. 2014). Although many of the assumptions are similar in this study, a key challenge is to frame it in a relevant way for the target group, i.e. private persons. Outside Sweden, especially NREL has published many studies regarding PV system performance, with the underlying goal of reducing uncertainty (e.g. Kurtz et al. 2009, Jordan and Kurtz 2012).

4.8.3. Criteria 3 – Relevance

The underlying assumptions of the calculations should be chosen in a way that suits households and their economic reasoning. Furthermore, the main target group of the tool are the adopter-categories subsequent to *innovators*. It is thus to some extent important to raise the view from current practices of communication (assuming that innovators and to some extent early adopters are the ones that adopt PV today), e.g. regarding abstraction levels of information and financing models. This stems from the observed notion that adopter categories further down the diffusion route have lesser possibilities of applying advanced technical knowledge and usually less room to engage in deals with a significant financial risk (Rogers 2003).

5. Swedish retail market for domestic PV

When an individual homeowner decides to adopt a new technology, he or she does so in a context of other adopters, installers, and information sources as well as the financial and legislative framework (e.g. Bergek et al. 2008, Rogers 2003). To gain understanding of the issue of perceived uncertainty among potential adopters, it is thus important to provide a 'decision-framework'.

The following chapter attempts to answer RQ1: "What characterises the Swedish retail market for domestic PV of today?" It's largely based on a literature study, and interviews with actors on the PV market. In the chapter, the main goal is to provide background of *what* a web tool can contain, and following questions are touched upon: What is essential to have in mind regarding PV production in Sweden? Are prices and supply of modules homogenous? What is the legislative and financial framework for homeowners?

5.1. Technical features

The lion's share of the Swedish PV systems is roof-mounted (Lindahl 2015). For maximum power output, however, the PV modules should be positioned at normal incidence to the direct solar light. Since tracking equipment (that follows the normal incidence of the sunlight), as well as assemblage in tilts and azimuths that differ from the slope and azimuth of the roof, accrues to increasing costs, there is a trade-off between increased electricity yield and higher installation costs. The PV modules in Sweden are thus commonly mounted directly on the rooftops, following the inclination of the roof (unless the rooftop is horizontal–which enables the possibility to mount the modules in optimal inclination)[24].

On the Northern hemisphere, the arrays should be oriented towards the south for maximum electricity yield. In Sweden, the optimal slope is 35-50% depending on geographical location (in the southern regions the optimal approaches the lower

[24] Johan Paradis, Consultant

boundary and vice-versa) (Stridh and Hedström 2011). The total output of a PV system doesn't, however, differ significantly for normal roof tilts (roof tilts between 20° and 60°, due south, give outputs at 100-95% of maximum) (Stridh 2013). PV arrays on vertical southern surfaces, or normal slopes directed towards east and west give outputs at 75-80% of the maximum output. According to Kjellsson (1999), over 90% of Swedish single-family buildings have roof constructions[25] of which the average roof tilt is around 30%.

The PV output, for a system directed towards south and with few losses due to shading, ranges at most places in Sweden between 800 and 1000 kWh/kW_p (Stridh and Hedström 2011). At some places, such as the mountainous north, or off the coasts, lower respective higher values have been observed. Most PV systems pointing south are likely to produce electricity at around 900 kWh/kW_p. The global irradiance is, however, variable both in space and time and can deviate at a rate of 10% for longer time periods (SMHI 2007), which is reflected by the shape of figures 5.2-5.5.

Figure 5.1: Monocrystalline PV modules

[25] The most common roof construction is a pitched roof, comprising 85% of the roof area of all the one family dwellings in Sweden. The average roof tilt of these houses is 31°.

Modelled PV output[26] in different Swedish locations in 2007

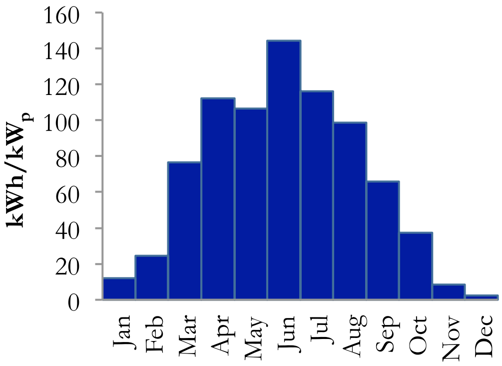

Figure 5.2: Luleå. Σ 810 kWh/kW$_p$

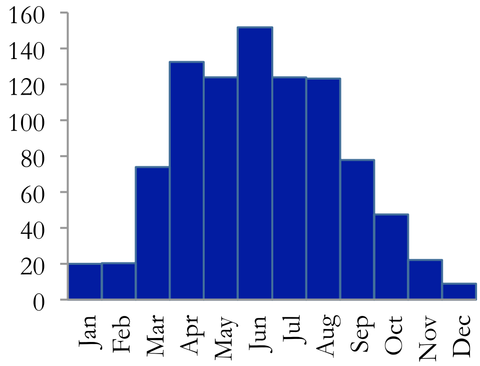

Figure 5.3: Stockholm. Σ 930 kWh/kW$_p$

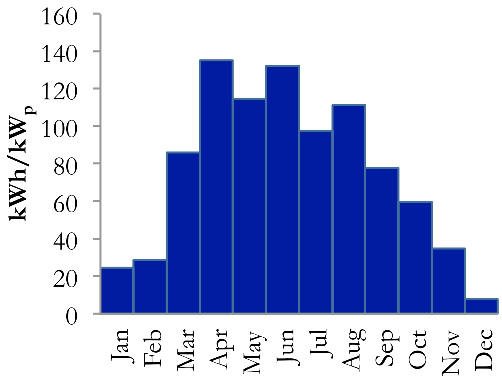

Figure 5.3: Göteborg. Σ 910 kWh/kW$_p$

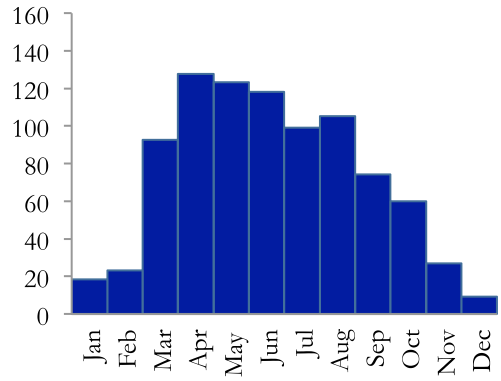

Figure 5.5: Malmö. Σ 880 kWh/kW$_p$

[26] The annual PV output was modelled with a 30° roof-tilt, due south, by using the equations from Norwood et al. (2014) with a few exceptions. The temperature dependency of the solar cells was modelled by using diurnal averages, instead of hourly, and, as Widén (2011) by using equation 23.3.3 of Duffy (2013, p. 758). The same assumptions for system losses were used as in PV Watts, a commercial tool developed by NREL (2015). The performance ratio was 0.78 in all locations, thus corresponding well with the commercial tool PV Syst, and several measured PV systems in Sweden (Widén 2011). The PV output gave virtually identical results as another commercial tool, developed by Widén (2011), both on a monthly and annual basis. Hourly data for global horizontal irradiation and normal beam irradiation of 2007 was used from SMHI (2015).

One aspect that reduces PV output is soiling due to snow, dirt, and pollen. Especially the issue of snow is often ventilated due to Sweden's northern latitude[27]. However, only a small percentage of the annual PV production is generated during the winter months in all parts of Sweden (figure 5.2-5.5). For example, if it were assumed that the PV modules were snow-covered constantly from the beginning of November until the end of February, the loss would be between 4-6% at all modelled locations. Thus, in most locations in Sweden, the issue of snow is probably negligible. In Northern regions, however, the loss due to snow covers could become substantial if the PV arrays are covered ranging into March and April.

The albedo (a material property which denotes of how large share of the solar light that is reflected) does also have a marginal role. By changing from a constant annual value of 0.2 (which often is assumed for city landscapes, e.g. by Widén (2014) to 0.6 (1 would mean that all sunlight is reflected by the ground[28]), the PV output increases by merely 2% in Luleå for the modelled year (for a roof-tilt of 30°). A higher albedo, though, would increase the yield more for steeper surfaces.

5.2. Choice of modules and inverters

The most common PV module today consists of crystalline silicon, comprising roughly 80% of the cell production worldwide (IEA 2014b). Commercially available PV commonly have an efficiency ranging from 14% to 18% (IEA 2014b). Crystalline solar cells are thereafter categorised into poly- (cheaper per m^2) and monocrystalline (higher efficiency). In Sweden, 2014, the most commonly installed module for residential customers among the interviewed installers was understood to be monocrystalline[29] at a comparatively high efficiency between 15.5-17%[30,31,32]. The expressed views ranged from statements such as "we have a few pallets of polycrystalline in stock, but they're only used when the customer wants the cheapest

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[27] In the survey with the energy advisors a couple of the respondents expressed concerns and interest of the losses due to snow covers (and also of gains due to the increased albedo of snow).

[28] The albedo for snow is 0.4 – 0.95 whereas for soil it is 0.05 – 0.4.

[29] Lars Holmquist, Egen El.

[30] Petter Sjöström, Solkompaniet.

[31] Magnus Hellberg, Kraftpojkarna.

[32] Andreas Molin and Elin Molin, PPAM.

possible option"[31] to "there is very little difference in price per kW and last year we got a good deal on monocrystalline"[29]. Since the systems are priced in kW_p (where differences are very small[33]) the choice between mono- and polycrystalline cells is not one of particular economic importance for the customer.

The PV modules generate direct current electricity (DC). In order to feed in electricity to the grid (or the house) the DC output needs to be converted into alternating current (AC) by using an inverter. If a system is subject to partial shading, an inverter will generate AC current according to the module with the lowest voltage in a string (since the modules are coupled in series). In these cases technologies such as power optimizers, or microinverters, can be used to ensure maximum possible generation. Inverters with multiple MPPT (maximum power point tracking) can also be used if several strings are installed, for example with different azimuths, to reduce the dependency of the "weakest link". Among the Swedish installers and retailers, different views were encountered regarding the choice of inverter. Both interviewed installers[34,35] use mainly conventional inverters, in one case referring to unnecessary costs regarding installing power optimizers. One point was made that power optimizers is more novel (and thus more prone to teething problems) than modules and inverters[36]. Elsewhere, power optimizers were advocated[37] (despite an estimated cost increase of 5-6%[37]), mentioning the possibility of individual monitoring of the modules, less vulnerability due to partial shading as well as less vulnerability in case of fire[38]. Microinverters were deemed costly and problematic–"more electronics on the roof"[36,37]–according to several of the inquired market actors.

5.3. The installation process

The installers gave a picture of similar business practices, i.e. by selling PV systems per kW and offering warrantees for the continuous function of the components. No

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[33] Johan Ehrenberg, ETC Egen El
[34] Petter Sjöström, Solkompaniet
[35] Andreas Molin and Elin Molin, PPAM
[36] Bengt Stridh, ABB
[37] Magnus Hellberg, Kraftpojkarna
[38] Due to DC current, PV cannot be turned off (if the sun is up). In case of fire this *could* mean that fire extinguishers refuse to put the fire out to avoid hazardous currents. Installed power optimizers would effectively mean that the voltage could be shut off.

cases of leasing or "per-kWh" pricing models were encountered among the larger actors. Once contact is taken with an installer the site of the prospective PV system is evaluated. The largest installers[39,40,43] examine the rooftop's (if PV are mounted on a rooftop) suitability and the dimensions by studying satellite pictures and by looking at pictures from the site, i.e. no site visit is carried out prior to the installation. Some of the other interviewees[41,42] expressed suitability of doing site visits, but for a refundable cost ranging between 500-1500 SEK (in case of deal). For residential systems, shading analysis and dimensioning for small systems are carried out manually (as opposed to software modelling) by using rule-of-thumbs[40], or simply by observing that nothing is in the way[41,42]. Shading controls by using software can be done in some cases, but the costs are often too high for residential systems[43].

5.4. Installation costs

Costs for standard turnkey 5 kW_p systems ranged between 17 SEK/W_p[43] (18 SEK/W_p for the monocrystalline cells) to around 20 SEK/W_p[40,42], according to the interviewed market actors (5 kW_p is a common residential system size[42,40]–smaller systems carry an increasing share of overhead costs and becomes more expensive per kW_p). This price-level was reflected by the survey with the energy advisors where the average "recommended cost per installed kW" was slightly less than 19 SEK/W_p[44] (see figure 5.6). Price differences *could* stem from geographical circumstances, different organisational setting (for example, some installers install through an energy company, whereas others install and manage the customer contact themselves), and–in the case of *some* of the energy advisors–a lack of updated or realistic information. A conducted survey with the installers themselves, however, gave exactly the same average price estimation, 19 SEK/W_p including VAT for residential systems <20 kW (Lindahl 2015). The price information given on the websites of the energy companies was often slightly higher than 20 SEK/W_p (Stridh 2015a). The larger the systems,

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[39] Lars Holmquist, Egen El.

[40] Petter Sjöström, Solkompaniet.

[41] Johan Paradis, Consultant.

[42] Magnus Hellberg, Kraftpojkarna.

[43] Elin Molin and Andreas Molin, PPAM.

[44] There were 61 survey answers with complete data. (Some respondents, for example, replied that they didn't give price indications.) The average was used in cases when a range between two values was given.

though, the lower the price per kW–and vice-versa. A plausible estimation suggested the price per kW above 5 kW_p lies at around 15 SEK/kW_p[42].

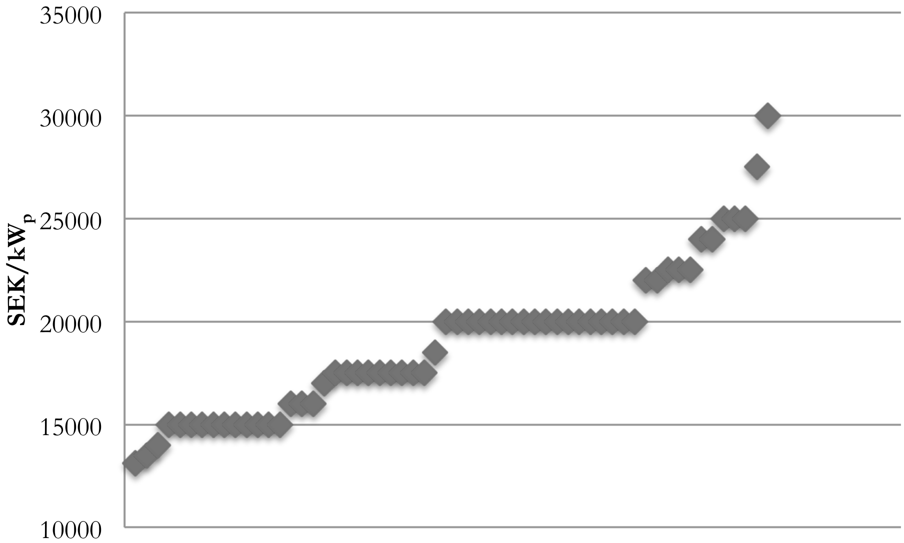

Figure 5.6: SQ40 "What cost-per-kW recommendation do you give regarding a turnkey domestic PV system (incl. VAT; excl. ROT and investment support)?" Each dot represents a respondent.

5.5. Legislative landscape for micro-producers

In Sweden, tax-exempted self-consumption of electricity is allowed and micro-producers[45] have the legislated right to feed in electricity to the grid at all times (1994:854, chapter 4 §10). The grid owners are responsible for installing two-direction metering equipment at the connection points.

The Swedish electricity market is subject to an extensive legislation, and there are several support schemes for renewable energy technologies in general, and PV in particular. Since the first of January 2015, micro-producers have the right to a 0.60 SEK/kWh tax reduction for every kWh that is exchanged with the grid on a yearly-basis (1999:1229). Sweden's main policy instrument to stimulate the growth of renewable energy technologies–the technology neutral market-based green certificate

[45] Defined as systems smaller than 43.5 kW, with a fuse at the connection point of maximum 63 A. The annual production shall not exceed the consumption, nor 30 000 kWh.

program–is likewise applicable for electricity generated by PV[46]. Other policies that affect market deployment of PV in Sweden are the direct investment support[47], the ROT-program[48] and grid benefit compensation[49].

There is not a nationally homogenous legislation regarding the necessity of building permits as the municipalities interpret the building codes independently. Annual registration and payment of VAT for sold electricity is required (Skatteverket 2015), albeit for small sums for micro-producers.

5.6. PV economics

Although there are several options to calculate the profitability of PV, e.g. LCOE and cash flow analysis, this study focuses on the notion of payback-time since it is, in discussion with the energy and climate advisors, deemed the most relevant method regarding the economic reasoning of most homeowners[50,51].

$$I - \sum_{i=1}^{p} \left(\frac{v_i * y * (1-z)^{i-1}}{(1+d)^i} - a_i \right) = 0 \qquad (1)$$

I is the investment cost, P the payback in years, v_i is the value of electricity, y is the electricity yield year 1, z is the annual degradation rate, a_i the annual maintenance cost, and d is the discount rate.

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[46] Most domestic PV systems only receive certificates for the net-delivery to the grid. In order to receive certificates for the self-consumption extra metering equipment needs to be purchased. Since these PV systems are small the income from the green certificates does not always merit for the extra investment. The maximum time period for receiving green certificates is 15 years (2011:1200, chapter 2 §7).

[47] Since January 2015 it amounts to a maximum of 20% of the investment cost for homeowners. The scheme has a queuing system that manages who receives support (2012:971).

[48] The ROT tax deduction means that repair, maintenance and renovation to existing built structures is tax deductible for labour costs up to 50 000 SEK. The house needs to be over 5 years old. A homeowner can either choose the ROT tax deduction or the investment support – not both (2009:689). The share of labour costs of a PV installation is often at 30% according to a lump sum (Svensk Solenergi 2015), which results in an investment support of 15%.

[49] Grid benefit compensation (1994:854, chapter 3 §15) is received since distributed electricity generation help to reduce transmission losses in the grid. It varies depending on grid owner and municipality.

[50] Zandra Wenngren, Municipality of Västerås.

[51] Mats Danielsson and Mikael Eriksson, Municipality of Göteborg.

5.6.1 Costs of electricity

PV systems pay back by reducing the costs for bought electricity and by selling the surplus to electricity retailers. The bought electricity comprises the spot prices, the variable part of the electricity transmission fee as well as energy tax, green certificates, and the VAT. In 2014, most Swedish households paid a retail price of 1.25–1.50 SEK/kWh depending on contract (including taxes, VAT, as well as the variable and fixed grid fees) (SCB 2014). In order to calculate the payback for PV systems, however, one would need to use only the *variable* part of the grid fee, since the fixed part would have to be paid by a PV household anyway. According to a long-term prognosis carried out by Sweco (Eriksson et al. 2013), the cost of bought electricity (including variable grid fees) for household customers with a contract based on hourly trading prices is projected to be at an average of 1.20–1.40 SEK/kWh during the lifetime of a PV system. The higher amount refers to electricity prices in southern Sweden (as there are geographical differences, *mainly* regarding energy taxes).

The prices for sold (surplus) electricity has up until now changed significantly in time and among the retailers (Stridh 2015b) and it has often been higher than the hourly market price, hinting that many electricity retailers buy PV electricity for other than strictly commercial reasons. As installed capacity increases, however, it is likely that the fee received for surplus electricity will converge with the hourly Nord Pool spot prices[52,53]. The average of the spot prices that coincided with PV production ranged from 0.29 to 0.59 SEK/kWh between 2004 and 2014, with an average of 0.39 SEK/kWh (Nord Pool Spot 2015). The difference between the average spot price and the PV spot price amounted to 2.6 percentage units due to higher electricity demand, and thus higher spot prices, during the day (figure 5.7).

[52] Bengt Stridh, ABB

[53] Johan Lindahl, Uppsala University

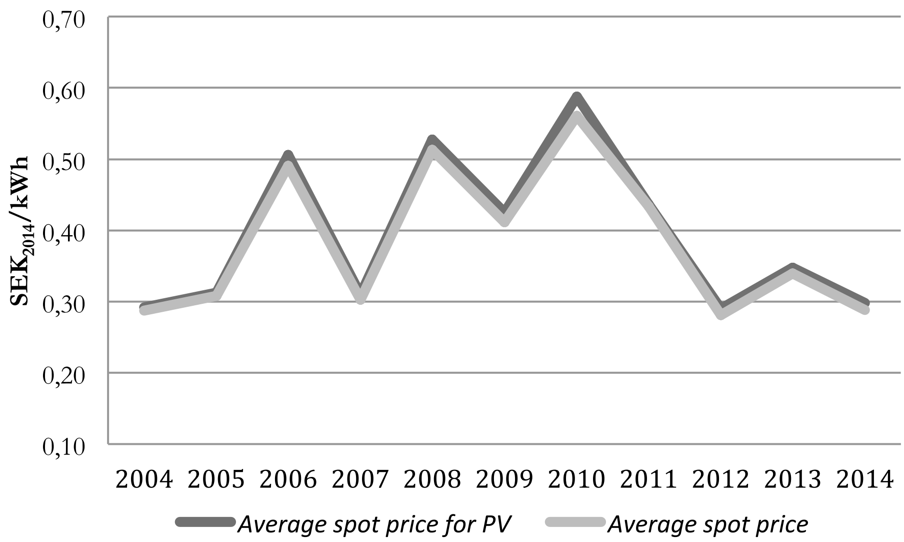

Figure 5.7: Modelled average spot prices (SE3 region) and average spot prices coinciding with PV production (prices in 2014 value). Source: Nord Pool Spot 2015

The spot prices are *expected* to remain at similar levels as today during a foreseeable future (until 2020) according to several inquired actors from academia and industry. The potential shutting down of nuclear reactors, increased transmission capacity to central Europe, developments of the EU-ETS for carbon, could, however, all lead to higher spot prices, whereas a substantial growth of PV capacity could mean that the mid-day spot prices decrease due to large supply. Yet, owing to the balancing role of Swedish hydropower, price fluctuations are comparatively small and estimations deem it would require PV capacity at a magnitude of 10 GW (a more than 100-fold increase from today's level) to significantly alter the spot prices during the hours of PV generation. (Diurnal consumption variations of 5 GW or more are not uncommon, and intra-day variations can be even larger (Nord Pool 2015).)

Further income from surplus electricity includes electricity certificates (which averaged at 0.23 SEK/kWh between 2004 and 2014 (Energimyndigheten, 2015c)), a grid-balancing fee (~0.05 SEK/kWh but dependent on region and season), certificates of origin[54], and the tax reduction of 0.60 SEK/kWh (1999:1229).

[54] The certificates of origin are meant to provide the customers a guarantee that the bought electricity comes from renewable energy sources, but the market value remains rather unclear (Lindahl 2014).

5.6.2. Self-consumption

Residences do not commonly use all electricity themselves (the hours when the sun is up do naturally not always intersect with the load profiles). Since the value of purchased and sold electricity is different the degree of self-consumption of electricity needs to be estimated in order to calculate the payback time. The self-consumption in households varies mainly depending on the ratio between the PV production and the total electricity consumption (Widén 2014). Although there are possibilities of load shifting, the incentives remain rather small as of today[55]. The values in figure 5.8 represent the only Swedish study of typical households, PV generation and self-consumption (Widén 2014).

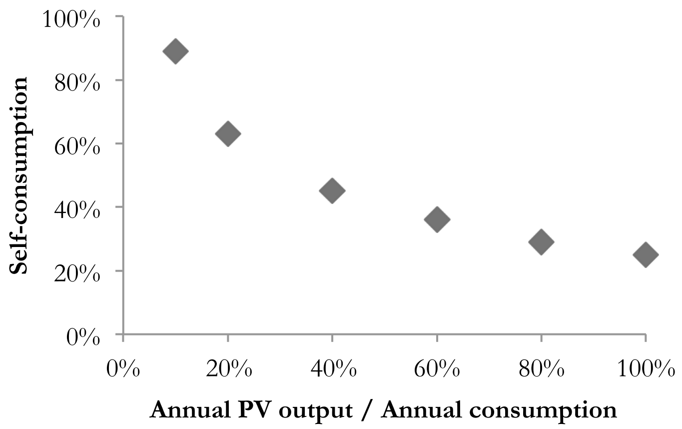

Figure 5.8: Self-consumption as a function of the annual PV output and electricity consumption for residential households. The ratios are calculated for a system of 6 kW_p without load shifting. Source: Widén (2014, p. 206).

5.6.3. Lifetime, degradation and O&M

Confident predictions regarding the technical degradation, life-length of the components, and O&M costs, are key regarding lowering risk and increasing reliability of an investment in PV (Kurtz et al. 2009). The mean value in a compilation of a large set of international studies on the degradation of PV systems was found to be 0.5 %/year (Jordan and Kurtz 2013, Stridh et al. 2014). The only identified study carried out in Swedish climate showed an average degradation of less than 0.2%/year after 25 years of operation for 20 crystalline silicon modules

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[55] For an average household, self-consumption could be increased by around 200 kWh/year by shifting loads (Widén 2014).

(Hedström and Palmblad 2006)–which possibly hints towards better long-term performance for PV in Northern climates.

Most suppliers offer warranties for PV modules of 25 years (Zweibel 2010), although an estimated lifetime of 30 years is becoming somewhat of a norm (Branker et al. 2011, Stridh et al. 2014). The upper limits for modern modules, however, are yet unexplored due to the novelty of the technology, and thus a lack of long-term empirical observations (Zweibel 2010). Of all the components in a PV system, only the inverter is likely to need periodic maintenance (after ten years or more it will need to be partially replaced) (Zweibel 2010). O&M costs could be assumed at 100 SEK/kW$_p$, at a level so the inverter can be exchanged once during the lifetime of the system (Stridh et al. 2014). Keating et al. (2015) recommends using a maintenance cost at slightly higher levels for domestic PV systems (130 SEK if the same conversion rate is used).

5.6.4. Discount rate and financing

Ultimately, the profitability of PV investments depends on the discount rate and of how the financing is obtained. The discount rate is a major determining factor of the profitability of the investment and thus of particular *academic* interest (Bazilian et al. 2013, Darling et al. 2011, Stridh et al. 2014). As pointed out earlier, the discount rate puts a time preference on money, and often varies depending on the perceived financial risk, and of the purpose of the investment (Branker et al. 2011). The discount rate tends to be higher for private entities searching to maximise short-term profit as compared to governments investing in long-term projects with social benefit.

A reasonable, theoretical, discount rate for private persons could for example be the real interest after tax deduction (Stridh et al. 2014). In Sweden for a bank loan of 5% the real interest after interest deduction would be 2% while using the average inflation between 2000-2013. Kost et al. (2013) proposes 2.5% in $WACC_{real}$[56] (weighted average cost of capital) for small-scale PV investments.

[56] The discount rates are in the study determined through the usual cost of capital on the market (WACC). The authors assume that 20% of the financing comes from private equity with 6% interest rate. An inflation of 2 % is used. In Sweden there is an interest deduction at 30% that in this case would be applicable only for the loan part of the investment.

5.7. Summary of economic input

The technological characteristics and input for calculating payback-time mentioned in this section are summarised in table 5.1. Context dependent parameters regarding self-consumption and electricity yield are left out.

Table 5.1: Input parameters for calculating payback time

Parameter	**Value and unit**	**Sources**
Spot prices	0.40 SEK/kWh	Nord Pool 2015 (historical)
Retail prices (incl. VAT and transmission)	1.20-1.40 SEK/kWh	Eriksson et al. 2013, Stridh et al. 2014
Green certificates	0.20-0.25 SEK/kWh	Energimyndigheten 2015 (historical), Stridh et al. 2014, Eriksson et al. 2013
Credit from DSO	0.05 SEK/kWh	Eriksson et al. 2013
Tax reduction	0.60 SEK/kWh	Skatteverket 2015
Lifetime	25-30 years	Zweibel 2010, Branker et al. 2012, Stridh et al. 2014
Degradation	0.2-0.5 %/year	Hedström and Palmblad 2006, Jordan and Kurtz 2012, Branker et al. 2012
O&M costs	100-130 SEK/kW/year	Stridh et al. 2014, Keating et al. 2015
Discount rate	2.0 %	Stridh et al. 2014

6. Perceived uncertainties on the market of domestic PV

Uncertainties, or knowledge gaps, imply transaction costs due to the increased necessity of gathering and processing information. This could *for example* translate into high discount rates to mitigate a financial risk (Branker et al. 2011, Sutherland 1991), or, if the level of uncertainty is not reduced to an acceptable level, rejection might occur (Rogers 2003). Whereas the previous chapter mapped the framework of the market of domestic PV, this chapter searches to interpret this framework through the lenses of potential PV adopters. The following chapter attempts to answer RQ2: Which are the most salient uncertainties perceived by potential adopters of domestic PV? The survey with the energy advisors constitutes the empirical base of the chapter along with complementary data from the interviews. Each subchapter is followed by a checklist with advice for households regarding the main decision steps. The steps are kept to a minimum not to exaggerate the notion of complexity.

6.1. Overview of uncertainties and obstacles

The survey was concluded with two open-ended questions, which also proved to be the most general observations of the uncertainties on the Swedish residential market. The energy advisors were asked to "identify the areas where homeowners perceive most uncertainties" and, relatedly, requested to "identify the areas where homeowners encounter most difficulties in obtaining information of PV".

A vast number of issues were brought up, basically ranging all of the described topics in the previous chapter. The vast majority of uncertainties could, however, be derived to the common denominator of payback-time or economic uncertainties in general [57]. 28 comments mentioned difficulties of interpreting the legislative framework or obtaining clear information from the authorities on support schemes

[57] Virtually all of the comments could to an extent be related to the economic performance of the system, i.e. lifetime of modules, investment support, electricity prices, irradiation, etc. 'Legislation' comprises all comments that had something to do with the rules and policy schemes that effect PV. Issues of solar irradiation, lifetime of PV and dimensioning of systems were categorised as technology.

and rules. 8 comments mentioned technological aspects. Several energy advisors mentioned multiple reasons, thus resulting in a total amount of input that exceeded the number of analysed survey responses (75).

Table 6.1: SQ53 Identify the areas where homeowners perceive most uncertainties. Some selected responses.

"The pay-off time, the lifetime of PV, and how much they produce"
"What happens with the prices of electricity further on? The green certificates? The lifetime of PV"
"Are there any remaining investment supports? Very frustrating when you don't know if there is money or not! The new tax reduction scheme is very confusing for the consumers, one would CERTAINLY wish that our politicians could develop a more comprehensible and accessible solution"
"The uncertainty if they will receive the investment support or not. If the technology will continue to develop, if one should dare to go for it – or wait. Confusing with received fees *for the surplus electricity* (author's note), etc."
"Clear, LONG-TERM, and simple and comprehensible payback information"
"The economic framework feels insecure. It has all along been a slow response time à 1.5-2 years in Skåne *for investment supports* (author's note). Future price developments and level of received fees of surplus electricity is a factor of uncertainty. If one is uncertain of continuing to reside in the house for a long time, it's good to know that the fee will be higher in case of selling the house, e.g. an assurance of the house increasing in value"
"How does the investment support work, taxes, etc. All too much uncertainty regarding these issues means that people don't dare to invest"

The issues of finding and selecting installers as well as relevant price information were the main topics that were brought up in SQ50 (main difficulties finding information) but not in SQ53 (main perceived uncertainties). 13 of the respondents mentioned finding trustworthy installers, and 9 identified accessible price information of PV as the main difficulty. The number of respondents mentioning troubles orientating amidst the legislation (25) and technological complexity (10) were largely the same. Several respondents answered that, to an extent, it's not the sheer information that is needed, but rather simple ways of translating or processing it.

Table 3.2: SQ50 Identify the areas where homeowners encounter most difficulties in obtaining information of PV. Some selected responses.

"It's probably not difficult to find information, but…I would guess that it's difficult to apply the information for one's own house. Exactly what type of information that is difficult to find is difficult to say. You could find the most, but then you need to ask about and where to look. There is generally little knowledge among the public, and it creates uncertainties for the customer (homeowner). It could stem from different things: lack of interest among homeowners- bad knowledge about the house- the structural abilities of the roof- difficulties to calculate- not wanting 'lessons'- the terminology is relatively new and therefore difficult for a lay person (homeowner) to understand."
"All the info in a simple manner; complicated with all the support systems, ROT, the tax reduction, VAT registration, green certificates, certificates of origin, etc., etc. Confusing!"
"It's not the information per se *that is needed* (author's note), but a person to discuss with and an advisor that can help out to ask the right questions to installers"
"How to do all the paper work: contact with the grid owner for registration and exchange of the metering equipment, building permit, VAT-registration, tax reduction, find prises of at which level and to whom the surplus electricity is sold to, as well as register for electricity certificates and register a Cesar account. If a PV installer would communicate and help out with these things I'd guess many would breathe a sigh of relief"
"Which local entrepreneurs are there, and which one "can I trust to do a good job?"

6.2. Technical features

In the diffusion of innovations literature, complexity and compatibility are identified as important barriers towards the diffusion of high-tech innovations (Rogers 2003). PV is (in the mind of adopters) more complex compared to the pre-existing alternatives, partly due to the sheer scale (enables micro-production, whereas most people have not generated their own electricity); it generates DC current (houses are powered by AC current), etc. Particularly complexity has been identified as a barrier among potential adopters of domestic PV (Farhar and Coburn 2000).

In the open comment fields of the survey, uncertainties determining yield (3), lifetime of PV (2), location (2), and shading (2) were identified. In the discussion with the energy advisors it was concluded that questions relating to electricity yield and inclination of the roof[58][59] are always taken up and were thus left out from the survey. The most frequently posed technical question in the advisory discussion is regarding the lifetime of the system (SQ20, Appendix C). The question is important for determining the time horizon of the investment (effectively compared with the plans for the house).

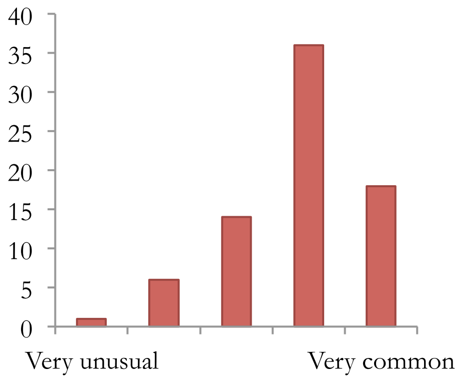

Figure 4.1: SQ20 What is the lifetime of PV?

Thereafter come the questions of shading and soiling (e.g. due to snow covers) These are contextual – not all roofs have problems with shading, and not all houses are located in regions where snow covers lay deep during several months of the year. As a result, there are apparent difficulties in generalising[60], although the sensed prospect of snow soiling might be exaggerated (unless most inquiries come from people in Northern regions). The question regarding how to connect the system to the grid is also common, reflecting the novelty of being able to produce electricity. The least frequent questions are, in order of descending frequency, the efficiency of PV (modules), importance of roof material for cost outcome, aesthetical properties of PV (e.g. are there PV in nice colours?), issues of fire safety, efficiency of the other components, and technology specific questions regarding microinverters or power optimizers.

Arguably, as abstraction levels increase, the frequency of a question in advisory discussions decreases. The most frequent questions are also the ones with least

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[58] Mats Danielsson and Mikael Eriksson, Municipality of Göteborg

[59] Zandra Wenngren, Municipality of Västerås

[60] Bengt Stridh, ABB Corporate Research

technical jargon. The questions are most often solution-based, rather than trying to understand the rudiments of how the technology works. Qualitative conclusions can be drawn from comparing SQ29 and SQ30 (figure 6.2-6.5), since they largely revolve around the same issue, shading. Whereas few ask about microinverters and power optimizers, which effectively are used to mitigate shading problems, most people are more interested in knowing if there are solutions to shading issues in general. Relatively few seem to be interested in the efficiency of modules, which suggests most see the PV system as a whole–that yields a certain amount of electricity for a certain amount of money.

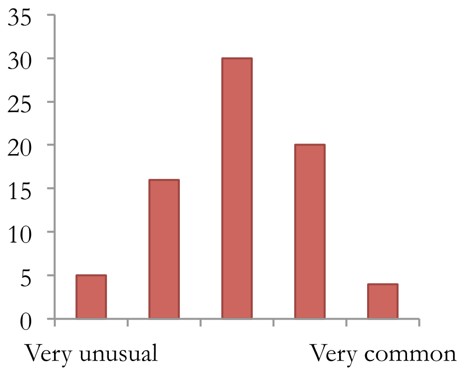

Figure 6.2: SQ29 What do I do if my roof is partially shaded?

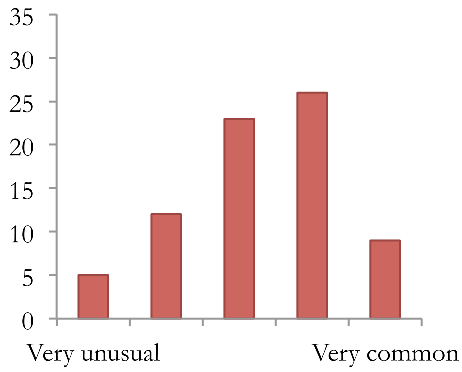

Figure 6.3: SQ36 How do I do to connect to the grid?

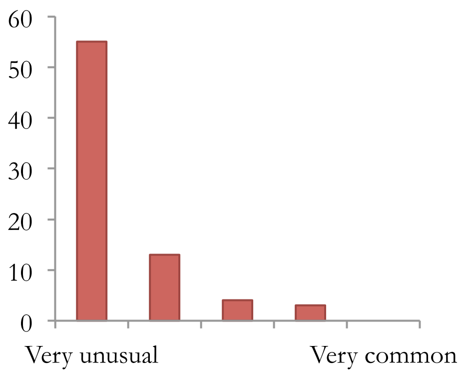

Figure 6.4: SQ30 Is a power optimizer or a microinverter suitable for me? (The y-axis has different scale than the other figures)

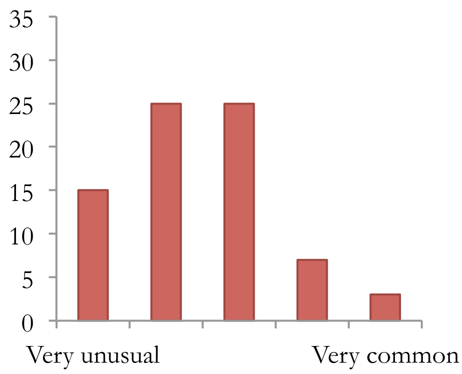

Figure 6.5: SQ38 What is the efficiency of PV?

It is important to emphasise that survey responses are based on potential adopters, rather than the clientele who de facto adopt PV in Sweden today. The most knowledgeable do probably not contact the energy advisors. However, several interviewed market actors presented a picture of relatively low knowledge levels among PV adopters as well. One interviewee expressed that the customer-acquisition process had become economically unsustainable due to the many questions prior to an investment. Another interviewee mentioned that it could take half a year of mailing or calling back and forth, departing from the first contact until a sealed deal. There are likely many 'innovators' who currently adopt PV in Sweden. As a whole, however, Rogers' (2003) characterisation of innovators–being able to apply and understand complex technical knowledge–seems quite detached as an overall generalisation of the current adopters of domestic PV in Sweden.

There is an obvious information asymmetry on the PV market, and a point of concern was expressed broadly[61,62], that there is a risk that installers sell equipment despite troublesome shading circumstances, induced by evident economic interests (i.e. effectively describing what Akerlof (1970) calls 'lemons' (inferior products) which in a worst case scenario would impose bad reputation to serious actors). Another correlated observation, taken up by the interviewees, concerned exaggerated predictions of PV output in general[62,63,64]. It is however impossible to evaluate to what extent such situations occur since most of the expressed comments were anecdotal in general, and sometimes depicting circumstances from abroad. The general picture offered by the interviewees was one of high mutual trust–"I could be employed by most of my competitors, we trust each other", as one interviewee put it –which is an indication that most actors are serious. The picture of a market with high levels of trust is also reflected by Sandén et al. (2014b).

[61] Petter Sjöström, Solkompaniet

[62] Johan Paradis, Consultant.

[63] Bengt Stridh, ABB

[64] Magnus Hellberg, Kraftpojkarna

Table 6.3: Checklist for estimating electricity yield

What	How
Estimate the yield	At most locations in Sweden, PV pointing south will generate around 900 kWh/kW for a normal roof-tilt (with little shading and soiling). If the PV arrays point east or west the yield will be at around 75-80% of maximum. The roof-tilt isn't especially important, but one should avoid installing panels horizontally. The yield could be higher for systems by the coasts, or less in the very North. Choosing between poly or monocrystalline modules isn't a choice of economic importance.
Estimate shading	PV should not be installed on an area with much shading. Since the modules are coupled in series, one shaded module will reduce the output from the whole string. If you have little shading (like a flag post) there are solutions such as power optimizers for an increased cost (around 5-6% for a system).
Estimate soiling due to snow	Since little electricity is produced during winter, snow is generally not a problem (around 4-6% of the annual electricity is produced between the beginning of November and end of February). If the modules are snow covered ranging into March and April, there will be significant losses.

6.3. Finding and selecting an installer

Finding and selecting installers carries transaction costs, which tend to be higher when there are few firms selling an item on a market (Ostertag 1999).

Although, the number of installers has increased much the recent years–from 37 in 2010 to 126 in the end of 2014 (Lindahl 2015)–many energy advisors point towards difficulties for homeowners finding and selecting local installers they can trust. (The largest interviewed installers, however, mentioned they install all over the country[65,66].) Also, one of the most frequent questions in the survey responses in section four[67] (SQ18) referred to difficulties finding an installer. As the energy advisors provide commercially neutral advice, they are not allowed to answer such questions. If the advice seekers are aware of this fact, the responses to SQ18 could even be an underestimation of the real difficulties of homeowners. Similar necessity

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[65] Petter Sjöström, Solkompaniet

[66] Andreas Molin and Elin Molin, PPAM

[67] The section of the survey where the energy advisors where asked to indicate how frequent a specific topic or question is in advisory discussions.

of commercial neutrality was expressed by one of the consultants[68]. Of the identified information sources in table 6.4, only the "acquaintances that already have installed PV" are likely to be able to provide suitable advice regarding finding an installer.

Table 6.4: SQ49 Which are the most important information sources for private persons on PV?

Information source	**Respondents[69]**
Bengt Stridh and his blog	38
Municipal energy advisors	31
The Energy Agency	30
Installers	13
Johan Ehrenberg /ETC (daily newspaper)	12
"An acquaintance that has installed PV already"	5
County administration board (Länsstyrelsen)	5
Solelprogrammet	4
The local energy offices	3
The energy companies	3
Solenergiförening (an interest organisation)	3

Although the previous chapter depicted the PV market as one of relatively homogenous price setting and transparent price information (i.e. installers and most energy advisors had similar pictures of reasonable costs for turnkey systems), several energy advisors (9) points at finding accessible cost and price information as a main difficulty for households. This could stem from the fact that price levels have changed substantially recent years, or from uncertainties determining prices for site-specific cases, which renders marketability more difficult (i.e. reflecting one of Williamsons' (1981) determinants of transaction costs).

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[68] Johan Paradis, Consultant

[69] Since many of the energy advisors mentioned several information sources, the total input supersede the number of respondents. The answers should be read with some scepticism, especially regarding the importance of the Energy Agency and the municipal energy advisors, since it was the energy advisors themselves who identified the information sources.

Most price information, either expressed in the interviews or given as information on websites specified some initial conditions for the price to be valid, e.g. a certain distance to the switchboard, a maximum roof tilt, circumstances beneath the roof (such as cumbersome circumstances for putting up scaffolding) or maximum distance to the house. Roof materials such as clay tiles, tin, or similar, are standard and priced equally. The cost variances, however, were in most cases deemed to be relatively small[70]. A steeper roof than the nominal (30°) should not increase the cost of a domestic system by more than 1000 SEK/kW$_p$[70]. (It was also mentioned that it wasn't likely that the installers would use a protractor once on site, thus, small variances would remain unnoticed). Similar, or lower, price variations were mentioned for roofs with misplaced chimneys or longer distances to the switchboard[71]. Transport is likely a minor contribution in most cases (10-15 SEK/km was mentioned as typical transport costs for systems of 5 kW$_p$[70]). One aspect that, hypothetically, could accrue to substantial cost increases, was in cases where roof-security would be difficult to fasten on the roof. (Such situations, however, hadn't appeared up until then for small-scale domestic installations for one of the largest installers[70].)

It was expressed from several market actors that prices are most often set on a general kW-basis, where the margin is set over an aggregate of several projects rather than for the individual cases[72,73], further strengthening the notion of quite a homogenous price-setting. One difficulty for homeowners, however, could be vague marketing. For example, if a potential customer has a roof-tilt of 33° (or doesn't know the tilt of the roof), a bothersome chimney, or lives far from a city, it is probably rather difficult to have a sense of the implications for the total cost. (Starting this project, it *was* for the author.)

[70] Petter Sjöström, Solkompaniet.

[71] Magnus Hellberg, Kraftpojkarna.

[72] Andreas Molin and Elin Molin, PPAM.

[73] Magnus Hellberg, Kraftpojkarna.

Table 6.5: Checklist for finding and selecting installer

What	How
Ask for references	To ensure that the installer is serious. A good way is to ask for a couple references from earlier installations.
Compare offers	Technical characteristics can be difficult to distinguish. The installers are probably the most knowledgeable people and they will in most cases provide the best information. To get help to ask the right questions and what to look for in offers, the municipal energy advisors can be valuable to contact. 20 000 SEK/kW is a common price for a system of 5 kW, and will in most cases not differ significantly. Larger systems should be cheaper.

6.4. Sifting through the legislation

The legislation for PV households is identified as a *main* source of uncertainty by 28 energy advisors. Several of the respondents mention the legislation as complicated in general (as some of the energy advisors in table 6.1 and 6.2 emphasise). The predominance of legislative issues mentioned in the open-ended questions underbuilds one of the central notions of technical innovation system theory, i.e. that the success of a technological innovation and dissemination process cannot be determined solely by the technical characteristics, or the relative costs, of a technology (Bergek et al. 2008).

The investment support was explicitly mentioned 17 times–followed by administration (3), tax reduction (3) and electricity certificates (2). Both the length of the queue and the level of support are among the most common inquiries in the advisory discussions (figure 6.6 and 6.7).

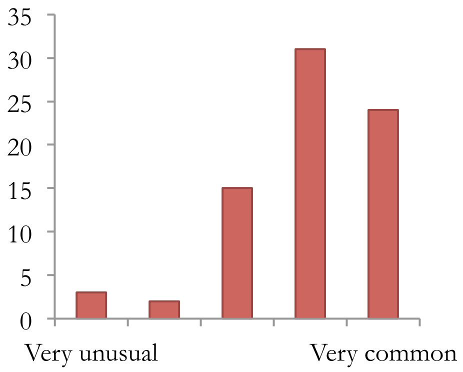

Figure 6.6: SQ31 How long is the queue for receiving the investment support?

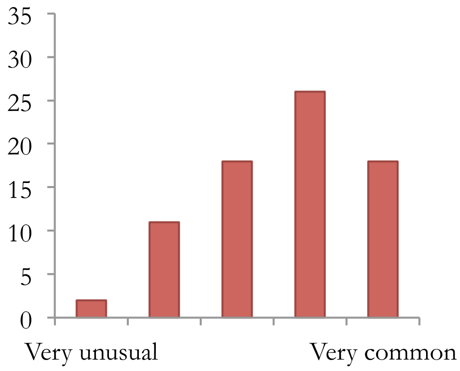

Figure 6.7: SQ44 What is the level of the investment/ROT?

The obvious reason for the inquiring about the investment support is the uncertainty of receiving it and the length of the queue; according to a couple of energy advisors it could take as long as 1-2 years from submitting the application until a decision is made. Also market actors[74, 75, 76] refer to increased customer-acquisition costs stemming from unusually long and artificial decision processes, where many projects do not materialise in wait for the investment support.

In general, a theme common to the technical inquiries can be observed; the most basic questions relating to financing, and the ones, arguably, coming in first in a decision process, are also the most commonly asked. To some extent, it is also the simplest (or, rather, the policy instruments people are used to) legislative questions that are asked: the ROT-deduction, building permits and to some extent the investment support (which is not common from other areas in peoples everyday life but conceptually easy to understand). The green certificates are specific for the power sector and probably something few have heard of before pondering an investment in PV (and something that, hypothetically, comes in later, or not at all[77], in the process). The VAT registration and tax reduction are new since January and difficult to evaluate at this stage.

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[74] Arne Andersson, Consultant.

[75] Petter Sjöström, Solkompaniet.

[76] Magnus Hellberg, Kraftpojkarna.

[77] Far from all micro-producers are registered for electricity certificates (Lindahl 2013)

Rogers' (2003) technological features, that to an extent determine the diffusion rate of an innovation, could arguably also be taken into account when evaluating the legislative barriers towards increased adoption. Legislation that is perceived as most *compatible* and least *complex,* for example compared to legislation in other areas of peoples' lives, will likely pose smaller barriers towards adoption.

The tax reduction is not time-scheduled, nor guaranteed during the life-length of current installations, which implies inherent uncertainties of how to treat it in economic calculations. As of now, there is a political consensus of the existence of the scheme[78], although a couple of interviewees expressed a concern that the tax reduction might be reduced or taken away in case of a rapid growth in PV capacity[79,80]. A modest growth, however, would mean that the scheme remains a small budget line, and thus probably unaltered. Also a high diffusion of PV could mean that the inertia of reducing or taking away the tax reduction increases, since the political interests and lobbying power of the prosumers grow accordingly[81]. Furthermore, politicians tend to treat policies that individuals have based their household economies upon carefully.

A micro-producer, in order to be defined as a micro-producer with taxation advantages, is not allowed to generate more electricity on annual basis than what is consumed in the household. "How much PV shall I install?" is the most frequently asked question in the advisory discussions (among the topics listed in section four, Appendix C), which indicates most potential PV adopters have difficulties relating the output of PV with the electricity consumption[82] or the size of their roof (figure 6.8). The case might also be that some draw parallels with heating systems, where systems are dimensioned to heat the building over the year (the parallel was mentioned in a couple of the open comment fields in the survey).

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[78] The scheme was proposed by one of the political coalitions prior to the election in 2014, and adopted by the other coalition.

[79] Bengt Stridh, ABB.

[80] Johan Lindahl, Uppsala University.

[81] Johan Ehrenberg, Egen El.

[82] Although low energy literacy is widespread among private persons (Brounen et al. 2013), the survey responses suggest that most advice seekers seem able to estimate their electricity consumption yield (Appendix C, SQ16).

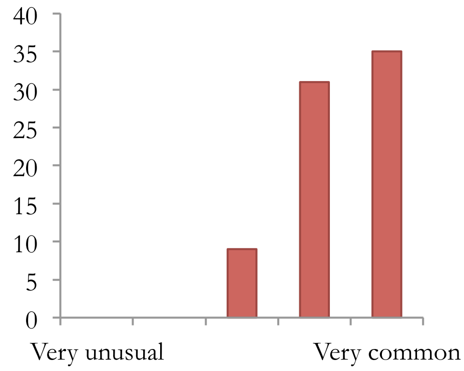

Figure 6.8: SQ21 How much PV shall I install?

The regulatory framework is no doubt complex for homeowners. However, as pointed out[83,84], the situation is always more complicated in *general,* than it is in *particular* for the household. Table 6.6 presents a list with important choices that needs to be undertaken prior to an investment decision as well as the administrative steps. The table is colour-coded to show which steps are only undertaken if an investment support is received (orange), or if a building permit is required (green).

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[83] Johan Paradis, Consultant

[84] Arne Andersson, Consultant

Table 6.6: Checklist for orientating in legislation and administration

What	How
ROT or the investment support	The investment support is 20% of the investment. Whether one receives it is uncertain and there is a queue. For the ROT there is no queue, and it amounts to around 15% as long as the ROT is set at 50% of the labour cost. Both cannot be received.
Dimensioning the system	In order to be defined as a micro-producer (with tax advantages) you cannot produce more than you use on an annual basis. System smaller than 5 kW becomes increasingly expensive per kW. A common roof size is 110 m^{2}[85]. If 50 m^2 can be covered with PV it would be equivalent to a system of around 8 kW.

Administrative steps	What needs to be done?	Who is responsible?
Apply for investment support	Send in an application to Länsstyrelsen	Homeowner
Apply for building permit	Send in an application to the municipality	Homeowner or installer[86]
Register PV system with grid owner		Installer or electrician
Register for electricity certificates[87]	Register an account with CESAR	Homeowner
Transfer electricity certificates to electricity retailer (annually)		Homeowner
Register the electricity production if investment support is obtained (annually)	Register with Länsstyrelsen for three years	Homeowner
Register VAT (annually)	Register with the Tax Agency	Homeowner

6.5. What is the payback?

Most identified uncertainties (table 6.1) have economic issues as their common denominator. Several survey respondents suggested there was an overall uncertainty regarding how to calculate the payback time.

85 According to Kjellsson (1999), Swedish one-family houses have an average roof area of 113 m^2.

86 Andreas Molin, PPAM.

87 Registering for electricity certificates isn't mandatory, but not doing it will effectively mean that no electricity certificates is obtained for the surplus electricity. In order to receive certificates also for the self-consumption, the customer needs to purchase extra metering equipment.

The most frequently identified (non-legislative) economic factor was the difficulty of predicting electricity prices (9 mentions). This is not exclusive to PV investments, as electricity price developments has been identified also in the 'energy efficiency gap'-debate as an inherent economic uncertainty (e.g. Sutherland 1991). Many interviewees expressed that they don't give advice regarding the developments of electricity, referring to evident difficulties. One of the energy advisors declared that he doesn't give explicit advice, but rather mentions that he has "read many reports on the electricity price developments, and they all have one thing in common–none has been right." One interviewee explained that when he discusses PV economy, he chooses to refer to it as a hedge towards future price developments–or a way of "securing the level of ones' electricity bills"[88].

Several energy advisors mentioned difficulties determining the price of surplus electricity–likely since the offered fees have changed significantly the recent years. These prices are, however, expected to converge with the spot prices sooner or later[89,90].

The rate of self-consumption is another factor brought up occasionally in advisory discussions (SQ23). Since few homeowners have access to exact load curves, it poses evident difficulties to decide how much electricity the household will use. One option, however, is to use lump values–for example those developed by Widén (2011, 2014). Since the tax reduction was introduced, the self-consumption rate is not a factor of economic importance (assuming it will remain).

Degradation of the modules and lifetime of the inverter (i.e. maintenance costs), were among the least frequent inquiries in the advisory discussions. Yet, due to a general confusion regarding PV economics, it would probably be wrong to refute these questions as unimportant for potential adopters. Also, it is likely that potential adopters further down the diffusion curve have less "ability to deal with abstractions than do earl*ier* adopters" (Rogers 2003, p.289), or as an energy advisors puts it, "we will likely see a change from 'idealists' to 'economists' and a necessity for calculations

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[88] Johan Paradis, Consultant

[89] Bengt Stridh, ABB

[90] Johan Lindahl, Uppsala University

that include everything for a electricity generating system". The necessity of well-researched assumptions is also applicable to the notion of legitimacy, and the importance to reduce the 'liability of newness' surrounding a novel technology (Bergek et al. 2008).

In Sweden, no standard method for calculating the profitability of domestic PV exists[91,92], although attempts are in the making to establish one (e.g., Stridh et al. 2014). PV economy is furthermore a hot topic in the public debate, and several differentiating views have been expressed during the recent years–most noticeably in the tech weekly Ny Teknik (e.g. Karlberg and von Schultz 2012, Stridh 2012, Ehrenberg 2014). Also, a broad variety of economic reasoning and assumptions were encountered during the interviews, thus strengthening the picture of a quite confusing climate for homeowners regarding the economics of PV.

Advice-seekers seldom ask about suitable discount rates for PV. Either it is not a topic one seeks advice for–or, more plausibly, the homeowners who currently ponder investing in PV do not evaluate risk or calculate investments by using discount rates other than the interest rate that become imperative while taking up bank loans (figure 6.10). Evaluating the risk of an investment could be done in many ways, for example by trying the sensitivity of ones' assumptions or checking if the investment pays back within a range that has acceptable error-margins. The way private persons use discount rates, or evaluate risks, is in general likely to differentiate from economists.

A common picture of the households currently investing in PV is that they are financially strong and that mortgage loan financing of PV is unusual. Few advice seekers bring up the topic of mortgage loans (figure 6.9), and in a follow up question, whether the energy advisors, themselves, had the perception of difficulties obtaining loans, the vast majority (57 of 69 valid answers) answered they were uncertain. (Several of them expressed in a comment that they believed the people currently investing in PV do it with their own savings). Ten energy advisors answered that no difficulties existed (however depending on credit history), whereas two respondents

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[91] Johan Lindahl, Uppsala University

[92] Bengt Stridh, ABB

from municipalities in the northern regions of Norrbotten and Jämtland respectively expressed difficulties obtaining loans due to uncertain long-term value of property in rural municipalities.

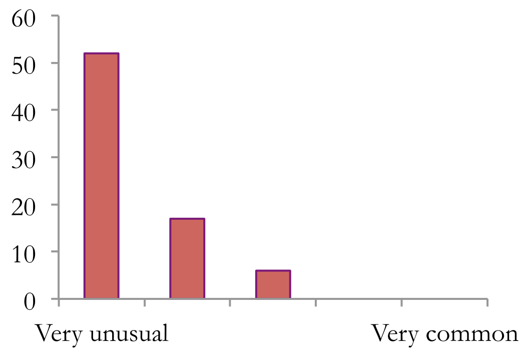

Figure 6.9: SQ41 Is it easy to obtain mortgage loans for investments in PV?

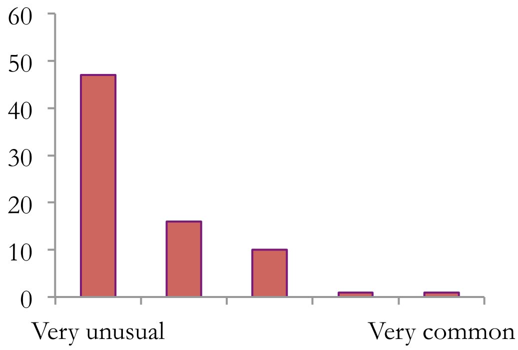

Figure 6.10: SQ35 Which discount rate should I use for the economic calculation?

As the customer base move along the diffusion curve of Rogers (2003), from the relatively financially strong earli*er* adopters, to the early and late majority, taking up mortgage loans to finance PV will have to become norm (>80 000 SEK is a very significant amount for most Swedish households to pay up front).

7. Discussion

This chapter comments on the methodological choices, evaluates the theoretical framework and proposes future research. Research question 3 is specifically discussed: How can the study of the Swedish market of domestic PV contribute to the theoretical understanding of functions required to decrease uncertainty surrounding a novel technology?

7.1. Methodology

Sending out a survey to the energy advisors expanded the scope of how much data could be obtained during a limited time period. The empirical base of the survey responses consists of the inquiries from almost 4 000 advice seekers–assuming the energy advisors grounded their answers on 50 PV inquiries in average. This is not far from the total amount of PV households in Sweden. Since the main goal of the study was to understand aspects that shape peoples' perceptions and subsequent investment decisions–not primarily to categorize or understand the group who de facto adopt PV–the energy advisors, and their role as sounding boards for potential PV adopters, was an ideal source of information.

Alternative methods could have been to target installers with an experience of customer-acquisition, or PV households directly. An equivalent survey to installers could have been adequate to map common inquiries during the customer-acquisition process. Commercially sensitive issues, however, for example of finding installers or choosing assumptions in economic calculations, would likely have been lost in the analysis. Interviews with installers was, furthermore, a difficult and time-consuming way of gathering suitable data on a third party (i.e. homeowners). The fact that PV is in an early growth phase in Sweden (Sandén et al. 2014) means there are many aspects that generate uncertainties. It is thus difficult to distinguish the hierarchy of issues in relatively few interviews.

Contacting PV households directly would carry the advantage of first-hand accounts of the experiences leading up to adoption. It would, however, not necessarily lead to better results. By only including individuals who ultimately adopted PV, important difficulties, and reasons for rejection, would to an extent have been omitted. This would not be exclusive to this study, as one of the most prevalent shortcomings of the diffusion of innovations literature has been coined its "pro-innovation bias", i.e. the assumption that an innovation should ultimately be diffused among all members of a social system (Rogers 2003, p. 106). One reason for the pro-innovation bias has been the commonplace method of studying a diffusion process in hindsight, when the innovation already has spread among a population, by asking individuals to recall information about their adoption. Here, the survey to the energy advisors provided a mean of overcoming the pro-innovation bias by not studying the diffusion per se, but rather the information seeking activity of the potential adopters.

The categorisation of the individuals contacting the energy advisors has been central in understanding the survey results and their value. A thorough discussion can be found on page 24-26, thus, here it suffices to mention that they are a heterogeneous group, with varying levels of technical knowledge, economic drivers, and energy literacy. In terms of financial strength, the advice seekers seem to be part of the earl*ier* adopter categories according to Rogers (2003). It is, however, clear that it is not the most technically skilled that contact the energy advisors for advice (although many seem to have an interest in technology). As a whole, one could assume the individuals who contact the energy advisors are slightly more representative of the adopter categories further down the diffusion route–than the actual PV adopters.

In the survey, particularly the open-ended questions, where the energy advisors were asked to identify the *main* uncertainties (SQ53), and the *main* difficulties (SQ50), provided insights of which factors need to be addressed to reduce barriers for PV adoption. The largest section (four) of the survey, where the respondents were asked to indicate the frequency of topics in the advisory discussions, was mainly important in understanding what homeowner encounter *first* in an information seeking process (since that is when most advice seekers contact the energy advisors). The most frequent questions have particular importance (both regarding content and abstraction level) since their answers might determine if and how an individual chooses to go forth with an investment decision.

7.2. Theoretical framework

Reducing the 'liability of newness' of PV, not the least in the eyes of households, remains a major task. The language to describe how the uncertainty can be reduced for PV adopters was mainly borrowed from the technical innovation system literature, in shape of the function 'legitimation' (Bergek et al. 2008b). Although the literature on transaction costs and energy efficiency have presented qualitatively similar barriers to adoption, e.g. where uncertainty translates into higher discount rates (e.g. Sutherland 1991), it doesn't provide as compelling of an explanation as the uncertainty that surrounds PV on a societal scale–in this study represented by the many uncertainties forwarded by the energy advisors. Also, there is a semantic issue in describing behaviour in strictly economic terms, whereas the studied population in this study doesn't seem to evaluate risk in terms of *discount rates*.

Transaction cost economics helped understand theoretically that the vertical integration of market actors has a direct effect on the scope of transaction costs. Thus, in a market where the customer base to a large extent is comprised of individual households, transaction cost as a barrier towards technological diffusion becomes even more important. Since organisational factors, and corresponding transaction costs, in general, likely is an important describing factor of barriers facing a technology in its childhood, innovation system theory could find it rather useful to incorporate such theories (and vice-versa[93]).

The diffusion of innovations literature (Rogers 2003) proved valuable in emphasising that adopter categories and their characteristics differ along a diffusion process, as well as how technical characteristics *partly* determine barriers of diffusion. It is apparent, however, that explaining the barriers towards diffusion by solely analysing technical characteristics and behavioural characteristics of the adopters is unsatisfactory. Stemming from the perceived importance of exogenous factors in this study–especially regarding the role of the legislation and the practices of the market actors–it was integral to complement the theories from the diffusion of innovation literature with a system perspective. Any study with the goal of mapping barriers

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93 As transaction cost economics is rather ill equipped to describe the evolutionary process in the early stages of a diffusion process (e.g. Nelson and Nelson 2002).

towards technological diffusion from an adopter-centric perspective will arguably confront similar problems.

In general, this study provides an enhanced understanding of what shapes uncertainty in the childhood of a diffusion process. The analysis of the data suggest there are several areas where an innovation system infrastructure can be strengthened, for example by establishing standards for economic assumptions, accessible information sources as well as functions to find and select suppliers. A main finding is that sheer information is not enough–what is needed is also to simplify and package information in a comprehensible way. The study can, more specifically, contribute to the notions of how legitimation is formed within a TIS, and particularly for qualitatively similar technologies[94] taken up on fragmented markets.

Ultimately it can be noted that there are several theories explaining how and what shapes attitudes to a technology that are not brought up here. In order to design suitable policies and market strategies to aid the diffusion of desirable technologies and practices on fragmented markets, a deeper understanding of how different *sociological* factors shape uncertainty and legitimation would be valuable. This is an area of possible future research.

[94] Technologically advanced with high upfront costs and where the investments pay back by reducing energy costs.

8. Conclusions

The Swedish legislative landscape for micro-producers is perceived as complicated by homeowners due to several sources of uncertainty and an amalgam of policies–including the investment support, ROT-deduction, building permit, VAT registration, electricity certificates, certificates of origin, and the tax reduction. The investment support is the most highlighted aspect due to the queue and uncertainty of receiving it. The tax reduction is not time-scheduled which leads to difficulties of how to treat it in economic calculations.

PV economics is the common denominator of almost all *main* uncertainties taken up by the energy advisors. Several of energy advisors bring up the difficulty of predicting electricity prices, along with the legislative parameters. The Swedish market for domestic PV is essentially screaming out for a *simple* and standard way of calculating payback-time that can be utilised by homeowners.

The technical aspects of PV are undoubtedly a concern for many, although issues regarding legislation and economy are higher on the list of uncertainties presented by the energy advisors. Most questions in the advisory discussions are basic: how much to install, how to connect to the grid, what is the yield, is it possible to install despite shading, how long time will I have a functioning system? Technology specific questions regarding efficiencies, or about the specific components, are seldom asked, which hints that most see the PV systems as a whole–that yields a certain amount of electricity, for a certain amount of money, for a certain amount of time.

Finding and selecting installers is identified as one of the areas where homeowners perceive difficulties finding information. This could stem from the fact that there are still few domestic PV systems, and thus few that have “acquaintances that has already installed PV” that can recommend reliable installers. Most of the pre-existing information sources on the Swedish PV market are not apt, or willing, to provide commercial advice. From the other side, the relatively low knowledge levels of the clientele poses ethical questions to sellers of PV systems, and it will be important to hinder 'lemons'[95] from entering the market.

8.1. Main design decisions for a web tool

As pointed out by two of the interviewees, "the legislation is always more complicated in general, than in particular"[96,97]. The goal with the tool is to sort out aspects that are not important for potential adopters, and emphasise aspects that are.

An economic calculation tool is developed. The default assumptions are largely based on Stridh et al. (2014), and related literature, to help establish alignment regarding economic assumptions on the market of domestic PV. The tool is presented in a way that suits the economic reasoning of most private persons. This is done by using payback-time as the method, and by assuming that a mortgage loans is taken up. A change of commonplace financing methods, from up-front payment to mortgage loan financing, will be important if domestic PV is something that most households can engage in further on. The importance of finding an electricity retailer, that pays much for the surplus electricity, could be played down by communicating what several experts predict–that sooner or later the surplus electricity will be sold at the spot market price[98,99].

There are several commercial programs to calculate an approximate electricity yield. The challenge is to provide a tool that is sufficiently simple for anyone to use. In this case the language is Swedish (and without too much PV jargon). Also, the importance of exact inclination of the roof, soiling (for most parts of Sweden) and albedo is played down. The tool shouldn't be over-optimistic–i.e. reasonable losses for real PV systems are assumed.

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[95] Lemons refer to inferior products that can impose bad reputation to serious actors and products. In the case of PV, as pointed out by several market actors, lemons could for example take the form of bad technical equipment, defect assemblage, or actors who utilise the lacking knowledge of the customer base to sell systems despite severe shading.

[96] Arne Andersson, Consultant.

[97] Johan Paradis, Consultant.

[98] Johan Lindahl, Uppsala University.

[99] Bengt Stridh, ABB.

As of now, no design decisions have been made *vis-à-vis* finding and selecting installers. This could however come in later in the process, for example by providing possibilities for the users of sharing experiences of previous installations, thus enhancing the *peer effects* of PV diffusion (one way of hindering low quality products and unserious actors, or 'lemons', to enter the market).

8.2. The role of policy and business practices

There is an obvious need to simplify, and ensure long-term, legislation for micro-producers. Despite possibilities of communicating the legislation in a comprehensible manner, some aspects of the current Swedish legislation are inherently uncertain, specifically whether and when one will receive the investment support, as well as the undefined time perspective of the tax reduction.

This study has made it clear that organisational aspects of legislation (i.e. not only the level of subsidies etc.) are important factors in shaping the perceptions of a technology among potential adopters. The concepts of complexity and compatibility, borrowed from the diffusion of innovations literature (Rogers 2003), also seem applicable for policies, i.e. policies that are difficult to understand, and alien from everyday life, will likely provide higher barriers for technological adoption. A political framework for micro-producers should, thus, be designed to be as simple as possible.

Following the *perceived* complexity of dimensioning, administrating and maintaining a PV system, many homeowners would probably prefer to not do everything themselves. An energy advisor expressed explicitly that, "if a PV installer would communicate and help out with *administration, registering, communication with authorities (*author's note), I'd guess many would breathe a sigh of relief". There is, thus, likely a latent demand for other business models on the market of domestic PV, e.g. per kWh-pricing models, or all-inclusive installations where the suppliers take responsibility of administration and maintenance. Also, clearer price information from the suppliers could help reduce uncertainty, e.g. by explaining how much transportation costs, or how prices will change if the standard conditions do not apply.

Currently, there is no official function on the Swedish PV market that can supply consumerist advice other than the municipal energy advisors. Few individuals, however, use the energy advisors to compare offers and technical characteristics of PV. Although the energy advisors can't give commercial advice, they can be utilised more in helping homeowners to identify important aspects in offers and ask the right questions to suppliers.

8.3. Theoretical conclusions

The findings in this study emphasise notions from innovation system theory–that a range of issues inflict uncertainty on a novel technology, and thereby barriers against its diffusion; most noticeably in this study due to complicated and short-term legislation, difficulties predicting economic performance, perceived technical complexity, as well as troubles finding and selecting installers.

Technical innovation systems, and especially the function legitimation, proved valuable in explaining the necessity of reducing the 'liability of newness' and thus increase the social acceptance of a novel technology. As customer groups have different organisational setting, however, the content and scope of a legitimation strategy is likely to differ concurrently. In the case of individual homeowners, strategies of legitimation could consist of establishing *comprehensible* information sources[100], reducing legislative complexity, developing standard and simple ways of calculating profitability, as well as functions or marketplaces where transparent supplier and price information is presented. All these aspects become increasingly important when the peer effects remain small in a system.

A suitable methodology in understanding barriers and uncertainties in the diffusion of domestic PV was to study the information seeking activities (i.e. discussions with energy advisors), rather than the individual adopters. Thus, by not only focusing on cases where adoption occurred, the study could overcome the pro-innovation bias– otherwise common in diffusion studies.

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[100] As the example of Bengt's Villablogg proves. Homeowners and market actors alike uses his blog for knowledge gathering. One interviewed market actor put it amply, "if the Tax Agency releases a report on a new law the 22nd December, you'll find it on Bengt's blog the 23rd in a language people can understand. What you can't find there isn't worth knowing" (Magnus Hellberg, Kraftpojkarna).

9. Web interface prototype

This chapter is in English for presentation reasons. A physical tool would be in Swedish. The design decisions are made according to the criteria listed on page 28-29.

The idea is that this guide and calculation program can be used by a household before an investment in domestic PV. The calculations are based on the input and equation presented in chapter 5. The default settings are based on expert advice, reports and articles in scientific journals. The purpose is to enable homeowners to take decisions based on the same information and knowledge as professional investors, but without having to do all the research themselves. The sources as well as the math behind the calculations can be found in chapter 5. The calculations and results will come adjoined by several checklists: to orientate amidst administration, to find and select a suitable installer and to predict the electricity yield. These can be found throughout chapter 6.

The calculation should be seen as nothing more than support, and the author reserves himself from any responsibility that the calculations turn out in reality as they are presented here.

9.1. Input data

The calculations are based on the parameters in this section. It is possible to change the input parameters in the purple area to see how the results change below.

Parameter	Input	Unit	Comment
Fee sold electricity	0.40	SEK/kWh	The last ten years the spot price has averaged at 40 öre/kWh during the sunny hours. Most experts think the spot prices will remain quite low during the foreseeable future. Even though there are electricity retailers who buy electricity for a higher fee

			than this, several experts think the price will drop to this level sooner or later. An assumption between 35-45 öre is thus reasonable.
Cost purchased electricity (incl. VAT and variable transmission fee)	1.40	SEK/kWh	According to a report by Sweco, retail prices for electricity is projected to average at 1.20-1.40 SEK/kWh during the lifetime of PV. The lower value is for northern Sweden where energy taxes are lower. 1.40 SEK is for southern Sweden.
Green certificates	0.20	SEK/kWh	This is the price one receives for producing renewable electricity. Most prognoses deem the price will be between 20 and 25 öre. 15 years is the time limit of receiving electricity certificates.
Credit from DSO	0.05	SEK/kWh	This is the fee one receives for reducing transmission losses in the grid. It varies depending on grid owner and location, but is often around 5 öre/kWh.
Tax reduction	0.60	SEK/kWh	For every kWh you feed in to the grid, you will get 60 öre in tax reduction at the tax return every year. The scheme is not time-scheduled but there is a political consensus that we should have a tax reduction.
Lifetime	25	Years	Most suppliers offer a guarantee of 25 years. Many experts believe the PV will continue to produce electricity long time after that. It is for example becoming somewhat of a norm to assume a lifetime of 30 years. Since the PV are quite new there are few long-term measurements (>30 years). The

			upper level for the lifetime is thus not really known.
Degradation	0.5	%/year	A large international study on degradation rates found that most degraded at around 0.5%/year. The only Swedish study found that after 25 years the average degradation was less than 0.2%. Somewhere in between these two values is a good assumption.
O&M costs	130	SEK/kW/ year	Between 100-130 SEK/kW/year is a reasonable maintenance cost. This will for example cover replacement or partial replacement of the inverter.
Discount rate	0	%	A 2% discount rate corresponds quite well to the interest rate after tax deduction while taking a mortgage loan. This will only enter the calculation if you invest with your own money (otherwise the calculation will use the loan rate entered in next part).

9.2. Investment

The user enters all the squares that are coloured green. In some boxes you can choose to increase the available information. The squares that will appear are orange-coloured. Unless you enter specific roof tilt, a normal roof-tilt of 30° will be assumed.

Investment	**Fill**	**Unit**	**Options/comments**
Where do you live?	Brännö		
Size of the system	4.8	kW	
Are you doing the assemblage yourself?	No	▼	Yes / No
Cost turnkey system	96 000	SEK	
Which support do you want?	ROT	▼	ROT / Investment support
Support	14 400	SEK	
Σ after support	**81 600**	**SEK**	

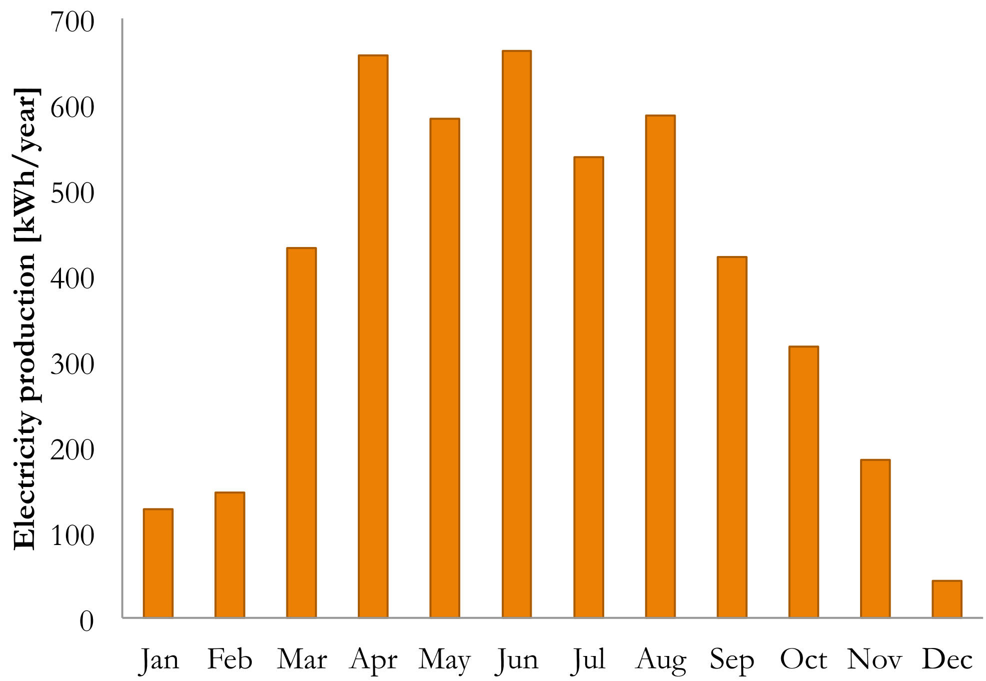
System design			
Electricity consumption / year*	10 000	kWh	*Approximately
Do you want to enter *exact* roof tilt, orientation, snow and shading losses* and/or electricity consumption curve?	No	▼	Yes / No (*Snow and shading losses of 3% and 3% are taken into account already)
In what orientation do you want your PV?	South	▼	South/South East/East/ South West/West

Investment structure			
Down payment	10 000	SEK	
Mortgage loan	71 600	SEK	
Mortgage interest rate*	3.0%		*Before interest deduction
Payment plan	16	Years	
Share of mortgage loan	88%		
Amortisation/year	4475	SEK	

9.3. Results

Technical performance

Annual electricity production*	4700	kWh	*Year 1
Self-consumption*	45%		*Approximately
Electricity to the grid*	55%		*Approximately
Do you want to see the performance details?	Yes		Yes / No
PV performance / kW	980	kWh	
Global irradiation / m^2	1020	kWh	
System efficiency	0.78		



Pay-back time

Pay-back time	18	Years	
Years with "free" electricity*	7	Years	*It is however likely that the PV system will continue to produce electricity long after that

Year	Income and reduced electricity costs	Amortisation and interest	Net (incl. down payment)
1	5 548 kr	-5 728 kr	-10 180 kr
2	5 517 kr	-5 650 kr	-133 kr
3	5 486 kr	-5 571 kr	-86 kr
4	5 455 kr	-5 493 kr	-38 kr
5	5 424 kr	-5 415 kr	10 kr
6	5 394 kr	-5 336 kr	58 kr
7	5 364 kr	-5 258 kr	106 kr
8	5 334 kr	-5 180 kr	154 kr
9	5 304 kr	-5 102 kr	202 kr
10	5 274 kr	-5 023 kr	251 kr
11	5 245 kr	-4 945 kr	300 kr
12	5 215 kr	-4 867 kr	348 kr
13	5 186 kr	-4 788 kr	397 kr
14	5 157 kr	-4 710 kr	447 kr
15	5 128 kr	-4 632 kr	496 kr
16	4 619 kr	-4 553 kr	65 kr
17	4 592 kr	0 kr	4 592 kr
18	4 566 kr	0 kr	4 566 kr
19	4 540 kr	0 kr	4 540 kr
20	4 514 kr	0 kr	4 514 kr
21	4 488 kr	0 kr	4 488 kr
22	4 463 kr	0 kr	4 463 kr
23	4 437 kr	0 kr	4 437 kr
24	4 412 kr	0 kr	4 412 kr
25	4 386 kr	0 kr	4 386 kr
Σ	**125 045 kr**	**-82 251 kr**	**32 795 kr**

9.4. Input from interviewees

During the suite of this project I have had the pleasure to meet people from the industry, from academia and many municipal energy advisors–either face to face, or through the survey answers. I have received a lot of input; either by asking directly for it, or sometimes, from people with the good taste of planting an idea. Some of the input has entered the general consciousness; some, the design process directly, and some ideas might enter the development process at a later stage. In table 9.1 are a few extracts of thoughts that have shaped the process in an important way.

Table 9.1: Quotes from interviewees

"Everyone wants to know the potential yield, although it is difficult to determine the shading and snow-soiling losses" Bent Stridh, ABB
"Solar electricity needs to be communicated as something easy!" Johan Ehrenberg, ETC Egen El
"A way of determining the self-consumption would be good" Andreas Molin, PPAM
"It needs to be updated!" Johan Paradis, Consultant
"If you're doing a calculation tool, you need to be able to change the "maths" and the assumptions. Otherwise we will know one thing; and that is your app will always be wrong" Arne Andersson, Consultant
"It could be coupled to the postal codes, then it would be possible to connect to the grid owner, and the phone number to the municipal energy advisor." Petter Sjöström, Solkompaniet
"The economic calculation should be in line with the way most household think when they consider making investments, like how many years of savings it takes to cover for the whole investment" Jörgen Larsson, Chalmers

"I don't know how many times I have spoken in public about LCOE *regarding energy efficiency measures (author's note).* I try to keep things plain and simple in the beginning, but then, somewhere around when I come to the discount rate – half of the auditorium falls into daydreams" Hans Nilsson, FourFact

"Such a tool would be very appreciated, that shows how much a system generates in different cases, which rules apply, but also how the actual payback looks like – something many perceive as difficult and few know of. The calculation is messy and it's hard to found out what the actual electricity is worth and which model is most lucrative (use the electricity oneself contra selling it). So, an actual calculation template would be invaluable, and which isn't over-optimistic." Maria Gungner, Energikontoret Östra Götaland

"I think they miss a checklist, step-by-step. But mainly clear information from the government of what they want with the long-term PV development " Anonymous energy advisor

"They need simple information of what a PV system is and what you need to think of (cables, room for the inverter, connection to the electricity central…) so they can reflect how it would work in their house and how I would solve the different issues. What installers are there, and which one should I choose." Anonymous energy advisor

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Appendix A – Interviews and oral communication

Table A1: Interviews and oral communication

Interviewees	**Current position**	**Comment**	**Date of interview**	**Interview format**
Petter Sjöström	CFO Solkompaniet	Large installation company ~150 installed residential systems in 2014	19-03-2015	Phone
Magnus Hellberg	CEO Kraftpojkarna	Largest Swedish PV retailer	09-03-2015	Face to face
Andreas Molin	Chairman PPAM	Large installation company ~150 installed residential systems in 2014	24-03-2015	Phone
Elin Molin	CEO PPAM		24-03-2015	Phone
Johan Ehrenberg	Chairman Egen El	Large installation company ~80 installed residential systems in 2014	06-04-2015	Face to face
Arne Andersson	Consultant	Independent, previous Bixia	03-03-2015	Face to face
Johan Paradis	Consultant	Paradis Energi	04-03-2015	Face to face
Bengt Stridh	ABB corporate research	Author of Bengt's Villablogg	10-03-2015	Face to face
Johan Lindahl	Researcher Uppsala University	Lead author of IEA PVPS Sweden	31-03-2015	Phone
Zandra Wenngren	Municipality of Västerås	Energy & climate advisor	10-03-2015	Face to face
Mats Danielsson	Municipality of Gothenburg	Energy & climate advisor	06-03-2015	Face to face
Mikael Eriksson	Municipality of Gothenburg	Energy & climate advisor	06-03-2015	Face to face
Lars Holmquist	CEO Egen El		06-04-2015	Face to face
Hans Nilsson	Honorary chairman IEA-DSM	Expert of energy efficiency and heat pump diffusion in Sweden	11-03-2015	Face to face
Tore Carlsson	The Swedish Energy Agency		11-05-2015	Electronically

Appendix B – Survey Questions

Section 1

1. Which energy office do you belong to?
2. How large is the city where you work?
3. Has your municipality a solar map?
4. How long time have you worked as an energy and climate advisor?

Section 2

5. How many have contacted you (in your role as an energy advisor) to inquire about PV the last six months?
6. How many people have in total contacted (in your role as an energy advisor) you to inquire about PV?
7. How large share has been a home- or villa owner?
8. How large share has been from a housing organisation?
9. How large share has been from a private company?
10. Other comments regarding the interest.

Section 3

11. In what phase is the advice seeker normally in?
12. Which situation corresponds best to advice seeker of PV?
13. Which of the following descriptions corresponds best to advice seekers? (Reason for contact)
14. Which of the following descriptions corresponds best to advice seekers? (Technology interest)
15. Which of the following descriptions corresponds best to advice seekers? (Economic reasoning)
16. Which of the following descriptions corresponds best to advice seekers? (Energy literacy)
17. Would you like to clarify anything of the above?

Section 4

18. Are there any (good) local installers?
19. What are the electricity prices going to be during the lifetime of a PV system?
20. What is the lifetime of PV
21. How large PV system should I install?
22. What discount rate should I use?
23. How large self-consumption is reasonable?
24. What is the lifetime of inverters?
25. What degradation rate should I use in the economic calculations?
26. What type of administration is necessary?
27. Is it easy to obtain bank or mortgage loans for PV investments?
28. Is clay/tin or copper good/suitable for PV?
29. If my roof is subject to partial shading – can I still install PV?
30. Is a power optimizer or a microinverter a good option in my case?
31. How long is the queue for the investment support?
32. How do the electricity certificates work?
33. Will PV continue to decrease in price?
34. How do snow/pollen/soiling affect PV output?
35. Is it easy to obtain building permits for PV?
36. How do I do to connect to the grid?
37. Which electricity company pays best for the surplus electricity?
38. What is/should the efficiency be for PV?
39. What is the efficiency of the other components in a PV system?
40. Are there PV in certain colours/that can aesthetically be integrated in the roof?
41. Is it possible to store the surplus electricity?
42. Are there health hazards with PV components due to electro-magnetic radiation?
43. How does the tax reduction work?
44. What level is ROT/investment support at?
45. Is it possible to combine PV with solar heating?
46. Are there security issues with PV in case of fire?
47. Other comments about the questions

Section 5

48. What do you normally mention as a typical price for a turnkey system (per kW, incl. VAT, excl. investment support or ROT)?
49. Which are the most important information sources for private persons in Sweden regarding PV?
50. What is most difficult to obtain information about for private persons?
51. Do you perceive it's difficult for homeowners to obtain bank or mortgage loans for PV?
52. If your municipality gas a solar map, what are the pros and cons?
53. What are the largest uncertainties for private persons regarding investments in PV?
54. Do you have any other comments about the advisory discussions?

Appendix C – Survey responses

In the first and second section of the survey (survey question 1- 10), all survey responses are presented. Since the energy advisors that had been contacted by fewer than ten advice seekers in total were sorted out from the data analysis, the *analysed* survey responses are presented specifically in the right columns. In survey questions 11 – 54, only the relevant analysed survey responses are presented.

Table C1: SQ1 Which local energy office are you part of?

Local energy office	**Respondents**	**Analysed answers**
Energikontoret Västernorrland	0	0
Norrbottens energikontor	7	6
Jämtland läns energikontor	4	3
Energikontor Värmland	3	3
Gävle Dala energikontor	5	4
Energikontoret i Mälardalen	11	8
Kommunförbundet Stockholms län	1	1
Energikontoret Östra Götaland	3	2
Energikontoret Regionförbundet Örebro	3	3
Hållbar Utveckling Väst	18	15
Energikontoret Region Halland	4	4
Energikontoret Norra Småland	7	6
Energikontoret Sydost	14	12
Energikontoret Skåne	7	7
Other / I don't know	1	1[102]
	Σ 88	**Σ 75**

[102] The respondent commented that he/she worked at a municipality under the Energy Agency and don't belong to a local energy office. The energy advisor works however as a municipal energy advisor in Norrbotten.

Table C2: SQ4 How long times have you worked as an energy and climate advisor?

Time	Amount	Analysed responses
> 5 years	36	36
1 – 5 years	41	34
< 1 year	11	5
	Σ 88	**Σ 75**

Table C3: SQ5 How many have contacted you to inquire about PV the last six months?

PV inquiries	Amount	Analysed responses
< 10	31	18
10-50	40	40
50-100	12	12
100-200	4	4
> 200	1	1
	Σ 88	**Σ 75**

Table C4: SQ7 How large share of the advice seekers are private persons/homeowners?

Share	Amount	Analysed responses
100-80%	49	40
80-60%	34	32
60-40%	2	2
40-20%	0	0
20-10%	1	1
10-0%	2	0
	Σ 88	**Σ 75**

Table C5: SQ11 Which phase is the advice seeker most often in when you are contacted?

Statement	Respondents
The advice seeker is in the beginning of the process and has just understood it's possible to generate own solar electricity. He/She wants to learn more about the technology and its costs.	52
A suitable rooftop is identified and the advice seeker wants to know more specific things about the technology and the support schemes.	22
The advice seeker has contacted an installer and wants to compare and discuss offers	1
	Σ 75

Table C6: SQ14 Which of the following statements fits best for the advice seekers of PV?

Statement	Respondents
The advice seekers are generally tech-savvy with much knowledge of PV. The asked questions are advanced.	3
The advice seeker is generally interested in technology but with quite low knowledge of PV. They treat technical words well but ask rudimentary questions about PV.	47
Not technically skilled. Questions of energy are rudimentary in general. The advice seeker isn't knowledgeable of PV.	25
	Σ 75

Table C7: SQ16 Which of the following statements fits best for the advice seekers of PV regarding awareness of the domestic electricity consumption?

Statement	Respondents
The advice seeker has..	
…relatively low awareness of the domestic electricity consumption. He/She has difficulties answering questions of annual or monthly electricity consumption.	10
…average awareness of the domestic electricity consumption. He/she can coarsely estimate an annual or monthly consumption, but not how it changes over the year. He/she knows if the electricity is paid according to fixed or variable pricing.	51
…good awareness of the domestic electricity consumption. Both annual and monthly electricity consumption can be estimated. He/she can determine the price per kWh.	14
	Σ 75

Table C8: Survey questions and answers in section 4

SQ	Question	Average of the perceived frequency[103]	Scale 0 - 100	Standard deviation (scale 0-100)
18	Are there any (good) local installers?	3.8	70	30
19	What are the electricity prices going to be during the lifetime of a PV system?	2.8	45	28
20	What is the lifetime of PV	3.8	70	23
21	How large PV system should I install?	4.3	83	18
22	What discount rate should I use?	1.6	15	23
23	How large self-consumption is reasonable?	3.1	53	28
24	What is the lifetime of inverters?	2.1	28	25
25	What degradation rate	1.8	20	23

[103] All questions were answered by choosing one option on a bipolar numerical format, ranging between very common (5) and very unusual (1). For readability the scale has been transformed into 0 – 100 where 0=1 and 5=100. The same has been done for the standard deviation. Most questions came with a clarification, mentioning that all questions that had similar qualitative significance should be taken into account. For example: What will the electricity prices be during the lifetime of the system? Or other versions of the advice seeker wanting you to reason about the future developments of the electricity prices.

	should I use in the economic calculations?			
26	What type of administration is necessary?	2.4	35	28
27	Is it easy to obtain bank or mortgage loans for PV investments?	1.4	10	15
28	Is clay/tin or copper good/suitable for PV?	2.0	25	28
29	If my roof is subject to partial shading – can I still install PV?	3.0	50	25
30	Is a power optimizer or a microinverter a good option in my case?	1.4	10	20
31	How long is the queue for the investment support?	4.0	75	25
32	How do the electricity certificates work?	2.2	30	24
33	Will PV continue to decrease in price?	3.6	65	23
34	How do snow/pollen/soiling affect PV output?	2.9	48	30
35	Is it easy to obtain building permits for PV?	3.4	60	25
36	How do I do to connect to the grid?	3.3	58	28
37	Which electricity company pays best for the surplus electricity?	3.2	55	28
38	What is/should the efficiency be for PV?	2.4	35	25
39	What is the efficiency of the other components in a PV system?	1.5	13	20
40	Are there PV in certain colours/that can aesthetically be integrated in the roof?	1.8	20	23
41	Is it possible to store the surplus electricity?	2.6	40	23
42	Are there health hazards with PV components due to electro-magnetic radiation?	1.2	5	13
43	How does the tax reduction work?	3.2	55	28
44	What level is ROT/investment support at?	3.6	65	28

Appendix D – A thesis of the Challenge Lab

> "It's clear to most everyone, regardless of politics, that the big issues – labor, race, food, immigration, education and so on – must be "fixed," and that fixing any one of these will help with the others. But this kind of change must begin with an agreement about principles, specifically principles of human rights and well-being rather than of making a favourable business climate."
> – Mark Bittman (2015)[104]

The world is standing in front of several colossal challenges. Other than the mentioned climate challenge, Rockström et al. (2012) have for example pointed at transgressed planetary boundaries regarding nitrogen and phosphorus flows and loss of biodiversity. As these treat environmental systems, one can only raise the viewpoint to identify threats and on-going catastrophes, also in our societal systems (e.g., World Bank 2015, Piketty 2014).

Thus, as a consequence, there is an ardent need of directing our time, motivation and abilities towards finding solutions to aforementioned challenges. In all its modesty, this is where the Challenge Lab comes in.

The Challenge Lab is a master thesis format at Chalmers University of Technology, where the participants, and thus the master theses, put the mentioned sustainability challenges in centre stage. The master students are not by default attached to a research department or a company. Instead, they work in the gap of the triple-helix–academia, business and society–in an independent manner. The process values a more entrepreneurial perspective, where the participants generate the research questions themselves from an early stage. In order to ensure both the academic

[104] From the opinion piece "What is the Purpose of Society?". Published in The New York Times, 11-02-2015

process, and the societal need of the project, a discussion with researchers, businesses, and public entities evolves in tandem with the master thesis.

D1. Theories

A sustainability transition is a complex process that requires action at many different levels. One way of looking at transformation processes is through the lenses of the multi-level perspective. According to Geels (2005) system innovations occur through the interplay between artefacts, regulatory frameworks, markets and infrastructure. At the heart sits a *techno-social regime*. The regime is inherently stable and maintained by investments in the current infrastructure, and by rules culturally embedded in our "knowledge base, engineering practices, corporate governing structures, manufacturing processes and product characteristics" (Rip and Kemp 1998, p. 340; cited in Geels 2005). The inertia is thus high while political and private actors often work to maintain the status quo. Innovations, on the other hand, develop in *niches*, in context of the incumbent regime and landscape developments. Landscape developments, for example in our environmental systems or by changed problem formulations on a societal scale, can weaken regimes by affecting attitudes and values in a society. Innovations can then seize 'windows of opportunity' and diffuse in society on a wider scale. Ultimately the regime can be replaced.

One method of dealing with complex issues is to start by formulating the criteria that has to be fulfilled in an ideal future (Homberg and Robèrt 2000). This can help decision makers to decouple from the short-term visions that might be leading to lock-in effects, and instead raise the view towards what is affecting the long-term success of a company or a society. This concept is central to one of the *contextual* methodologies of the Challenge Lab–backcasting as proposed by Holmberg and Robèrt (2000).

In brief, the master students commence by together identifying guiding principles of the four dimensions of sustainable development: environment, society, economics, and well-being. The three former can be seen as foundation pillars and largely *instrumental*, whilst the later, well-being, should be seen as the overarching goal of societal development (e.g., Neef 1992).

Thus, the guiding principles of the Challenge Lab of 2015 have been developed in order to steer the master theses towards problem-solving for a desirable future. Rather than focusing on marginal, right-here-right-now issues of special interests–the guiding principles will allow for necessary reflection on what human demeanour should strive for in the long-term. Naturally, change is most often incremental, and rightly so, since change often demonstrates unexpected outcomes. The idea with the backcasting methodology, and hence the master theses, is not to provide silver bullets to complex societal issues–but rather to establish a mind-set where the chosen path, and the underlying motivation, is reflected upon.

The second step of backcasting is to assess the current system in relation to the identified criteria, i.e. to allow for the identification of a 'gap'. It is important to acknowledge the complexity of the system and to identify the aspects where, if intervention is done, outcome can be greater than expected (Meadows 1999). These aspects are called leverage points.

D2. Identifying the research question

The research questions of the Challenge Lab master theses are formed in the gap between the identified criteria and the current state of the system. The process does, however, not only have an outside-in perspective, i.e. where research questions are determined by identifying gaps between an ideal situation and the current, but also an inside-out perspective, where the strengths and values of the participant are taken into account. In this case, it was clear that the master thesis should revolve around the energy system–due to educational background and my strong interest thereof.

The motivation of conducting this thesis can be derived to the abundance of solar energy coupled with the learning curve of solar photovoltaic cells–i.e. the notion that, as installed capacity of PV increases, the costs per installed watt decrease concurrently (e.g. Bazilian et al. 2013). This is one of the most promising developments currently affecting the energy system. It basically means that, if we can continue to install PV, we might also pull down the production costs to a level where we end up with a carbon neutral, cost efficient and virtually abundant option to current modes of fossil power production. This basic notion can be seen as the starting point for the conducted study.